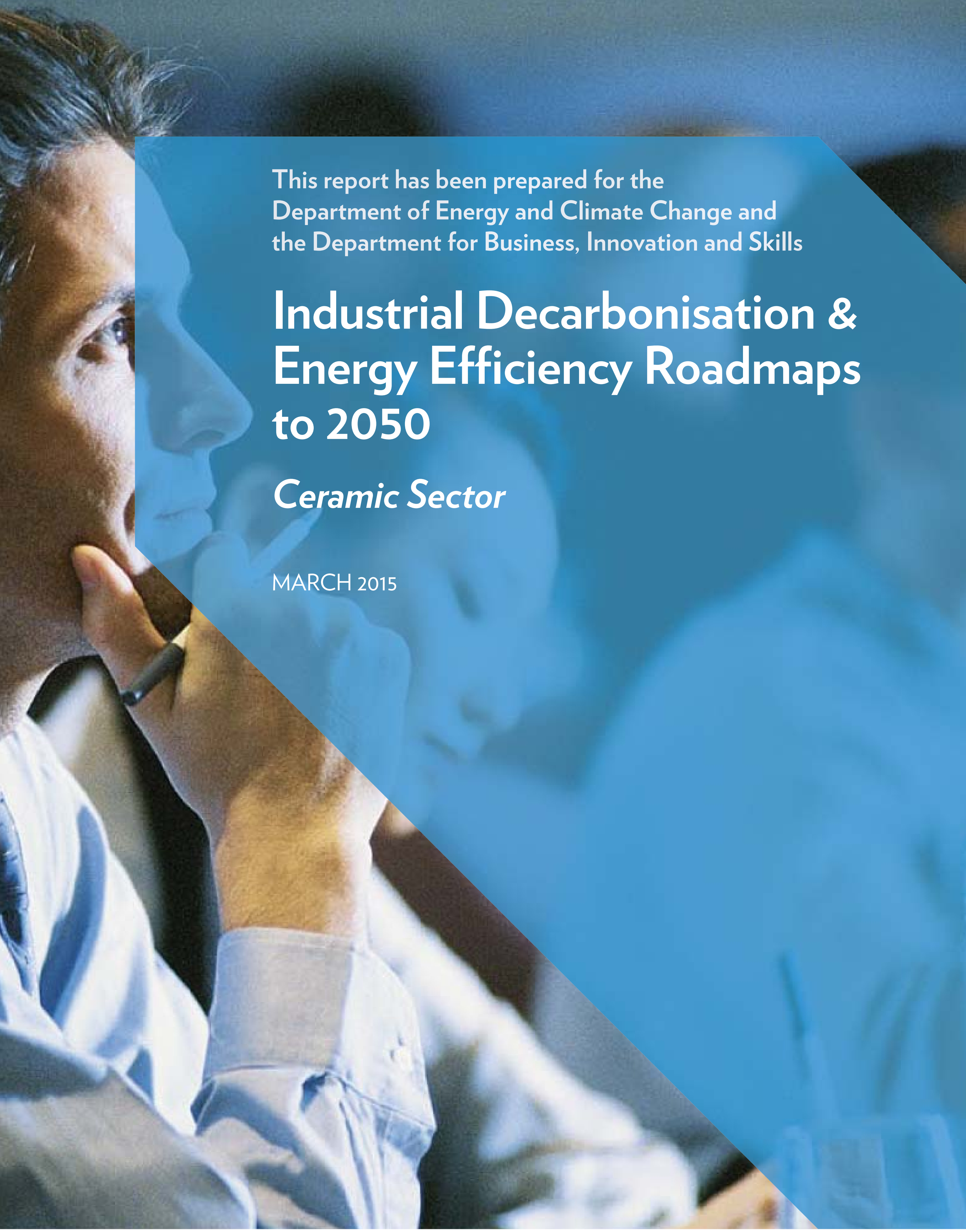

This report has been prepared for the Department of Energy and Climate Change and the Department for Business, Innovation and Skills

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050

Ceramic Sector

MARCH 2015

WSP | PARSONS BRINCKERHOFF

DNV·GL

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ACRONYMS

ADOPT	Adoption Rate
APP	Applicability Rate
BAT	Best Available Technology
BAU	Business As Usual
BCC	British Ceramic Confederation
BIS	Department of Business, Innovation and Skills
Capex	Capital Expenditure
CC	Carbon Capture
CCA	Climate Change Agreement
CCS	Carbon Capture and Storage
CCU	Carbon Capture Utilisation
CHP	Combined Heat and Power
CO_2	CO_2
DECC	Department of Energy and Climate Change
EII	Energy Intensive Industries
ESCOs	Energy Service Companies
EU ETS	European Union Emission Trading Scheme
GDP	Gross Domestic Product
GHG	Greenhouse Gases
ICT	Information and Communication Technologies
ITT	Invitation to Tender
Max Tech	Maximum Technical
NAEI	National Atmospheric Emissions Inventory
OEMs	Original Equipment Manufacturer
OBR	Office of Budget Responsibility
ORC	Organic Rankine Cycle
R&D	Research and Development
RD&D	Research, Development and Demonstration
REA	Rapid Evidence Assessment
RF	Radio Frequency
ROI	Return On Investment
SIC	Standard Industrial Classification
SME	Small and Medium Sized Enterprises
SWOT	Strengths, Weaknesses, Opportunities, Threats
TRL	Technology Readiness Level
UEP	Updated Energy Projection
VSD	Variable Speed Drive

1. EXECUTIVE SUMMARY

1.1 What is the 'Decarbonisation and Energy Efficiency Roadmap' for the Ceramic Sector?

This report is a 'decarbonisation and energy efficiency roadmap' for the ceramic sector, one of a series of eight reports that assess the potential for a low-carbon future across the most energy intensive industrial sectors in the UK. It investigates how to decarbonise and increase energy efficiency industry whilst remaining competitive.

Changes in the international economy and the need to decarbonise mean that UK businesses face increasing challenges, as well as new opportunities. The UK Government is committed to moving to a low-carbon economy, including the most energy-intensive sectors. These sectors consume a considerable amount of energy, but also play an essential role in delivering the UK's transition to a low-carbon economy, as well as in contributing to economic growth and rebalancing the economy.

The roadmap project aims were to:

- Improve understanding of the emissions abatement potential of individual industrial sectors, the relative costs of alternative abatement options and the related business environment including investment decisions, barriers and issues of competitiveness.
- Establish a shared evidence base to inform future policy, and identify strategic conclusions and potential next steps to help deliver cost effective decarbonisation in the medium to long term (over the period from 2020-2050).

Each roadmap aims to present existing and new evidence, analysis and conclusions to inform subsequent measures with respect to issues such as industry leadership, industrial policy, decarbonisation and energy efficiency technologies, business investments, research, development and demonstration (RD&D) and skills.

This roadmap is the result of close collaboration between industry, academics and government (Department of Energy and Climate Change (DECC) and Department for Business, Innovation and Skills (BIS)), which has been facilitated and delivered by independent consultants Parsons Brinckerhoff and DNV GL; the authors of the reports.

1.2 Developing the Ceramic Sector Roadmap

The development of the ceramic sector roadmap consisted of three main phases:

1. Collection of evidence relating to technical options and business-related enablers and barriers for decarbonisation. Evidence was collected via a literature review, analysis of publicly available data, interviews, workshops, and surveys of ceramic manufacturing companies. Validation of evidence and early development of the decarbonisation potential took place during an initial workshop.
2. Development of decarbonisation 'pathways' to 2050 to identify and investigate an illustrative technology mix for a range of emissions reduction levels. Draft results were validated at a second workshop.
3. Interpretation and analysis of the technical and business-related evidence to draw conclusions and identify potential next steps. These example actions, which are informed by the evidence and analysis, aim to assist with overcoming barriers to delivery of technologies within the decarbonisation and energy efficiency pathways while maintaining international competitiveness.

A sector team comprising representatives from the ceramic industry and its trade association, the British Ceramic Confederation (BCC), the government and Keele University has acted as a steering group as well as contributing evidence and reviewing draft project outputs. In addition, the outputs have been independently peer-reviewed. It should be noted that the findings from the interviews and workshops represent the opinions and perceptions of particular industrial stakeholders, and may not therefore be representative of the entire sector. Where possible we have tried to include alternative findings or viewpoints, but this has not always been possible; this needs to be taken into account when reading this report.

1.3 Sector Findings

The ceramic sector is characterised by the use of high temperature kilns to make products ranging from familiar products such as bricks, wall tiles and tableware to specialist products such as high temperature refractories, armour plating, electronic substrates and artificial joints. Throughout the entire sector drying and firing processes use large amounts of energy, predominantly natural gas, while a smaller number of specialist kilns are heated using electricity. The combustion of fossil fuel, indirect emissions from electricity consumption, plus process emissions (resulting from chemical changes in the raw materials during firing) makes up the ceramic sector carbon dioxide emissions shown in Table 1, the smallest among the eight sectors.

SECTOR	TOTAL ANNUAL CARBON EMISSIONS 2012 (MILLION TONNES CO_2)
Iron and Steel[1]	22.8
Chemicals	18.4
Oil Refining	16.3
Food and Drink	9.5
Pulp and Paper	3.3
Cement[2]	7.5
Glass	2.2
Ceramic	**1.2**

Table 1: Energy-intensive industry total direct and indirect carbon emissions in 2012 (data sources include Climate Change Agreements (CCA), European Union Emissions Trading Scheme (EU ETS) and National Atmospheric Emissions Inventory (NAEI))

The ceramic sector employs specific mechanical and chemical processes to convert raw materials into a powder, malleable solid or slurry. These are then shaped, typically by pressing, extruding or casting, and the resultant blank products are dried and fired to a high temperature. Further finishing processes or firing steps may be undertaken for specific products. The ceramic sector produced over four million tonnes of diverse products in 2012; 89% comprised heavy clay construction products, and the remaining 11%, refractories, whitewares and technical ceramics. The sector contributed a direct value to the UK economy of £1 billion in 2012.

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[1] For the iron and steel sector, the reference year used is 2013. This was chosen due to the large production increase from the re-commissioning of SSI Teesside steelworks in 2012.

[2] For the cement sector, the 2012 actual production levels where adversely affected by the recession. Therefore we have assumed production of 10 mtpa (rather than the actual production in 2012) and normalised emssions to this production level

The ceramic sector is energy intensive; fuel costs represent up to 35% of total manufacturing costs. In 2012 it was estimated to emit 0.94 million tonnes/year of carbon dioxide (CO_2), with a further 0.28 million tonnes/year emitted in electricity production for use within the sector.

1.4 Enablers and Barriers for Decarbonisation in the Ceramic Sector

In this report, we look at 'enablers', 'barriers' and 'technical options' for decarbonisation of the ceramic sector. There is some overlap between barriers and enablers, as they sometimes offer two perspectives on the same issue. Based on our research, the main enablers for decarbonisation for the ceramic sector include:

- Projects providing multiple benefits (energy, carbon and labour cost reduction, improved production yield, increased capacity to satisfy a growing market, etc.) are more likely to be invested in
- Compliance with legal obligations (e.g. environmental licence)
- A strong, evidence-based business case for energy and decarbonisation measures that capture all benefits and cost
- Stable and internationally competitive business and regulatory environment that encourages long term capital investment in new technology and innovation
- Willingness of top management to make carbon emission reduction a priority
- The need to replace obsolete equipment, expand production or reduce operational manpower

The main barriers to decarbonisation have been identified as:

- Long investment cycles (given equipment life of up to 40 years) and high capital costs of new technologies
- Low margins affecting ability to invest and limiting the appetite for innovations that risk diminishing product quality or causing production disruption
- Increasing concern about the security of energy supply where an interruption can cause major damage taking months to repair coupled with increasingly volatile electricity and gas prices
- Threat of rising energy prices, the cost of carbon and UK-only climate related charges
- Requirement for very high rates of return or short payback time on all projects including energy efficiency
- Shortage of proven, financially viable and demonstrated energy-efficiency technologies
- Lack of government support (e.g. financial) for sector research, development and demonstration (RD&D) and future implementation of emerging and breakthrough technologies
- Regulatory uncertainty on energy, climate, environmental and innovation issues undermines the business case for high cost, long-term investment
- Lack of reliable information about technical feasibility, costs and benefits of new technologies
- Limited access to affordable capital and adequate grants

1.5 Analysis of Decarbonisation Potential in the Ceramic Sector

A 'pathway' represents a particular selection and deployment of options from 2012 to 2050 chosen to achieve reductions falling into a specific decarbonisation band relative to a reference trend in which no options are deployed. Two further pathways with specific definitions were also created, assessing (i) what would happen if no particular additional interventions were taken to accelerate decarbonisation (business as usual, BAU) or (ii) the maximum possible technical potential for decarbonisation in the sector (Max Tech). A pathway is an illustration of how the ceramics industry could potentially decarbonise from our reference year 2012 to 2050. These pathways include deployment of options comprising (i) incremental improvements to existing technology, (ii) upgrades to utilise best available technology (BAT), and (iii) the application of significant process changes using 'disruptive' technologies that have the potential to become commercially viable in the medium term.

The pathways investigated created in the current trends scenario, the central of three scenarios used in this study, are shown below in Figure 1.

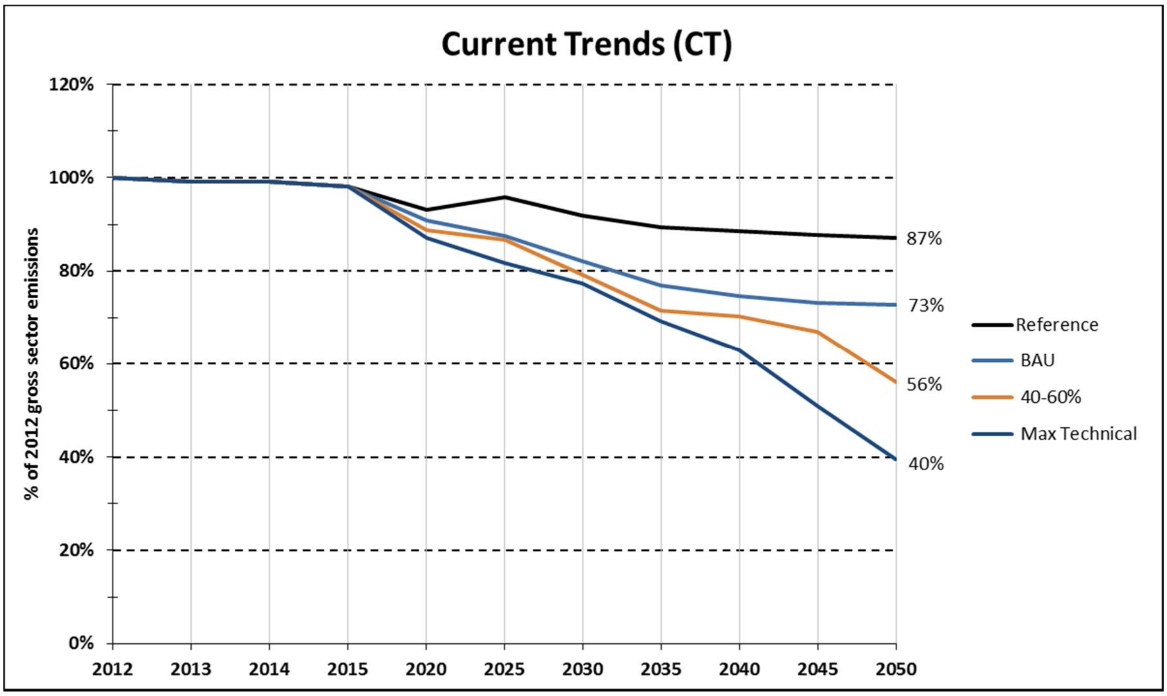

Figure 1: Decarbonisation and energy efficiency pathways results for current trend scenario

The analysis carried out showed that the max tech pathway would result in an emissions reduction of 60%, relative to the 2012 base year. This pathway simulated deployment of a range of technical options; the greatest decarbonisation came from:

- Decarbonisation of heat by substituting fossil fuel with electricity, comprising:
    - Replacement of conventional gas fired kilns and associated driers with electric kilns and driers, applied throughout the sector
    - Decarbonisation of the electricity grid
- Decarbonisation of heat by substituting fossil fuel with biomass, using onsite gasification technology at the larger production facilities
- Carbon capture (CC) applied to larger heavy clay facilities

The BAU pathway resulted in an emissions reduction of 27% relative to the reference year, resulting from incremental improvements to existing technology and the deployment of best available technology (BAT) across the sector.

Analysis of the costs of the pathways used order of magnitude estimates to add up the capital cost of each pathway. As an indication, the net present capital cost for the pathways, discounted at 3.5%, falls within an estimated range of £300 million[3] to £700 million[4]. There is a large degree of uncertainty attached to the cost analysis, especially for options which are still in the R&D stage. Also, costs of operation, energy use, RD&D,

[3] For the BAU pathway in the current trends scenario
[4] For the Max Tech pathway in the current trends scenario

civil works, modifications to plant and costs to other stakeholders are significant for some options, but not included here. The costs presented are for the study period and are adjusted to exclude residual value after 2050, thus a proportion of the costs of high capex items deployed close to 2050 is excluded. Great care must be taken in how these costs are interpreted. While implementation of some of the options within the pathways may reduce energy costs due to increased efficiency, the scale of the investments associated with the pathways must be considered by stakeholders when planning the next steps in the sector.

1.6 Conclusions and Key Technology Groups

The following conclusions have been drawn from the evidence and analysis:

Strategy Leadership and Organisation

It is critical that the ceramic sector, the government and other stakeholders recognise the importance of strategy and leadership in the context of decarbonisation and energy efficiency and in strengthening the short and longer term competitiveness of the sector.

Business Case Barriers

One of the most important barriers to decarbonisation and increased energy efficiency is reported by many in the sector as lack of funding for such projects in the UK due to low margins, limiting available capital, lower returns and higher risks compared with competitor economies.

Future Energy Costs, Energy Supply Security, Market Structure and Competition

It is clearly critical to ensure that future decarbonisation and energy efficiency actions maintain the position with respect to overall cost-competitiveness of the UK sector compared to competing businesses operating in other regions of Europe, Asia and the US. This strategic conclusion links to a number of external factors that influence the business environment in which the sector operates. These include energy security and energy and carbon cost comparison to other regions (both reality and perception), as these factors are important criteria for investment decisions.

Industrial Energy Policy Context

Long-term energy and climate change policy is key to investor confidence. Many in the industry believe that there is a need for incentive schemes to become long-term commitments, as changes in policy can be damaging, particularly when the business case for investment is marginal and is highly dependent upon factors such as (fluctuating) energy related costs.

Life-Cycle Accounting

The ceramic sector uses raw materials from, and provides its products to, other parts of the economy. There needs to be a means of understanding the overall carbon impact of the entire product life-cycle. For example a ceramic building product or a refractory material for a glass furnace may deliver significant energy savings in its lifetime of use. Wider application of tools to measure and allocate these products may enable investments to be made through recognising life-cycle benefits.

Value Chain Collaboration

The carbon emissions of the ceramic sector are significantly affected by the expectations of consumers, the business needs of users together with the defined product standards. Better recognition of the opportunity and collaboration across the value chain could enable products with lower lifecycle carbon emissions to be developed and adopted.

Research, Development and Demonstration (RD&D)

The ceramic sector needs to explore and apply new technologies to reduce energy consumption and carbon emissions. The costs and uncertainties of RD&D are challenging to fund and the cost of commercial scale demonstrator projects needed before new technologies can be deployed often represent too large a risk for an individual company to fund. Collaboration and co-funding would be a solution but companies may be constrained in collaborating with direct competitors. There may be opportunities for addressing common issues across several sectors employing high temperature processes e.g. ceramic, cement, glass and iron and steel.

People and Skills

New manpower resources with specialised skills and knowledge in process and thermal engineering are increasingly needed by the UK ceramic sector. To make the choice between 'standard' equipment and more energy efficient equipment when making investment, knowledge is needed. This is, and will continue to be, key to decarbonising the sector. Advanced technologies are attractive to the younger generation so it is also an opportunity to attract more young people to start working in the sector.

The key technology groups that this investigation found made the largest contributions to sector decarbonisation are as follows:

Electricity Grid Decarbonisation

Decarbonisation of this key source of energy supply could provide a significant contribution to the overall decarbonisation of the sector. Actions will be required to ensure that this takes place while maintaining cost-competitiveness (see also *Future Energy Costs, Energy Supply Security, Market Structure and Competition* above). The Government's reforms of the electricity market are already driving electricity grid decarbonisation, and this report uses assumptions of a future electricity decarbonisation trajectory that is consistent with Government methodology and modelling.

Electrification of Heat

Ceramic sector energy use is dominated by fossil fuels. The pathway analysis has demonstrated that migration to low carbon electricity is a key option for decarbonisation. The heavy clay subsector has the largest energy consumption and carbon emissions but there are currently no large scale continuous kiln designs available to meet the needs of the subsector. A large scale continuous electric kiln would be very different to one designed to be heated by gas combustion and significant development will be required in collaboration with manufacturers to produce and demonstrate a suitable design for widespread application.

Fuel and Feedstock Availability (Including Biomass)

The availability and cost of biomass is a potential issue for sector decarbonisation, given its importance to the pathways (although the no biomass Max Tech pathway has shown that significant decarbonisation can be achieved without it). This availability issue is critical in view of the long-term investment associated with kiln upgrades. The security of biomass supply is particularly affected by competition between sectors, with large scale biomass use for power generation seen to be less price sensitive than the ceramic sector. The challenges are to understand where the greatest decarbonisation potential can be achieved with a limited resource, as well as to maximise the availability of the resource (links to *Life-cycle Accounting* above).

Energy Efficiency and Heat Recovery

The pathways demonstrate that the largest early improvements in carbon emissions result from the application of energy efficiency and heat recovery techniques, to both existing and new kilns. The improvement to energy efficiency by a range of measures related to combustion and reduction of heat losses is complemented by the application of increased heat recovery to kiln and drier exhaust streams. New BAT kilns include these features, although improvements in heat recovery technology to handle the challenging application will need further progressive development to maximise its potential on both new and existing kilns.

Carbon Capture

Individual ceramic sites are not considered to be of a sufficient scale to justify their own CO_2 pipeline and storage infrastructure. Collaboration is necessary to establish the networks, along with the availability of sources of funding appropriate to this type of shared infrastructure. In addition, while even large ceramic sites produce exhaust flows for which proven carbon capture technology exists, there are challenges of low CO_2 concentration and the presence of aggressive acid gases in the exhaust stream that are unprecedented. Work is therefore necessary to develop and demonstrate economic carbon capture technology appropriate to commercial application in the sector at this scale (links to *Research, Development and Demonstration* theme).

Other Technologies (Specific to the Ceramic Sector)

High temperature transformation of materials is characteristic of ceramic products. However the sequence and details of processing steps for each product can be refined for different purposes – to reduce costs, increase throughput, minimise rejects or reduce energy – and adjustments made to benefit one aspect may adversely affect another. There are therefore a range of improvements to ceramic processes that can be optimised or traded-off to reduce emissions, preferably in conjunction with reduced costs or increased throughput. These include changes to the composition of raw materials to permit lower firing temperatures to be achieved, changes in manufacturing processes to permit the omission of firing steps and adjustments to improve energy utilisation by closer kiln packing. Some of these improvements are inherently highly specific to products and production facilities, while others relate to materials properties that are generic. As a result some of these improvements can only be made at a company level, while others are perhaps best addressed in collaboration; in either case these relate to the *Research, Development and Demonstration* theme above.

Next Steps

This roadmap report is intended to provide an evidence-based foundation upon which future policy can be implemented and actions delivered. The way in which the report has been compiled is designed to ensure it has credibility with industrial, academic and other stakeholders and is recognised by government as a useful contribution when considering future policy.

2. INTRODUCTION, INCLUDING METHODOLOGY

2.1 Project Aims and Research Questions

2.1.1 Introduction

Changes in the international economy, coupled with the need to decarbonise, mean that UK businesses face increased competition as well as new opportunities. The government wants to enable UK businesses to compete and grow while moving to a low-carbon economy. The UK requires a low-carbon economy but currently includes industries that consume significant amounts of energy. These energy-intensive industries have an essential role to play in delivering the UK's transition to a low-carbon economy, as well contributing to economic growth and rebalancing the economy.

Overall, industry is responsible for nearly a quarter of the UK's total emissions (DECC, 2011)[5]. By 2050, the government expects industry to have delivered a proportionate share of emissions cuts, achieving reductions of up to 70% from 2009 levels (DECC, 2011). Nonetheless, the government recognises the risk of 'carbon leakage' and 'investment leakage' arising from the need to decarbonise and is committed to ensuring that energy-intensive industries are able to remain competitive during the transition to a low-carbon economy.

The Department of Energy and Climate Change (DECC) and the Department of Business, Innovation and Skills (BIS) have set up a joint project focusing on the eight industrial sectors which use the greatest amount of energy[6]. The project aims to improve the understanding of technical options available to sectors to reduce carbon emissions and increase energy efficiency while remaining competitive. This includes include investigating the costs involved, the related business environment, and how investment decisions are made in sector firms. This will provide the industry and government with a better understanding of the technical and economic abatement potential, set in the relevant business context, with the aim to agree measures that both the government and these industries can take to reduce emissions while maintaining sector competitiveness.

The project scope covers both direct emissions from sites within the sector and indirect emissions from the use of electricity at the sites but generated off site

The different industrial sectors evaluated in this project are listed in Table 2

Cement	Glass
Ceramics	Iron and Steel
Chemicals	Oil Refining
Food and Drink	Pulp and Paper

Table 2: Industrial sectors evaluated in this project

This report addresses the ceramic sector, comprising four subsectors identified by British Ceramic Confederation (BCC) as having different scales of production and types of product:

[5] It has also been estimated that 70% of industrial energy use is for heat generation (Source: Energy Consumption in the UK 2014: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk)
[6] The 'non-metallic minerals' sector has been divided into three sectors: glass, ceramics and cement.

- Heavy clay construction products (bricks, roofing tiles, clay drainage pipes etc.)
- Whitewares (sanitary ware, floor and wall tiles, tableware and giftware)
- Refractories (high temperature heat resistant materials vital in all high-temperature processes including metals making, the production of cement, petrochemical processes, glass and ceramic)
- Technical ceramics (special purpose ceramic components for electronics, medical, environmental protection, military and structural applications)

A fifth subsector, raw materials extraction and processing is related to ceramic sector as a supplier of some materials. It is not addressed in this study as it covers a diverse range of processes and supplies mineral products to numerous sectors in addition to ceramic.

2.1.2 Aims of the Project

The DECC 2011 Carbon Plan outlined how the UK would achieve decarbonisation and make the transition to a low-carbon economy while trying to maintain energy security and minimise negative economic impacts. This project aims to improve evidence on decarbonisation and energy efficiency for eight energy-intensive industry sectors.

The project consortium Parsons Brinckerhoff and DNV GL was appointed by DECC and BIS in 2013 to work with stakeholders, including the UK manufacturers' organisations (i.e. trade associations), to establish a shared evidence base to support decarbonisation. The roadmap process consisted of three main phases:

i. Information and evidence gathering on existing technical options and potential breakthrough technologies, together with research to identify the social and business enablers and barriers to decarbonisation
ii. Development of sector decarbonisation and energy efficiency pathways
iii. Conclusions and identification of potential next steps

A series of questions were posed by DECC and BIS as part of the project. These 'principal questions' guided the research undertaken and the conclusions of this report. The questions and the report section in which they are addressed are stated below:

1. What are the current emissions from each sector and how is energy used? - section 3.3
2. For each sector, what is the business environment, what are the business strategies of companies, and how does it impact on decisions to invest in decarbonisation? - section 3.4
3. How might the baseline level of energy and emissions in the sectors change over the period to 2050? - section 4.3
4. What is the potential to reduce emissions in these sectors beyond the baseline over the period to 2050? - section 4.4
5. What emissions pathways might each sector follow over the period to 2050 under different scenarios? - section 4.4
6. What next steps into the future might be required by industry, the government and others to overcome the barriers in order to achieve the pathways in each sector? - section 5

2.1.3 What is a Roadmap?

A 'roadmap', in the context of this research, is a mechanism to visualise future paths, the relationship between them and the required actions to achieve a certain goal. A technology roadmap is a plan that matches short-term and long-term goals with specific technology solutions to help meet those goals.

Roadmaps for achieving policy objectives go beyond technology solutions into broader consideration of strategic planning, market demands, supplier capabilities, and regulatory and competitive information.

The roadmaps developed by this project investigate decarbonisation in various UK industries, including how much carbon abatement potential currently exists, what technologies will need to be implemented in order to extend that potential, and how businesses will be affected. The roadmap aims to present existing and new evidence, analysis and conclusions as a 'consensual blueprint' to inform subsequent action with respect to issues such as future energy and manufacturing industrial strategy and policy, decarbonisation and energy efficiency business investments, R&D, and skills. The roadmaps consist of three components: evidence, pathways analysis and conclusions, as illustrated in Table 3. Each component is necessary to address the principal questions, and is briefly defined below.

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050			
SOURCES OF EVIDENCE	INTERMEDIATE OUTPUTS	PATHWAYS	STRATEGIC CONCLUSIONS AND EXAMPLE ACTIONS
Literature	Validated emission data	Analysis of evidence to construct decarbonisation and energy efficiency pathways	Analysis of evidence and pathways to develop strategic conclusions and possible next steps to: • Overcome barriers and strengthen enablers • Implement pathways
Publicly available emissions data	Decarbonisation options and associated data		
Interviews, surveys, meetings and workshops with stakeholders	Energy efficiency options and associated data		
Government policy and analytical teams, trade associations, academics as part of engagement with the sector team	Enablers and barriers to decarbonisation and energy efficiency options and investment		

Table 3: Inputs and outputs for the industrial decarbonisation and energy efficiency roadmap to 2050

The views of contributing organisations

These reports were commissioned by DECC and BIS, and jointly authored by Parsons Brinckerhoff and DNV GL. The project was progressed using a collaborative process and while important contributions were provided by the sector, it should not be assumed that participating organisations (i.e. government, BCC and their members and academic institutions) endorse all of the report's data, analysis and conclusions.

The findings from the interviews and workshops represent the opinions and perceptions of particular industrial stakeholders, and may not therefore be representative of the entire sector. We have tried to include alternative findings or viewpoints, but this has not always been possible within the constraints of the project. This needs to be taken into account when reading this report.

2.2 Overall Methodology

The overall methodology is illustrated in Figure 1 and shows the different stages of the project. As can be seen, the stakeholders are engaged throughout the process that follows the main phases of the project:

evidence gathering, modelling and pathway development and finally drawing out the conclusions and potential next steps. A detailed description of the methodology can be found in appendix A.

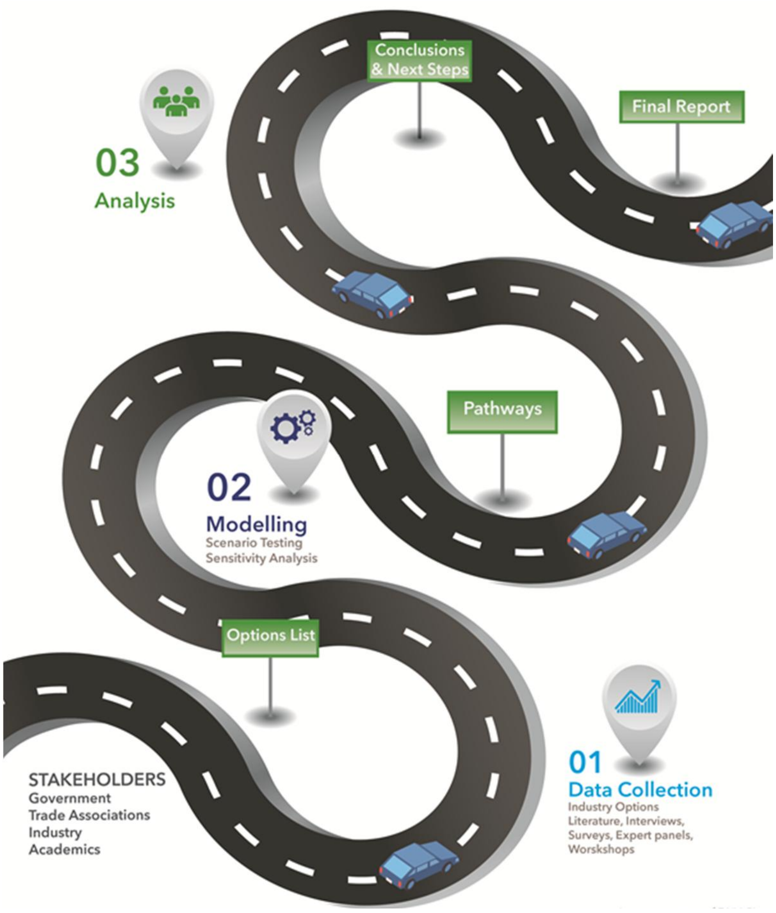

Figure 2: Roadmap methodology

Evidence was gathered for covering technical, and social and business aspects from literature reviews, interviews, surveys and workshops with relevant stakeholders. These different sources of information allowed evidence triangulation to improve the overall research. The data was then used to develop a consolidated list of enablers and barriers for decarbonisation, and a register of technical options for the industry. This was subsequently used to develop a set of decarbonisation and energy efficiency pathways to evaluate the decarbonisation potential of the UK ceramic sector and the main technical options required within each pathway.

Key to the overall roadmap methodology was engagement with all stakeholders, including with business and trade association representatives, academics and civil servants, to contribute to the evidence, validate its quality and interpret the analysis. We have worked closely with BCC, DECC and BIS to identify and involve the most appropriate people from the ceramic sector and other stakeholders, such as representatives from the financial sector. BCC identified relevant academics (from Keele University) who have contributed to the work.

Together with stakeholders, the enablers and barriers were reviewed to identify a range of possible next steps that could be implemented.

2.2.1 Findings

Evidence Gathering

The data focused on technical, and social and business information, aiming to acquire evidence on:

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

Such evidence was required to either answer the principal questions directly and/or to inform the development of decarbonisation and energy efficiency pathways for 2050. Four methods of research were used in order to gather as much evidence as possible (and to triangulate the information) within a short timescale. These methods were:

- **Literature review:** A short, focussed review of over 25 documents all published after 2000 was completed. The documents were either related to energy efficiency and decarbonisation of the ceramic sector or to energy-intensive industries in general. This was not a thorough literature review or rapid evidence assessment (REA) but a desktop research exercise deemed sufficient by the project team[7] in its breadth and depth to capture the evidence required for the purpose of this project. The literature review was not intended to be exhaustive and aimed to capture key documentation that applied to the UK. This included 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. Further details are provided in appendix A.
- **Interviews:** The ceramic companies interviewed, represented the four subsectors: heavy clay, whitewares, refractories and technical ceramics in the UK, and included 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. In liaison with BCC, DECC and BIS, these six face-to-face semi-structured interviews were carried out with Ibstock Brick, Naylor Industries, Portmeirion Group, Ideal Standard, DSF Refractories / Minerals and Mantec Group, using the 'interview protocol' (see appendix A). The purpose of the interviews was to obtain further details on the different subsectors within the ceramic sector and gain a deeper understanding of the principal questions, including how companies make investment decisions, how advanced technologies are financed, what a company's strategic priorities are and where climate change sits within this. The interviewees were interviewed using an interview protocol template, developed in liaison with DECC and BIS. This template was used to ensure consistency across interviews, fill gaps in the literature review, identify key success stories and extract key barriers to investment in low carbon technologies. The interview protocol can be found in appendix A.

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

- **Survey:** A survey was conducted with 31 managers from the UK ceramic sector to assess the impact of the identified enablers and barriers from literature review and interviews. This constitutes a good response rate of 31% and represents a balanced view across the four subsectors in scope: heavy clays, refractories, whitewares and technical ceramics. The questions were drawn up in consultation with DECC and BIS and the sample of respondents were selected based on coverage of a high proportion of sector emissions (nb the survey was not a census). The key questions focused on the respondents' view on the level of impact of the top enablers and barriers on the implementation of energy and decarbonisation options as identified from the interviews and literature review.
- **Workshops:** Two workshops were held, attendees for which were identified in consultation with BCC, DECC and BIS. The first evidence-gathering workshop focused on reviewing potential technological decarbonisation and energy efficiency options (that had been provisionally generated from the literature review) and discussing adoption rate (ADOPT), applicability rate (APP), improvement potential, ease of implementation, capital expenditure (capex), return on investment (ROI), savings potential and timeline for the different options. This was done through two breakout sessions: one focused on collecting more data and the other one on timelines under different scenarios. The second activity involved group discussions on enablers and barriers to energy efficiency and decarbonisation investment, and how to overcome them. The second workshop focused on reviewing the draft decarbonisation and energy efficiency pathways and identifying potential actions for delivering them. The workshop participants included the relevant trade associations, large companies with the aim of achieving representation of key companies and/or subsectors and academics with expert knowledge of the sector, PB and DNV GL consultants, DECC and BIS project managers and senior civil servants. The average size of a workshop was 40 people.

It should be noted that the evidence-gathering exercise was subject to several limitations based upon the scale of activities that could be conducted within the time and resources available. Interview and survey samples were gathered through purposive and snowball sampling techniques in collaboration with trade associations, DECC and BIS experts. But due to time, sampling and resource constraints the samples may be limited in terms of their numbers and/or diversity. Where possible we have attempted to triangulate the findings to counter any bias in the sample, but in some areas this has not been possible. Some caution should therefore be used in interpreting the findings. The literature review, while not intended to be exhaustive, aimed to capture key documentation that applied to the UK. The criterion for identifying and selecting literature is detailed in appendix A. Interviewees included UK decision makers and technical specialists in the sector.

The different sources of evidence together with the associated outputs are shown in Figure 3.

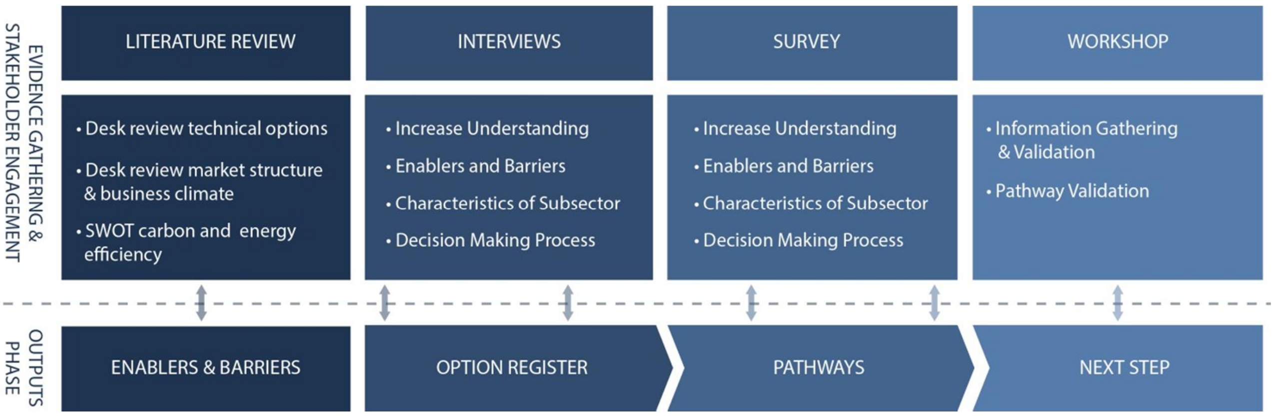

Figure 3: Evidence- gathering process

The different sources of evidence were used to develop a consolidated list of barriers to and enablers for decarbonisation and energy efficiency, and a register of technical options for the ceramic sector. Evidence on adoption rate (ADOPT), applicability (APP), improvement potential, ease of implementation, capex, ROI and saving potential of all options (where available) was collected, together with information on strengths, weaknesses, opportunities and threats (SWOT). 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. Further information on the SWOT analysis is provided in appendix B. The SWOT analysis was used to further understand and validate the surveys and initial findings from the literature review and provided the basis for workshop and interview discussions and further helped to qualify the interview and workshop outcomes. Enablers and barriers were prioritised as a result of the outcomes and analysis of the evidence-gathering process and workshop scores.

This information was used to inform the development of a set of decarbonisation and energy efficiency pathways to illustrate the decarbonisation potential of the ceramic sector in the UK. The summary and outcomes of this analysis are discussed in Section 4.7.

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 staff from DECC and BIS.

The evidence-gathering exercise (see appendix A for details) 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 identification of relevant information and data was approached from both ‘global’ and ‘UK’ viewpoints. The global outlook examined dominating technologies and process types, global production, CO_2 emissions (in the EU28), and the global outlook to 2050, including the implications for ceramic producers and consumers. The UK outlook examined the sector structure, recent history and context including consumption, demand patterns, emissions, the business environment, organisational and decision-making structures and the impacts of UK policy and regulation.

Options examined were relevant to preparation, forming, drying, firing and finishing processes of products, as well as options that substituted lower carbon fuels for the current energy sources. Potentially transformative options involving radical changes to manufacturing processes were identified and assessed for readiness for wide scale application.

Evidence Analysis

The first stage in the 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 the evidence, and whether the findings were validated by more than one information source. The evidence was also analysed and interpreted using a variety of analytical techniques. Elements of the Porter’s five forces analysis, SWOT analysis and system analysis were used to conduct the analysis of the business environment, and the enablers and barriers (section 3.4.5); while concepts from storytelling and root cause analysis were used during the interviews with stakeholders. These different techniques are discussed in appendix B.

The options register of the technology options for decarbonisation was developed based on the literature review, interviews, the evidence gathering workshop, and additional information provided by BCC and its members. The strengths, weaknesses, enablers and barriers of each option were taken into account to refine the options register, which was then used to build up the different pathways in the pathway model.

A second stage in the analysis was the classification of technological options and an assessment of their readiness.

Limitations of these Findings

The scope of the study did not cover a full assessment of the overall innovation chain or of present landscape of policies and actors. Direct and indirect impacting policies, gaps in the current policy portfolio, and how future actions would fit into that portfolio (e.g. whether they would supplement or supplant existing policies) are not assessed in the report in any detail.

2.2.2 Pathways

The pathways analysis is an illustration of how the ceramic industry could potentially decarbonise from the base year 2012 to 2050. Together the set of pathways developed in the study help give a view of the range of technology mixes that the sector could deploy over coming decades. Each pathway consists of different technology options that are implemented over time at different levels. Each technology option included a number of key input parameters including CO_2 reduction, cost, fuel use change, applicability, current adoption (in the base year), and deployment (both rate and extent). A 'pathway' represents a particular selection and deployment of options from 2014[8] to 2050chosen to achieve reductions falling into a specific decarbonisation band.

In this project, up to five pathways were developed, three of which were created to explore possible ways to deliver CO_2 emissions to different decarbonisation bands by 2050, as shown below:

- 20-40% CO_2 reduction pathway relative to the base year
- 40-60% CO_2 reduction pathway relative to the base year
- 60-80% CO_2 reduction pathway relative to the base year

Two further pathways - with specific definitions - were also created, assessing (i) what would happen if no action was taken to accelerate decarbonisation (business as usual, BAU) or (ii) the maximum possible technical potential for decarbonisation in the sector (Max Tech)[9].

The BAU pathway consisted of the continued deployment of technologies that are presently being deployed across the sector as each plant or site reaches the appropriate point to implement the technology.

Pathways were developed in an iterative manual process and not through a mathematical optimisation process. This was done to facilitate the exploration of uncertain relationships that would be difficult to express analytically. This process started with data collected in the evidence gathering phase regarding the different decarbonisation options, current production levels and the current use of energy or CO_2 emissions of the sector. This data was then enriched through discussion with the sector team and in the first workshop. Logic reasoning (largely driven by option interaction), sector knowledge and technical expertise were applied

[8] Model anticipates deployment from 2014 (assuming 2012 and 2013 are too early).
[9] Definitions are provided in the glossary.

when selecting technical options for the different pathways. These pathways were discussed by the sector team, modelled, and finally tested 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 are detailed in the options register and relevant worksheets of the model. The pathway model, which is available through DECC and BIS, is summarised in appendix A.

Scenario Testing

The different pathways developed have been tested under different scenarios (i.e. there are three different scenarios for each pathway). A scenario is a specific set of conditions that could directly or indirectly affect the ability of the sector to decarbonise. Examples of these are: future decarbonisation of the grid, future growth of the sector, future energy costs, and future cost of carbon. Since we do not know what the future will look like, using scenarios is a way to test the robustness of the different pathways.

For each pathway, the following three scenarios were tested (a detailed description of these scenarios is provided in appendix A):

- **Current trends**: This would represent a future world very similar to our world today with low continuous growth of the industry in the UK.
- **Challenging world**: This would represent a future world with a more challenging economic climate and where decarbonisation is not a priority and the industry is declining in the UK.
- **Collaborative growth**: This would represent a future world with a positive economic climate and where there is collaboration across the globe to decarbonise and where the industry has a higher growth rate in the UK.

In order to produce pathways for the same decarbonisation bands under the different scenarios, the deployment rate of the options varied according to the principals set out in the scenarios. For example, in order to achieve a specific decarbonisation band in 2050 in the collaborative growth scenario, options were typically deployed at a faster rate and to a higher degree as compared to the current trends scenario (provided this was considered to be consistent with the conditions set out in the scenarios).

Key Assumptions and Limitations

The pathway model was developed and used to estimate the impact on emissions and costs of alternative technology mixes and macro-economic scenarios. Modelled estimates of decarbonisation over the period (2013 to 2050) are presented as percentage reductions in emissions meaning the percentage difference between emissions in 2050 and emissions in the base year (2012). CO_2 emissions reductions and costs are reported compared to a future in which there was no further take up of decarbonisation options (referred to as the reference trend).

The model inputs and option deployments are based on literature review, interviews and stakeholder input at workshops and sector meetings. Parsons Brinckerhoff and DNV GL sector leads used these sources to inform judgements for these key parameters. Key input values (e.g. decarbonisation factors for options) are adapted from literature or directly from stakeholder views. If data values were still missing then values were estimated based on consultant team judgements. Decarbonisation inputs and pathways were reviewed and challenged at workshops. The uncertainties in this process are large given this level of judgement, however, uncertainties are not quantified. A range of sensitivity analysis was carried out including the development of alternative versions of the Max Tech pathway and also testing of different availabilities of biomass.

Deployment of options at five-year intervals is generally restricted to 25% steps unless otherwise indicated. For example, an option cannot be incrementally deployed by 25% over ten years, but has to deploy over five years and flat-line over the other five years.

In this report, when we report CO_2 – this represents CO_2 equivalent. However, other green house gases (GHGs) were not the focus of the study which centred on both decarbonisation and improving energy efficiency in processes, combustion and indirect emissions from electricity used on site but generated off site. Also, technical options assessed in this work result primarily in CO_2 emissions reduction and improved energy efficiency. In general, emissions of other GHGs, relative to those of CO_2, are very low.

Assumptions in relation to the Max Tech pathway

Max Tech pathway: A combination of carbon abatement options and energy savings that is both highly ambitious but also reasonably foreseeable. It is designed to investigate what might be technically possible when other barriers are set to one side. Options selected in Max Tech take into account barriers to deployment but are not excluded based on these grounds. Where there is a choice between one option or another, the easier or cheaper option is chosen or two alternative Max Tech pathways are developed.

The following assumptions apply:

1. Technology Readiness Level (TRL): process or technology at least demonstrated at a pilot scale today, even if that is in a different sector.
2. Other disruptive technology options that could make a significant difference but that are not mature enough for inclusion in the pathways are covered in the commentary.
3. Cost is not a constraint: it has been assumed that there are strong and growing financial incentives to decarbonise which mean that the cost of doing so is not generally a barrier.
4. Option deployment rate: the sector team followed the roadmap method process to develop and test option deployments in all pathways, including Max Tech. Hence, in each sector, rates at which the options can be deployed were considered as ‘highly ambitious but also reasonably foreseeable’.
5. Biomass: maximum penetration of biogenic material as fuel or feedstock assuming unlimited availability. Carbon intensity and sensitivities are included in each sector.
6. Carbon Capture (CC): All sectors have made individual (sector) assessments of the maximum possible potential by 2050 based on what is ‘highly ambitious but also reasonably foreseeable’. This assessment included the most suitable CO_2 capture technology or technologies for application in the sector, the existing location of the sites relative to each other and anticipated future CC infrastructure, the space constraints on sites, the potential viability of relocation, the scale of the potential CO_2 captured and potential viability of both CO_2 utilisation and CO_2 storage of the captured CO_2.
7. Electricity Grid: three decarbonisation grid trends were applied through the scenario analysis.

Option Interaction Calculation

The pathway model incorporated two methods for evaluating potential interaction of options. The first method reflected the assumption that all options interacted maximally, and the second method reflected the assumption that the options did not interact. Neither of these cases was likely to be representative of reality; however the actual pathway trend would lie between the two. The two methods therefore provided a theoretical bound on the uncertainty of this type of interaction in results that was introduced by the choice of a top down modelling approach. Figures calculated based on the assumption of maximum interaction are presented exclusively in the report unless otherwise stated.

Cumulative Emissions

An important aspect of an emission pathway is the total emission resulting from it. The pathways presented in this report are not designed or compared on the basis of cumulative emissions over the course to 2050. Only end-targets are assessed e.g., it is possible for a pathway of lower 2050 emission to have larger cumulative emissions, and thus a greater impact on the global climate system. The exception to this is in the cost analysis section where total CO_2 abated under each pathway – as calculated by the model – is quoted.

Scope of Emissions Considered

Only emissions from production or manufacturing sites were included in scope (from combustion of fuels, process emissions and indirect emissions from imported electricity). Consumed and embedded emissions were outside the scope of this project.

Complexity of the Model

The model provided a simplified top down representation of the sector to which decarbonisation options were applied. It does not include any optimisation algorithm to automatically identify a least cost or optimal pathway.

Material Efficiency

Demand reduction through material efficiency was outside the scope of the quantitative analysis. It is included in the conclusions as material efficiency opportunities are considered to be significant in terms of the long-term reduction of industrial emissions: see for example Allwood et al. (2012) and the ongoing work of the UK INDEMAND Centre.

Base Year (2012)

The Climate Change Act established a legally binding target to reduce the UK's GHG emissions by at least 80% below base year (1990) levels by 2050. DECC's 2011 Carbon Plan set out how the UK will achieve decarbonisation within the framework of the carbon budgets and policy objectives: to make the transition to a low-carbon economy while maintaining energy security and minimising costs to consumers. The Carbon Plan proposed that decarbonising the UK economy "could require a reduction in overall industry emissions of up to 70% by 2050" (against 2009 emissions).

In this project for the analytical work, we have set 2012 as the base. This is the most recent dataset available to the project, and was considered to be a suitable date to assess how sectors (as they currently are) can reduce emissions to 2050. This separates the illustrative pathways exercise from national targets, which are based on 1990 emissions.

2.2.3 Conclusions and Next Steps

The conclusions and potential next steps are drawn from the outcomes of the pathways modelling, the scenario testing and the potential actions to overcome barriers and enhance enablers that were identified together with stakeholders. The strategic conclusions can include high-level and/or longer term issues, or more specific, discrete example actions which can lead to tangible benefits. The potential next steps are presented in the context of eight strategic conclusions (or themes) and six or seven technology groups. The strategic conclusions or themes are:

- Strategy, leadership and organisation
- Business case barriers
- Future energy costs, energy supply security, market structure and competition

- Industrial energy policy context
- Life-cycle accounting
- Value chain collaboration
- RD&D
- People and skills

The main technology groups as presented in section 5 are:

- Electricity grid decarbonisation
- Electrification of heat
- Fuel and feedstock availability (including biomass)
- Energy efficiency and heat recovery
- Clustering
- CC
- Sector-specific technologies

3. FINDINGS

3.1 Key Points

Emissions in 2012 from ceramic production totalled 1.2 million tonnes of CO_2 (including fuel emissions, indirect emissions and estimated process emissions) and this was associated with the production of 4.2 million tonnes of ceramic products (BCC figures from CCA data, 2012). Whilst these emissions represent almost a third of production, on a per tonne basis, they are a small proportion of the overall UK emissions. Direct emissions originate from fuel combustion for firing kilns and dryers, and process emissions. While indirect emissions arise from electricity imported from the grid for process machinery and in a limited number of cases for heating electric kilns and furnaces. Process emissions result from inherent chemical changes in the raw materials (decomposition of carbonates and oxidation of organic content) as they are converted to ceramic products.

Before carbon-related legislation was introduced, the ceramic sector was already evolving towards a more carbon-neutral energy strategy. As energy can represent up to 35% of overall production costs (BCC, 2014), ceramic manufacturers have been driven to maximise the efficiency of their operations over several decades. Competing in fiercely competitive global markets provides further impetus. Literature review, survey findings, interviews and workshops feedback showed that energy efficiency is perceived as essential, but decarbonisation is generally a lower priority in the current investment climate for a variety of reasons, including[10]:

- Large equipment suppliers have little of their manufacturing or RD&D based in the UK
- Limited RD&D for the ceramic sector in the UK
- Companies are more willing to invest in financially viable technologies that have already been proven to be successful, to reduce commercial risks
- UK producers with headquarters overseas are in competition for funding with their peers abroad, and corporate investment may be targeted on locations with higher returns associated with lower energy and wage costs
- Large upfront costs and long life cycles of kilns (30-60 years) are disincentives to invest given the uncertain market conditions and UK regulatory environment, internationally disadvantageous energy and carbon prices and perceived long-term lack of support for UK manufacturing industry

The evidence gathering identified the main enablers for decarbonisation for the ceramic sector to be:

- Projects providing multiple benefits (energy, carbon and labour cost reduction, improved production yield, increased capacity to satisfy a growing market, etc.) are more likely to be invested in
- Compliance with legal obligations (e.g. environmental licence)
- A strong, evidence-based business case for energy and decarbonisation measures that capture all benefits and cost
- Stable and internationally competitive business and regulatory environment that encourages capital investment in innovation
- Willingness of top management to make carbon emission reduction a priority
- The need to replace obsolete equipment, expand production or reduce operational manpower

The evidence gathering found that the main barriers that hamper decarbonisation are:

[10] Based on interviews and surveys

- Long investment cycles (given equipment life of up to 40 years) and high capital costs of new technologies
- Risks that an innovation would diminish product quality or cause production disruption
- Increasing concern about the security of energy supply where an interruption can cause major damage taking months to repair coupled with increasingly volatile electricity and gas prices
- Threat of rising energy prices, the cost of carbon and UK-only climate related charges
- Requirement for very high rates of return or short payback time on all projects including energy efficiency
- Regulatory uncertainty affects the assessment of high cost, long-term investment
- Shortage of proven, financially viable and demonstrated energy-efficiency technologies
- Lack of government support (e.g. financial) for sector RD&D and future implementation of emerging and breakthrough technologies
- Lack of reliable information about technical feasibility, costs and benefits of new technologies
- Limited access to affordable capital and adequate grants

Future production for the UK ceramic sector is projected to grow somewhat, but with differing levels across the four subsectors. The heavy clay subsector could grow in response to recovery in the construction sector (however there is concern that this demand could instead be met with increasing levels of imports); whitewares is expected to have static output or grow more slowly; refractories anticipate growth with its markets in Europe and overseas, while technical ceramics expect continued stronger growth, although both of these latter subsectors have vulnerable electro-intensive production. These estimates are reflected in the current trends scenario with lower and higher rates of growth in the collaborative growth and challenging world scenarios.

The energy-saving options for the ceramic sector distilled from the literature review, interviews, surveys and workshops can be classified into four categories: heat recovery improvements, process improvements, fuel switching and CC options. The options were further grouped into incremental application of state-of-the-art technologies, major investment technologies (which involve significant change) and disruptive technologies (which result in major changes to production technology).

3.2 Ceramic Processes

The final product determines the detailed steps of manufacture, but all ceramic manufacturing processes have a common element: the ceramic material is fired to a temperature to instigate chemical and physical changes that develop the final properties of the product, including bonding to form a rigid matrix. Firing requires raw materials (e.g. clay, sand, other natural or synthesised materials), to be prepared and formed according to various subsector processes before being heated in a kiln to temperatures between 900°C and 2750°C. The fired product is then cooled and taken out of the kiln and possibly further processed with additional coating and firing steps or machining to produce the end product item. During these manufacturing processes, direct CO_2 emissions arise from the combustion of fossil fuels in the kilns, the chemical decomposition of carbonate minerals and the combustion of organic material in the raw materials.

Figure 4 outlines the brick-making process, but the generic stages are similar for all large-scale ceramic manufacturing processes.

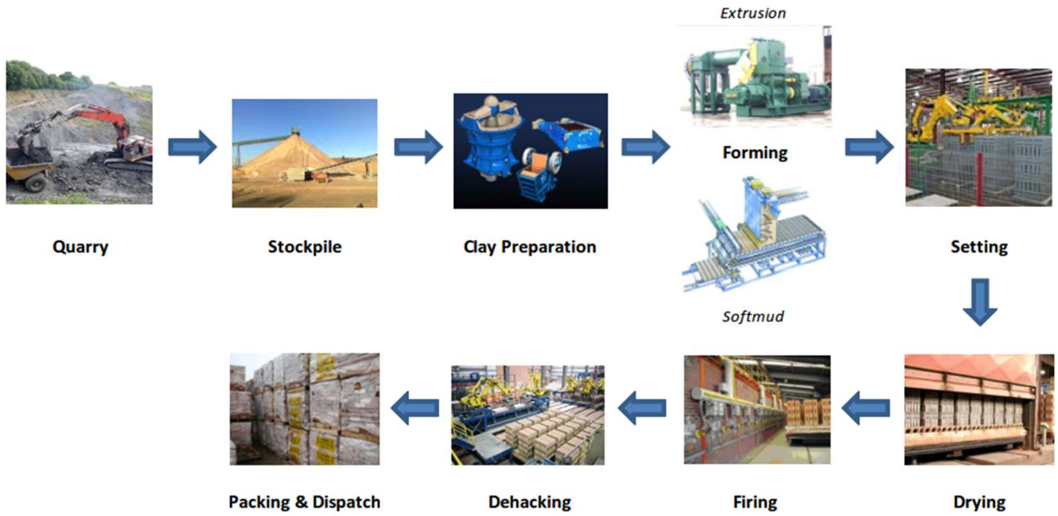

Figure 4: Stages in the brick manufacturing process (Carbon Trust, 2012)

The basic manufacturing process of ceramic consists of preparation of raw materials, forming, drying, firing, finishing processes (may include further steps of coating and firing or machining), inspection and packing. The specific processes used in each step vary between and within the subsectors according to the scale of production, the product and the raw materials used.

3.2.1 Preparation of Raw Materials

The raw materials used in the manufacture of ceramic range from naturally occurring minerals (e.g. clays, silica, feldspar etc.) to chemically synthesised powders with tightly controlled compositions and particle size distributions. The first step in the production process is to prepare the materials and ensure they are in a suitable form for subsequent processing. Raw material preparation processes are varied and may include ageing, homogenisation and mixing (raw materials, water and additives), particle size reduction and grading into size ranges. Some processes are conducted continuously, whilst others are batch operations. In some cases, after wet grinding, moisture is removed by filter-pressing or by spray drying.

3.2.2 Forming

Forming processes are equally varied in that dry powders, plastically deformable clay bodies or suspensions are consolidated to produce the desired shape and size. Dry forming consists of the simultaneous compaction and shaping of dry ceramic powders in a rigid die or flexible mould. Dry forming can be accomplished by a range of processes including dry pressing (e.g. floor and wall tiles), isostatic compaction (technical ceramics) and vibratory compaction (technical ceramics). Plastic moulding is accomplished by numerous processes that involve the application of pressure to shape a deformable mass, e.g. extrusion (heavy clay, refractories), jiggering (axially symmetrical whitewares) and injection moulding (technical ceramics). Suspension forming of ceramics is accomplished by moulding a shape from a pourable water-based suspension. Suspension forming includes slip casting (sanitaryware and complex shaped whitewares), tape casting and gel-casting (technical ceramics).

3.2.3 Drying

After forming, ceramics must be dried to remove moisture prior to firing. Drying is a significant energy consuming process. Drying must be carefully controlled to minimise drying time while avoiding differential shrinkage, warping, cracking and residual moisture. The most commonly used method of drying ceramics is by convection, in which heated air is circulated around the ceramics, in some cases using heat recovered from the cooling zone of the kiln. Dryers may be continuous, where product travels through a varying heat distribution along the length of the chamber, or intermittent (batch), where the product is stationary while the internal temperature within the dryer follows a time-varying profile. An alternative to convection drying is radiation drying in which microwave or infrared radiation is used to promote faster and more uniform drying of the products.

3.2.4 Firing

Firing is the process by which raw materials are thermally transformed from a friable blank into a robust, rigid product. This process may also be referred to as sintering or densification. Firing is the dominant energy- and emissions-intensive step. Conventional firing is accomplished by heating the dried ceramic to approximately two-thirds of the melting point of the material and holding at this temperature for a sufficient time for chemical and physical changes to develop the final properties of the product. There are two classes of kiln in which this heating process is done; continuous or batch kilns.

Continuous kilns are well suited to high volume production of similar items requiring the same heating and cooling profiles. The cross-section of such kilns can be as small as a fraction of a metre square (e.g. roller hearth kilns for floor and wall tiles) up to 10m wide by 5m high (a tunnel kiln for brick or roof tiles) with a length varying from 60 to 200 metres. In either case the product travels down the length of the kiln at low speed passing through zones of increasing temperature to the peak temperature, which may be maintained for some distance to allow the reactions to be completed, followed by a controlled profile of cooling until warm product items are delivered at the kiln exit. Heating in continuous kilns is generally provided by the staged combustion of fuel and the recirculation of hot gases though the kiln, while cooling is provided by controlled suction of air through the kiln. Product items may be stacked on insulated kiln cars that carry them through the kiln or may be moved along the floor of the kiln on a so-called roller hearth. The duration of the journey of the product through a continuous kiln ranges from 30 minutes to several days according to size, thickness and type of product.

As their name suggests, batch kilns process loads of ware through the firing cycle in an insulated enclosure with doors to permit unfired product items to be loaded and fired items unloaded. Such kilns may again vary in size from small, laboratory, table-top kilns to large room sized production kilns. The operating cycle of batch fired kilns can be as short as a few hours to in excess of a week according to size and thickness of the product. Batch kilns may be heated by fuel combustion or by electric resistance, electric arc or electric induction heating. The kiln temperature is controlled to a prescribed schedule which determines heat input and the operation of dampers and hatches that introduce ambient cooling air. Batch kilns offer broad flexibility in the heating and cooling profiles that can be achieved and thus are well suited for widely varying product sizes and firing conditions.

3.2.5 Finishing Processes

Following firing, some ceramic products are processed further to enhance their characteristics or to meet dimensional tolerances. Ceramics can be machined by abrasive grinding, chemical polishing, electrical discharge machining, or laser machining. Surface coatings are applied to many fired ceramics to create impermeable surfaces (glazed products) and for aesthetic appeal. Coatings also may be applied to improve strength and resistance to abrasion and corrosion. The application process may be by hand for specific high quality tableware and giftware, but more commonly automated techniques are used, including curtain coating, robotic spraying, contact printing and non-contact printing. Coatings may be applied onto the unfired product (where the coating and ceramic are fired simultaneously) or onto fired ceramics, necessitating an additional firing step. After the final finishing step products are inspected and packaged, either manually or by automated techniques.

3.2.6 Opportunities for Carbon Emission Reduction

Ceramics are one of the earliest manufactured products and remarkably advanced techniques were developed before the industrial age. Industrial manufacture has allowed much larger scale and more repeatable quality of products to be produced at a lower cost and with reduced energy input. However the basic drying and firing processes are energy intensive and, despite considerable innovation in recent decades, a radical further reduction in energy use is unlikely without fundamental improvements in materials and processes. Hence radical reductions in carbon emissions need to build on process and energy efficiency improvements but must be focussed on providing the necessary heat with minimum carbon emissions.

3.3 Current Emissions and Energy Use - Principal Question 1

This section provides an assessment of the range of questions under principal question 1: 'What are the current emissions from each sector and how is energy used?' It focuses on technologies that are currently used in the sector, the emissions associated with the activities, the heat and power demand of ceramic factories, the fuels that are used to deliver this energy, the lifespan of equipment and key timings for replacement or rebuild.

3.3.1 Evolution of Emission Reductions

The sector carbon emissions have not been tracked over a long period; however, the emissions are directly related to the energy consumption, which has been collected by BCC over a number of years. The trend in energy consumption since 2000 is shown in Figure 5. The adverse impact of the recession can be clearly seen by the near halving of consumption between 2007 to 2009 with the subsequent limited recovery to 2011.

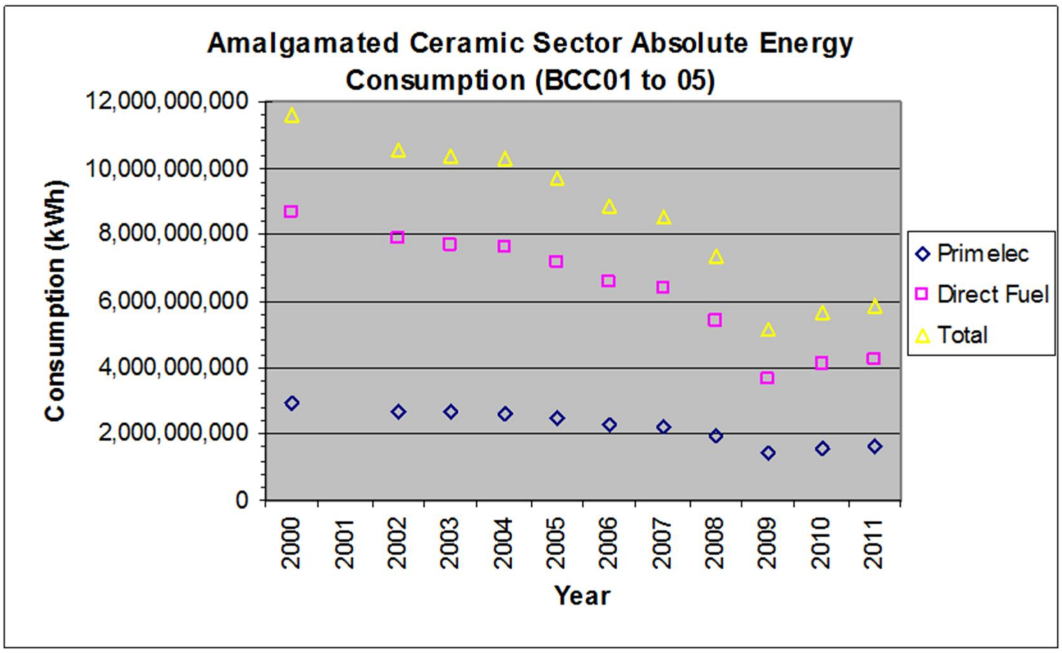

Figure 5: Historical energy consumption by ceramic sector (BCC, 2014)

Emissions

In 2012 the UK ceramic sector produced an estimated 4.2 million tonnes of ceramic products, with 0.94 million tonnes of direct CO_2 released by fossil fuel combustion and process emissions and an additional 0.28 million tonnes of CO_2 released in the production of electricity consumed by the sector (BCC, 2014).

The ceramic sector is diverse with very different scales of emissions and energy consumption across the four subsectors identified in section 2.1.1; the breakdown of emissions by subsector and source is summarised in Figure 6 below.

Sub-sector	Direct		Estimated Process	Indirect	Total	Percentage of Sector
	Natural Gas	Other fuels		Electricity		
Heavy clay construction	499,184	20,140	155,797	112,445	787,567	65%
White Wares	142,347	0	7,117	61,510	210,974	17%
Refractories	30,785	21,620	5,241	25,096	82,742	7%
Technical	42,970	13,386	0	78,990	135,347	11%
Total	**715,286**	**55,147**	**168,155**	**278,041**	**1,216,629**	

Figure 6: Direct, indirect and estimated process CO_2 emissions 2012, Mt/a, (BCC 2012 CCA data, 2014)

The production of the four subsectors in 2012 is shown in Figure 7 below:

Sub-sector	Production Tonnes
Heavy clay construction	3,748,481
White Wares	211,874
Refractories	200,128
Technical	30,310
Total	4,190,792

Figure 7: Subsector annual production 2012, tonnes, (BCC CCA data, 2014)

The subsectors differ in scale of production facility and average daily production per kiln, ranging from an average of around 200 te/day per kiln for the heavy clay sector, to an average of around 3 tonnes/day per kiln in the whitewares and refractories subsectors, to less than 0.5 tonnes/day per kiln in the technical sector.

The contribution to the sector's carbon emissions by the subsectors is shown in Figure 8. The heavy clay subsector dominates the emissions, but with its simpler processes, higher adoption of more-efficient continuous kilns and larger scale of production has lower emissions per tonne of product than the sector as a whole. Whitewares has substantial emissions due to the multiple firing steps, greater use of less-efficient batch firing and higher air to ware densities in the kiln, while refractories have an intermediate level of emissions per tonne due their simpler, but generally higher temperature, production of bulk products. The technical ceramic subsector has disproportionately large emissions due to the small scale of production coupled with the higher firing temperatures employed.

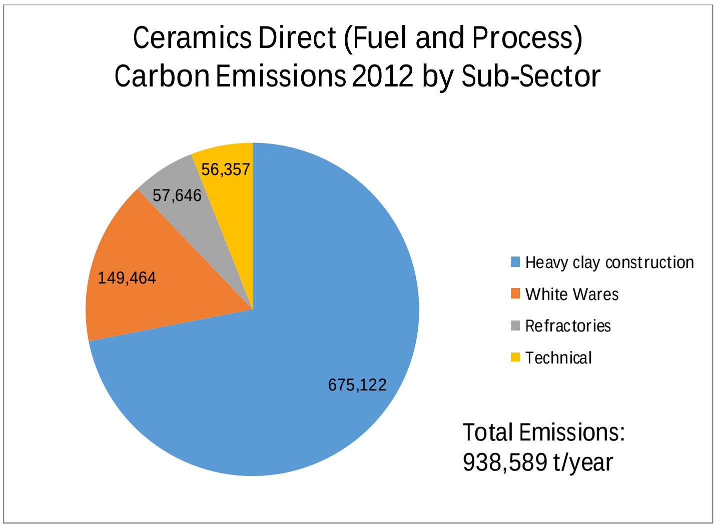

Figure 8: UK ceramic sector direct CO_2 emissions (BCC 2014 from CCA, 2012)

3.3.2 Heat and Power Demand

The heat and power consumption of ceramic facilities depend on the subsector and product.

As can be seen in Figure 9, for heavy clay, on-site energy demand is met mainly by fuel (92%) with significantly lower amounts of electricity consumption (8%). The majority of this fuel is utilised in the kiln, as shown in Figure 10. The dryer also consumes a notable proportion of fuel; however the heat requirement at the dryer is often met to a large degree by recycling cooling air from the kiln. The heat in the dryer exhaust air is quite difficult to reuse as it is wet and at too low a temperature, while exhaust gases from the kiln include challenging corrosive components that inhibit further heat recovery.

The other subsectors have proportionately higher electricity consumption; for technical ceramics, for example, electricity consumption is 38% of energy demand, typical of the higher proportion of electrically heated kilns in these subsectors coupled with the need for finer grinding.

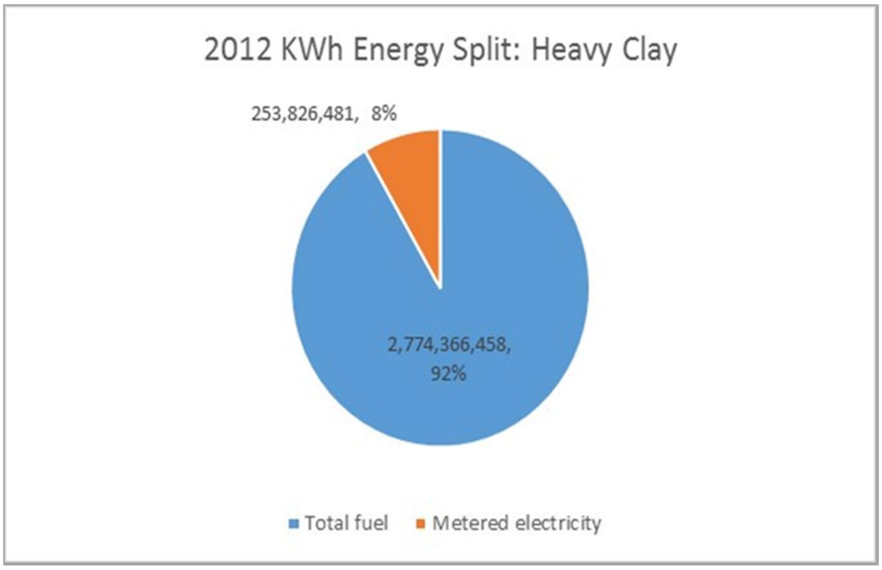

Figure 9: Typical energy split in the heavy clay subsector (BCC)

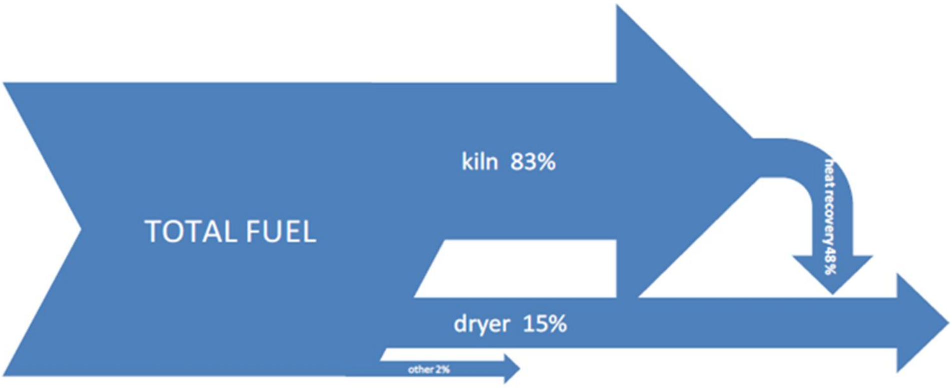

Figure 10: Typical energy breakdown of a brickworks showing heat recovery from the kiln to the dryer (Carbon Trust 2011)

It can be seen from this example that the primary focus for energy efficiency and carbon emission reduction in the ceramic sector will be the firing and drying steps.

Heat and power demand may change in the future due to trends in market behaviour, technological developments and regulation. Historically, there has already been a shift from coal to gas use and further change can be foreseen towards the increased use of electricity (for firing, increased automation and increased abatement of industrial emissions) and the possible substitution of biomass derived gas for natural gas (under the appropriate commercial and regulatory conditions). One of the options presented in the options register (see appendix C for more information) is the development and application of 100% electrically heated brick kiln, which would result in increasing decarbonisation as the electricity grid reduces its carbon intensity.

3.3.3 Fuels Used

The 2012 distribution of energy inputs for the UK ceramic sector is shown in Figure 11

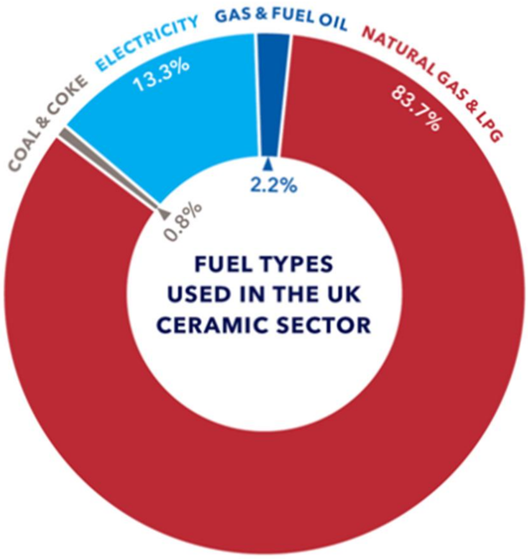

Figure 11: Distribution of fuel types in the ceramic sector

Kilns are predominantly fired with natural gas or electricity although other fossil fuels form a minor part of the fuel mix. Available sector-level data on electricity consumption is not divided between firing and other uses and BCC estimates that around 10% of the sector's electricity consumption is used to heat kilns. In total, 82% of energy is provided by natural gas, 13% by electricity with the balance of 5% by other fuels. Currently, renewable or low-carbon fuels are only used at a minimal level in the UK ceramic sector. It appears that temperatures available from combined heat and power (CHP) limit its use to materials processing in the UK raw materials subsector and in material preparation for floor and wall tile manufacture in Europe. Woody biomass is considered unsuitable for direct combustion as it adversely affects product quality and increase losses.

3.3.4 Lifespan of Equipment and Key Timings

The ceramic sector is a capital-intensive sector with long investment cycles; a ceramic production plant typically has a lifetime of over 40 years, although repair and partial replacement of refractories is common and upgrades to burners, control mechanisms and external components, such as fans and flue gas clean-up equipment may occur during the life. Upgrades and rebuilds may be coordinated with replacement of other product handling equipment to reduce manpower levels or increase throughput.

The last decade has seen the extensive closure and rationalisation of many facilities in the sector but the economic climate has limited new kiln construction and replacement to a lower level than is required to maintain capacity, even at the current reduced level. There is therefore a growing need for rebuild or replacement projects which needs to be addressed now and over the next decade if production levels are to be maintained. This shortfall represents a threat to the sector unless substantial investment is made, but also an opportunity to deploy lower carbon technology as BAT.

3.4 Business Environment - Principal Question 2

This section provides an assessment of the range of questions under principal question 2: 'For each sector, what is the business environment, what are the business strategies of companies, and how do these have an impact on decisions to invest in decarbonisation?'

3.4.1 Market Structure

The UK ceramic sector is an example of a traditional industry (GPrix Consortium, 2010). It has a fairly complex structure, which has evolved through more than 250 years of history. At present day, the sector can be divided into various distinct subsectors by the nature of production processes and the type of final products. For the purposes of this study, four subsectors have been used - heavy clay, whitewares, technical ceramics and refractories (Figure 12), however further subdivision is possible. For example heavy clay includes bricks, roof tiles and clay drainage pipes.

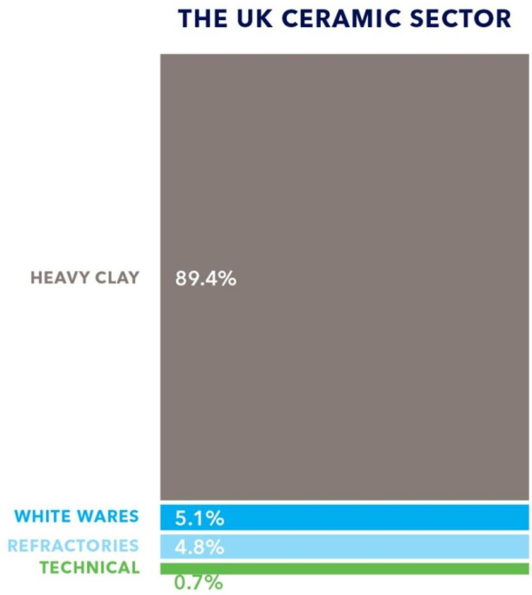

Figure 12: Shares of production in the four ceramic subsectors used in this study

Between 2000 and 2010 the sector has seen more than 40% decline across all subsectors, as illustrated in Figure 13. Total revenues in 2010 were £953 million compared to £1,953 million in 2000. Since 2013, the sector has been slowly recovering. However, sales figures are still lower than in 2007. The only exception is technical ceramics, where revenues have grown more than 30% compared to 2000. Analysis is based on data from BCC members.

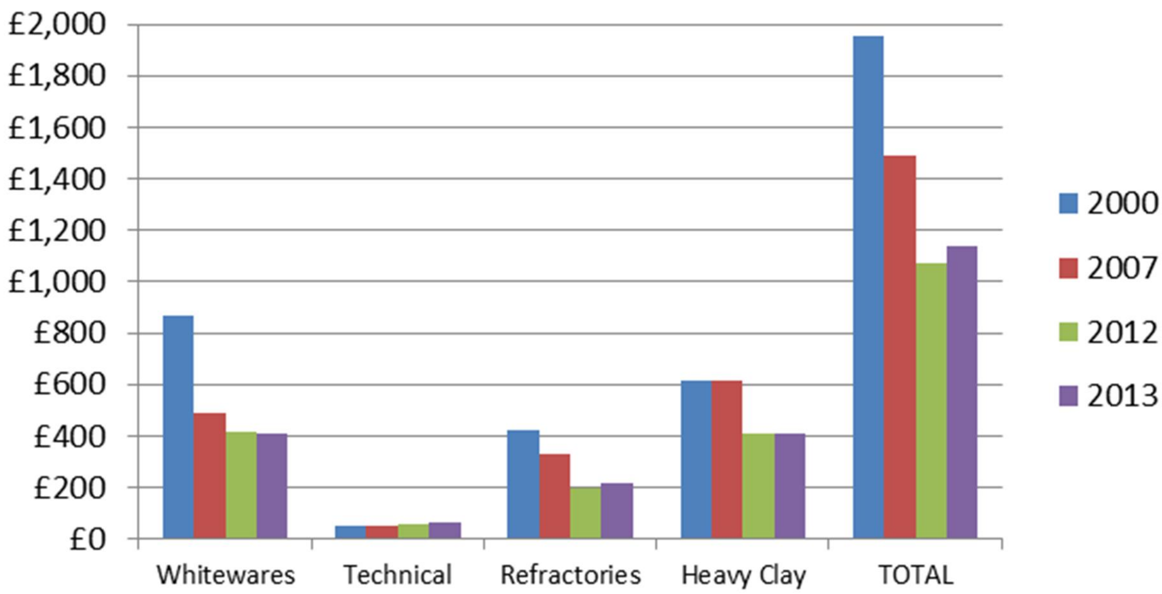

Figure 13: Total revenues in £ millions for selected years per subsector (BCC, 2014)

BCC data and all interviewed managers from the industry suggest that the main drivers of the decline have been recession in demand and downward pressure on prices from imports. The UK recovery started in 2013, especially for those making products used in house building. Heavy clay production increased and some plants were un-mothballed. However, imports have risen dramatically and there is still no sign of major capital investment in new assets. However, recovery in other subsectors has been more subdued.

Consolidation has been rapid in the past decade. According to BCC, whose membership includes the majority of ceramic manufacturers in the UK, there are around 100 companies, which in turn operate at 150 sites and represent 90% of the sector turnover. The consolidation of the sector can be seen in the heavy clay sector where the number of brick production sites has fallen from 180 to 63 in the last 30 years, according to one of the interviewees – a manager with technical and environmental responsibilities for a large manufacturers.

The UK ceramic sector is considered energy and heat-intensive. According to representatives from the industry the typical cost of energy is 30% of turnover, and can be as high as 40% for heavy clay and around 15% for whitewares. The sector is also labour intensive, with labour comprising 25-30% of turnover. Such a cost structure makes it very challenging for new market entrants in the UK as well as impeding competitiveness on the global market.

Such energy intensity of the sector makes it vulnerable. Extreme concern was expressed by BCC that current electro-intensive refractory and technical ceramic production is uncompetitive due to high electricity costs and is at risk of being lost to the UK.

The UK ceramic sector has strong tradition and high international reputation (GPrix Consortium, 2010). The sector is an active exporter, particularly industrial ceramics, refractories, tableware and giftware. The sector exports internationally, with the EU as the main market, followed by North America and Asia (Oceania). However, according to BCC data, the level of exports for refractories and tableware or giftware is still well below their pre-recession levels. Competition in the sector is high, with small margins, with UK manufacturers competing with Europe and internationally. Currency variations impact imports and exports, as companies seek to increase market share in regions that offer the highest profitability. All sectors are heavily trade exposed. Apart from the very small clay drainage pipe sector, the ceramic sector now shows a negative balance of trade.

The sector is also mature and capital intensive (IBIS, 2014). The level of competition is high in general with slight variations depending on the end product. Overall, the shrinking profit margins have resulted in a lower level of capital investment in new technologies.

3.4.2 Business Strategies

Interviewees and workshop participants from the industry reinforce the view that business and policy environment in the UK ceramic sector is volatile at the moment. This is especially supported by 21 of the survey[11] respondents agreeing that a more stable and internationally competitive regulatory and business environment will drive the sector's growth and investment in decarbonisation. Yet, various factors affect business strategies and behaviour.

Many managers from the sector expressed the view that current regulatory context could be detrimental to decarbonisation in the long term as investors look for stable and internationally competitive energy and carbon prices and an indication of the direction the government would like to take the energy market. Despite this concern over regulatory uncertainty, 25 of survey respondents and the majority of the 6 interviewees perceive compliance with environmental regulations and meeting CCA and EU ETS commitments as the main drivers of decarbonisation in the sector.

[11] The survey received responses from 31 managers in the UK ceramic sector.

The increase of energy prices is perceived as the biggest threat to the sector according to 30 of survey respondents – a view shared by the managers from the industry at the workshops. This can be explained to a large extent by the fact that up to a third of operational cost of ceramic manufacturers comprises energy. So there is a clear economic incentive to optimise and reduce energy consumption in order to maintain competitiveness and profitability. On the other hand if margins continue to shrink, this will significantly limit the ability of companies to invest in current or innovative technology required for decarbonisation. Decarbonisation is currently perceived to have less tangible benefits in the ceramic sector, especially as not the whole sector is encompassed within EU ETS and there is limited market demand for low carbon products. In fact, a recent independent study commissioned by a heavy clay manufacturer discovered that although approaching 40% of architects considered sustainability as important, fewer than 20% of building merchants and developers in the UK perceive it as added value to heavy clay products. Price is the main driver of demand and change in the preferences of customers can play an important role in the decarbonisation of the UK ceramic sector.

The poor market condition of the sector in recent years has fostered an even more risk-averse attitude to innovation. To support that, 25 of survey respondents would not implement any technology that risks diminishing the end-product quality or aesthetics, as these are perceived to drives sales. Additionally, only three of survey respondents perceive themselves as innovators when it comes to implementing new technologies for decarbonisation and energy reduction. The majority of the respondents prefer to see the technology proven before considering implementation as the high risks limits its appeal.

On the other hand, CCA targets (which for the sector are framed around energy efficiency improvements) have had a strong influence on how companies perceive energy efficiency and to a lesser degree decarbonisation. Mostly driven by compliance and reputational risk mitigation, some of the interviewed managers from the sector shared that they have incurred additional cost in order to improve efficiencies and meet their energy reduction targets. This is a clear indication that long-term energy and carbon regulation can have significant influence on the strategies of ceramic manufacturers in the UK.

Decarbonisation Strategies

The ceramic sector collectively is committed to contributing responsibly to a competitive low-carbon and resource-efficient economy. To sustain such a commitment, the European Ceramic Industry Association (Cerame-Unie) has developed a 2050 ceramic industry roadmap ‘Paving the Way to 2050’, which explores what level of decarbonisation might be possible, which technologies can enable the achievement of such a level of reduction and what regulatory support is necessary to achieve this by governments working in partnership with industry. However, at an individual company level there appears to be a different perspective on decarbonisation.

The survey results on business decision making related to decarbonisation showed that the majority (more than 21) of the companies that responded have carbon or energy reduction targets or goals, generally as part of the sector CCA. This observation has been confirmed by the interviewees as well. However, only half of the companies who responded to the survey claimed to have a robust decision making processes in place for new initiatives in relation to energy and decarbonisation. This is to suggest that while targets are in place, only half of the companies also use carbon and energy related criteria in their investment decision making.

What is also interesting to note is the impact of the decarbonisation strategies of the ceramic companies on their innovation, R&D agenda. When survey respondents were asked what their position was in regards to carbon and energy reduction, from ‘first mover’ to ‘laggard’, only three of the respondents considered themselves as first movers and already implementing new decarbonisation technologies. The majority of the respondents appear to be risk averse and prefer to see new technologies demonstrated and proven by their competitors or in other industries before they consider implementing them. There is very limited appetite for investing in unproven technology. Full breakdown of responses is shown on Figure 14.

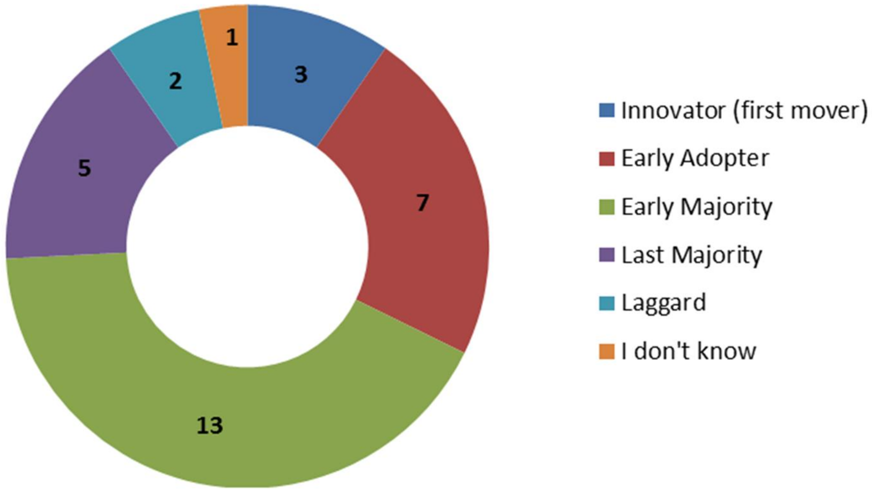

Figure 14: Attitudes to innovation

Although the EU ceramic sector has developed a 2050 roadmap which sets out a clear vision of what reduction might be possible, the UK ceramic sector has not yet set itself an overall quantitative reduction target for 2050. Although there are some platforms available to ceramic manufacturers for discussing their views on decarbonisation, there were limited examples of collaboration on any demonstration or pilot projects due to commercial confidentiality concerns. Two interviewed managers indicated that they had been involved in researching renewable energy generation on site but lack of sufficient financing, longer payback time than their investment threshold and planning approval difficulties deemed these initiatives unfeasible. Some examples were shared, at the workshops and during interviews, of collaboration between suppliers of equipment or raw materials and ceramic manufactures or customers and ceramic manufactures. Examples also exist of collaboration between non-competing ceramic manufactures, e.g. those operating in different subsectors. However, if the sector wants to move forward on the existing roadmap and progress disruptive technologies, greater collaboration is needed. Further research into providing collaboration platforms for ceramic manufacturers may be useful.

Funding issues for innovation are also seen to be a significant constraint. One UK manufacturer reported exploring co-funding from over eight UK and EU sources for a breakthrough technology to no avail. However its European competitors, with whom it was trying to work collaboratively, had been successful in receiving support from their governments for their parts of the project.

3.4.3 Decision-Making Processes

The survey results, displayed in Table 4, show high understanding of energy and decarbonisation (25 of the 31 survey respondents) with 22 tracking progress on energy and reduction projects at management meetings. However, given the importance of energy reduction to the companies' profitability, there are several areas that require further development to improve decision making within the companies. Only 16 of survey respondents have a systematic decision making process for new initiatives for energy and decarbonisation. To a similar degree, 20 of respondents have specific roles or allocated responsibilities within the company with regards to energy or decarbonisation and 16 of respondents have strong communication and information sharing channels. Employee engagement has been identified as essential in the future according to workshop participants; and transfer of knowledge is perceived as a barrier of medium to high impact to decarbonisation, according to majority of survey respondents and workshop participants.

Decision making factors	Respondents who agree or strongly agree
We have a systematic decision-making process for new initiatives with regards to energy and decarbonisation	16
We track progress of energy and carbon improvement projects in management meetings	21
We have specific roles or allocated responsibilities within the company with regards to energy or decarbonisation	19
We have strong communication and information sharing channels that support the successful implementation of options with regards to energy and carbon	16
We understand which energy and decarbonisation technologies can be implemented in our organization	25

Table 4: Survey responses to decision making factors for decarbonisation and energy reduction

Motives for investment are very similar but decision making processes vary largely based on size and ownership structure of the companies in the sector. Interviewed managers and workshop participants expressed the view that the requirement for short payback times for investment (typically one to two years) and high ROI, as well as limited access to capital are key barriers to investing in decarbonisation.

Ceramic manufacturers look to invest in new technologies or upgrade existing technologies in order to increase production capacity and improve efficiency to drive costs (including cost of energy) down and production yield up. This commercial approach is mostly driven by shrinking margins across all subsectors. This is well supported by survey respondents, who have identified a) projects providing multiple benefits such as energy and labour cost reduction, improved production yield, etc., as well as b) robust, evidence-based business case; as the top enablers of decarbonisation.

Processes for identification and appraisal of technologies, in SMEs, as shared by interviews managers, are rather informal and ad-hoc and involve management and specialised personnel. Interviewed managers shared that they gather information by looking internally for the most efficient existing installations and by engaging with equipment manufacturers and peers, externally. Typical investment criteria include maximum payback time of 2-3 years depending on the size of the investment and particularly the upfront cost. This is slightly shorter than large companies, as SMEs often try to fund small project from their revenues. For large projects of £1 million and above, external financing is considered. Decisions are finalised fairly quickly as there is only one level of sign-off – the board or the financial director if a privately own company.

Large companies have more structured and complex processes of decision making than SMEs. Ideas are generated on an annual basis by dedicated engineering teams, who put forward proposals for the annual capex budget. Proposals require technical specifications and financial justification. Criteria, approval processes and financing differ based on the size of the investment. In general literature and interviews suggest that projects can be divided into small - up to £1 million, medium - between £1 and £5 million; and large - above £5 million. Small projects often require a maximum of 12-18 months of payback and are decided on a site or local level. Medium projects are approved by the national management as part of the annual budget and require a payback time of maximum 2-3 years. Large projects can allow for payback time of 4-5 years but require solid financials and future-proofing of the technology. Such projects are approved first nationally and then considered by corporate together with proposals from all subsidiaries around the world. Interviewees suggested that this multi-layer approval process may take up to nine months. Large projects are financed by corporate exclusively so the internal competition is fierce.

It appears that in both cases, many of the remaining energy and decarbonisation opportunities with existing technologies require investments that are prohibitively expensive or have excessively long payback times.

Overall, climate change considerations to investments are related to energy savings and decarbonisation is not an explicit criteria. However, compliance with regulations, such as the CCA (relating to energy efficiency), can influence investment decision making, as disclosed by an environmental manager, when falling behind targets exposes the company to financial, legal and reputational risks.

3.4.4 Financing Investments

Based on the interviews conducted, the need for financing varies from company to company. It was reported by some that the availability of capital remains a real challenge, whilst others have access to capital and it is the issue of the attractiveness of investment the UK (and Europe) that presents an obstacle, often driven by higher energy prices. This variety of opinions is supported by the survey results as well where only 15 of respondents regard scarcity of funding as a high barrier.

Small-scale investments, mostly in upgrading projects, are typically financed internally and at site level and expect immediate returns. In large multinationals, a key barrier however is the limited availability of capital for improvement projects due to the high level of competition for internal funds and other projects more closely related to the core business. It is the case that internal financing is available, but decision-making processes tend to go against UK sites and operations. International management boards allocate capital on the basis of potential returns: higher UK costs and greater perceived uncertainty of business conditions in the UK make it more difficult or impossible to justify investment in longer-term UK manufacturing operations. In some organisations, internal company funds are the only route of finance.

Some of the interviewed managers from the industry indicated that they would not expect major investments in new plant to be made in the UK, given the higher potential returns that could be achieved in other markets (particularly Asia). Others expressed a concern that it is difficult for the UK to demonstrate a strong business case and to get to the point of financing.

SMEs interviewed stated that they often struggle to secure financing for medium and large-scale investments and look for financing outside. Banks (including the Green Investment Bank) are often unwilling to provide affordable finance over longer payback periods. Interviewees identified governmental, growth funding schemes and grants, and lease contracts with equipment manufacturers as key alternatives to bank loans.

3.4.5 Enablers and Barriers

One of the outcomes of the analysis of the sector is a list of the most prevalent enablers and barriers for decarbonisation. The enablers and barriers have been identified through a number of different research methods, namely literature review, interviews, surveys and workshops. Triangulating data has been of utmost importance. Seen below are details of the enablers and barriers that have not only been triangulated with regards to research methods, but were also selected at the workshops as the most important enablers and barriers.

Table 5 and Table 6 below indicate the most prevalent enablers and barriers across literature and interviews, as well as the perceived level of impact to decarbonisation as assessed by survey respondents and workshop participants. Although the number of times an enabler or barrier was referenced or highlighted could provide some guidance as to the strength of sentiment towards a particular enabler or barrier, the discussions during workshops and interviews provided a greater understanding as to the detail and context behind each enabler and barrier.

- There were 20 documents reviewed as part of the literature review. The number in the literature column below represents the prevalence in occurrence of the enabler or barrier; or in other words the number of sources that discuss it.
- There were six telephone semi-structured interviews in total. The number in the interview column below represents the prevalence in occurrence of the enabler or barrier; or in other words the number of interviewees that discussed it.
- The survey column shows the impact level of the enabler and barrier as assessed by 31 survey respondents, predominantly management-level representatives of UK ceramic manufacturers.
- The workshop column shows the impact level of the enabler and barrier as discussed and agreed by the evidence-gathering workshop group.
- The numbers on the left-hand side do not present a ranking but provide an easy point of reference to the order of analysis.

These enablers and barriers are illustrated throughout the text with supporting quotes and citations from interviews, workshops and literature. Further depth and interpretation is provided in the following paragraphs.

Top Enablers

#	Category	Enablers	Primary Source	Prevalence in occurrence		Level of impact	
				Literature	Interviews	Survey	Workshop
1	Investment	Multiple benefits	Literature	1	4	High	Medium-to-High
2	Investment	Strong, evidence-based business case	Literature	1	2	Medium-to-High	High
3	Regulation	Compliance with legal obligations	Literature	1	1	Medium-to-High	High
4	Management	Senior management commitment	Literature	2	1	Medium	Low-to-Medium
5	Operations	Replacement need and expansion	Literature	1	1	Medium	Low-to-Medium
6	Organisation	Engaged employees	Literature	1	1	Medium	Medium-to-High

Table 5: Top enablers

The first enabler – **multiple benefits** – was identified by literature (CSE, ECI, 2012) and was a key discussion point both in interviews and the workshops. As payback of new kilns is difficult to justify at current energy prices, companies seek additional benefits such as increased production yield and reduction in labour cost to meet investments requirements.

This is the enabler with the highest impact according to survey and workshop participants. Projects providing multiple benefits, not just decarbonisation benefits, are more likely to gain decision-makers' attention. Energy cost reduction offers recognised value but generally does not provide sufficient return alone to pass the currently stringent investment criteria. Increased capacity and reduced labour or maintenance cost have been identified as some of the other key benefits sought from investments. Under conditions of growing demand, technologies that offer improved yield with lower energy consumption will be preferred by ceramic manufacturers. Only the necessity for increased capacity provides sufficient justification for many large scale investments. This enabler has applicability across all subsectors. This enabler is relevant now, and will become increasingly important in the future.

One interviewee, responsible for environmental issues in the UK, stated: *"In our company payback is not acceptable just based on energy cost [reduction], so the other costs (e.g. labour) must be reduced as well or increase yield and output."*

A second interviewee, stated: *"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 or improved."*

The second enabler **– strong, evidence-based business case** – was highlighted in the literature review (Carbon Trust, 2011) and confirmed during the workshops and in the interviews. Capturing all benefits and costs, or the complete picture, can provide support to get executive buy-in and pursue more energy efficient technologies, which help reduce carbon emissions as well. This is strongly linked to the first enabler, as the business case, as debated by the workshop participants, must quantify the financial impact of all benefits, including reduced maintenance cost and benefits or expanded portfolio of products. Lack of reliable information about the technical potential and profitability of breakthrough or disruptive technologies has been identified as a significant barrier, especially for smaller companies. This enabler is relevant now, and will become increasingly important in the future.

"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 carbon reduction measure also help to deliver productivity improvements or reduce maintenance requirement." (Carbon Trust, 2011)

At the evidence-gathering workshop the attendees unanimously expressed the view that: "*Without it [robust business case] none of the proposed projects can reach a discussion at board level or final stage of decision making and sign-off process*."

The third enabler – **compliance with legal obligations** – was identified by literature (Frank Venmans, 2014). Despite the fact that only one interviewee - an environmental manager, had compliance with environmental regulations as a top enabler of decarbonisation, all workshop participants agreed that it is a driving force, largely as already perceived by the industry as the norm to comply fully and follow the rules. CCA targets, for example, have been key drivers for a lot of ceramic manufacturers, as stated by interviewees and workshop attendees; as they provide the right incentives to justify the investment in energy efficiency and decarbonising technologies. Compliance is also perceived by interviewed managers as very costly from reputational perspective as the risk of not complying with regulations may be quite damaging to the company brand. Nearly 80% (21) of the survey respondents assessed this enabler as having high impact on implementing decarbonising technologies. This enabler is relevant now.

A general manager for a small manufacturer stated: "*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 in cost of carbon from the plant*."

Workshop attendees concluded that: *"Enforcement is a key driver for example through policy inspections and audits. There is too high a risk of non-compliance and associated financial and reputational cost."*

"*A key policy enabler is to comply with legal obligations (e.g. environmental licence)"*. *(Venmans, 2014)*

The fourth enabler – **senior management commitment** – was identified by literature (Ricardo-AEA) and confirmed both by interviews and workshop. As with many industrial sectors we see today, senior management buy-in and formal business commitment, plus increasing willingness of top management to make climate change a priority, is an enabler for the level of support and prioritisation that a company's carbon strategy has compared to other aspects of the business strategy. This can create a cascade effect through the company.

Although reducing energy cost is perceived by industry as paramount to maintaining profitability, reducing carbon emissions is not such a priority for executives and management. Decarbonisation can therefore only occur when it contributes to maintaining business profitability. This could be significantly influenced if consumer preferences and attitude towards climate change was significantly more favourable. This enabler is relevant now, and will become increasingly important in the future.

One interviewee, responsible for environmental issues in the UK, stated: "Commitment from senior management has been essential to implement some of the recent technological improvements".

"Willingness of top management to make climate change a priority [is a key enabler]. This is crucial as it affects the overall culture of the firm." (Ricardo-AEA, 2013)

The fifth enabler – **replacement need and expansion**– was identified by literature (Frank Venmans, 2014) and confirmed both by interviews and discussions at workshop. With long lifespan of kilns, replacement of obsolete ones 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 kiln. Similar is the case when companies are looking to expand and add capacity to meet growing demand or diversify the product portfolio. However, BCC has reported that companies are not investing because of perceived lack of longer term business viability in the UK and that energy and climate-related policies are a significant issue here. This enabler is very relevant now.

One workshop attendee, technical manager for a small manufacturer, stated: "*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*".

An interviewee, general manager of a plant, stated "*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."*

The sixth enabler – **engaged employees** – was identified in the literature (European Commission, 2007) and confirmed through interviews. Although still gaining traction, there will be a switch of focus from energy to decarbonisation in the future and the mind-set of decision makers will change accordingly. Employee engagement and buy-in on decarbonisation is not yet perceived as a key driver according to the workshop participants but is expected to become more so in the future. In contrast, one interviewee, a general manager, considered it to be a key enabler in their company (an SME), as a change in attitude can quickly escalate up and encourage management commitment as well. Interviewees from the heavy clay and technical ceramic manufacturers supported the view that this has greater impact on their sectors. Possible actions to maximise engagement 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. This enabler will be increasingly relevant in the medium-to-long term.

One interviewee, an environmental manager, stated: "*Our own internal green team, which supports employee* engagement *in the area, can be often a critical enabler [to decarbonisation measures].*"

Top Barriers

#	Category	Barriers	Primary Source	Prevalence in occurrence		Level of impact	
				Literature	Interviews	Survey	Workshop
1	Investment	Long investment cycles and high capital costs of kilns	Literature	7	2	Medium -to-High	High
2	Investment	Long payback time	Literature	4	3	Medium -to-High	High
3	Investment	Scarcity of capital and financing	Literature	6	5	Medium -to-High	Medium-to-High
4	Market	Electricity and gas security.	Literature	0	2	Medium -to-High	High
5	Market	Rising UK energy prices perceived as non-competitive	Literature	3	3	Medium -to-High	Medium-to-High
6	Regulation	Regulatory uncertainty	Literature	3	3	Medium	Low
7	Innovation	Shortage of proven and demonstrated technologies.	Literature	2	4	Medium -to-High	Low-to-Medium
8	Innovation	Lack of reliable information	Literature	4	2	Medium	Low-to-Medium
9	Operations	Uncertainty regarding impact of new technology on product quality and production schedule	Literature	3	1	Medium -to-High	Medium-to-High
10	Organisation	Lack of skilled labour	Literature	5	3	Medium	Low-to-Medium

Table 6: Top barriers

The first barrier – **long lifetime and high capital cost of kilns** – was identified in the literature (Cerame-Unie, 2013) and was confirmed during the interviews and workshop. Sector investment cycles are to a large extent dictated by the lifespan of manufacturing equipment (kilns), which can typically be up to 40 years. This lifetime implies that there will only be one or, at most, two investment cycles between now and 2050 and limited opportunities for improvement. The majority of the manufacturers have equipment from different time periods and most of the equipment has been modernised at different times as well. 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 kilns. This is a barrier now and in the future.

Cerame-Unie roadmap states: *"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."*

Workshop attendee, technical manager for a small manufacturer, explained: "*With a 40 year lifespan of kilns there is no drive for kiln manufacturers to build 2050 capable kilns.*"

The second barrier – **long payback time** – was identified in the literature (CSE, ECI, 2012) and had been confirmed both by interviews and workshop. Interviews have confirmed that across the sector there is on average a requirement for maximum of 3-year payback for capex projects. This often puts decarbonising options in an unfavourable position relative to other investment opportunities (which include those overseas). Current level of energy prices in the UK and high upfront costs of equipment often make payback periods too long to be competitive. For external financing, banks (including the Green Investment Bank) are unwilling to provide affordable finance over longer payback periods. This is a barrier now and in the future.

One interviewee, responsible for energy management, stated: *"We typically require 3 year payback time for major capex projects and new technologies rarely fit within that threshold"*.

"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"." (CSE, ECI, 2012)

The third barrier – **scarcity of capital and financing** – was identified in the literature (Carbon Trust, 2011) and had been confirmed both by interviews and workshop. The UK ceramic sector has been very slowly recovering since the economic crisis and that has put a significant constraint in companies' ability to invest in major equipment. Large multinational companies also expressed concern that energy reduction projects often compete for limited funding with core business projects overseas; and longer payback times do not help secure that funding as risk is seen as too high. Lack of resources to identify available external funding, and reluctance to move to third party financing are seen by the sector as additional barriers to finding financing. Interviewees across the various subsectors indicated that there is a need for government backed financial schemes for industry to obtain finance at affordable rates or by funding improvement grants to help incentivise the uptake of energy and carbon efficient technologies. In addition, support for RD&D of emerging and breakthrough technologies is urgently needed. 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 competing manufacturers is limited. One interviewee, general manager for a small manufacturer, 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. This is a barrier now.

One interviewee, responsible for energy management, stated: *“Capital availability is paramount … as we have to compete internally for funding with non-energy related projects”.*

Another interviewee, general manager in the UK, explained: *“Financing is a key issue for us as we do not have the cash to invest upfront”.*

*“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.” (*Centre for Low Carbon Futures, 2011)

The fourth barrier **- electricity and gas security** – was identified during two interviews and confirmed at the workshop. Main concerns include that unplanned interruption of energy supply can cause major damage to continuous kilns resulting in shutdown for several months, loss of product and increased production cost per unit. The majority of survey respondents and workshop participants reinforced the view that shortage of gas supplies can cause major production disruptions and drastically increase the cost of natural gas. The threat of supply loss causes high price volatility making business models uncertain and deters investment in the UK in the sector. If not addressed, this may cause some businesses to close. This barrier will have an increasing importance in the future.

The fifth barrier – **rising UK energy prices perceived as non-competitive** – was identified in the literature (IEA, 2014; ICF International, 2012) and confirmed by the interviews and workshop. As an energy intensive industry (EII), with energy cost comprising 30-35% of total manufacturing cost, the international success of the sector is reliant on competitive energy and carbon prices. Divergence of these costs relative to competitor nations is perceived as a major threat to profitability of the UK ceramic manufacturers, especially since margins have been shrinking in the past years (BCC, 2014). It can be argued that rising UK energy prices may make it more attractive for ceramic companies to invest in energy-efficient technologies and for sites to justify any investments (and could therefore also be seen as an enabler). It is the industry view that increased costs in the UK as a result of higher energy prices reduces the capacity of the industry to invest. The view was expressed that unilateral policies were distorting international competition to the detriment of the UK.

This barrier is particularly acute for companies that form part of multinational organisations, where each site effectively competes against the others to secure long-term investment, which is heavily impacted by current and forecasted energy prices locally for each site. The perception is that this further promotes a difficult economic climate and the decline of the sector, making it difficult to obtain financing for large capital expenditures such as related to decarbonisation.

It was stated by interviewees that the industry specifically seeks overall reassurance by government that ceramic manufacturers (and other energy-intensive industries) are not driven out of the UK by policy decisions affecting pricing of energy and carbon. In this discussion it is important to differentiate between electricity costs and fuel costs. For large energy-intensive industries, the UK has among the highest electricity prices in Europe and in the mid-range compared to G7 countries; a growing proportion of that cost is linked to climate change policy (ICF International, 2012). Furthermore, unlike some overseas competitors, climate related charges on electricity are not compensated for UK electro-intensive ceramic manufacturers. Sector representatives emphasised that this issue needed to be addressed to enable UK manufactures to compete internationally. Average natural gas prices are amongst the lowest in Europe and are also low compared to most G7 countries (DECC, 2014). However, average prices are perceived by the UK industry to be higher than some competitor countries, such as North America and Russia. Price volatility is also perceived to be much higher in the UK than in most European countries. Price volatility, extended gas price spikes and the resulting inability to have a predictable business model has a severe and deleterious impact on investment in the sector.

A recent publication of Agora – Energiewende (2014), however, illustrates that the comparison of electricity wholesale prices between Sectors and countries is a difficult task. Moreover, a recent communication from the European Commission on energy prices and costs in Europe shows that UK electricity prices for industry are very similar to the average EU-27 prices (see Figure 11), although certain countries (like Bulgaria and Finland) show significantly lower prices (European Commission, 2014).

This is a barrier now and in the future.

"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." (Centre for Low Carbon Futures, 2011)

"While numerous European companies have complained of market distortion due to regulatory favouritism for Germany's energy-intensive industries, caution must be exercised when attempting to directly compare industrial end-use prices between countries and sectors. Because firms in different regions and Sectors vary considerably in the extent to which they pay wholesale market prices and/or receive tax exemptions and levy reductions, comparing prices between Sectors and countries is a difficult task. The heterogeneity of the situation is not fully and transparently captured by European statistics." (Agora – Energiewende, 2014)

A general manager for a SME manufacturer stated: *"Business is growing however we are penalised for this growth by the current carbon price and thus at disadvantage compared to non-UK competitors."*

The sixth barrier – **regulatory uncertainty** – was identified in the literature (Centre for Low Carbon Futures, 2011) but the impact of this barrier varies across sources. Interviewees and some workshop participants perceived the lack of long-term clarity on energy, climate, environmental and innovation policies in the UK as a significant barrier to the restoration of investment confidence. The sector, including BCC, consider this to be an extremely important barrier to investment by the sector, noting that the certainty of a high carbon price would deter investment in the UK rather than attracting funds to this sector, as returns would be higher elsewhere. Continuous alterations to policies and targets increases uncertainty in decision making, deterring investment and can render existing investments unviable. Some workshop participants, including BCC, reinforced the view that setting long-term regulatory framework and targets will provide the necessary certainty in future energy costs and the direction of government regulatory change. Other workshop participants considered the uncertainty as a barrier only to the extent it causes energy prices to rise. This is a barrier now and in the future.

A general manager stated: *"…Ever changing and over complicated carbon related compliance schemes that do not engage or encourage, just burden business."*

"Long-term clarity [of policy] was seen as vital to underpin high cost, long-term technology investment." (Centre for Low Carbon Futures, 2011)

The seventh barrier – **shortage of proven and demonstrated technologies** – was identified in the literature (Carbon Trust, 2011*) and* was confirmed both from interviews and the workshop. 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 successful already are more likely to gain traction. Only 10% (3) of the survey respondents identified themselves as first movers or innovators, which is another constraint on the rate of adoption of new technologies. However, the risks associated with investing in unproven technologies, the high level of resources required and the frequently long timescales involved are a strong disincentive for companies or subsectors to act in isolation. There is a need to bring breakthrough technologies to market in the near term to allow their progressive application as assets are slowly replaced given the long lifetime of ceramic plants (typically 40 years). This is a barrier now and in the future.

The eighth barrier – **lack of reliable information** – was identified from the literature (CSE, ECI, 2012) and was confirmed both by the interviews and workshop, as a factor that could potentially lead to less investment in low-carbon technologies. Interviewed managers expressed the concern that here is a shortage of technical knowledge and capacity within the UK ceramic businesses to identify new technologies and measures. Businesses 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. The need for greater knowledge-sharing and RD&D collaboration among countries to accelerate technology advancement along the curve from demonstration to commercialisation was also a theme mentioned during workshop. This is a barrier now and in the future as information is required on new technologies.

One interview, responsible for investments, stated: *"There is currently no sensible way for us to know what options are out there and what the benefits of various technologies are."*

A second interviewee, general manager, stated: *"A first priority should be for governments, industry and civil society to develop a common vision for the transition to low-carbon energy. The process of developing the vision should involve sharing information and views on the importance of using a portfolio of low-carbon technologies, the costs and benefits of various technology options, and the need for infrastructure and technology change."*

The ninth barrier – **uncertainty regarding impact of new technology on product quality and production schedule** – was identified by literature (Carbon Trust, 2011) and confirmed during the workshop. The potential impact of any changes in operations on machine operability, and any impact on production and quality, is a barrier to decarbonisation that requires changes to machinery. Risk of production disruptions from retrofit technologies is an even larger concern for small companies with limited production capacity. Interviewed managers were concerned about installing new technologies and its implications on product quality so that they can continue to meet customer demands and specifications.

"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." (Ricardo-AEA, 2013)

The tenth barrier – **lack of skilled labour** – was identified in the literature (McKenna, 2009) and was confirmed both by the interviews and workshop. A shortage of technically competent staff and a lack of funding for training prevent any further advancement of the sector. There is a particularly increasing demand for specialised engineers in heat exchange, combustion and firing technologies. Some workshop participants expressed concern that the ceramic sector is not attractive to young engineers anymore and that trend will continue unless an industry-level action is taken. This is a particular barrier now, as the workforce in the sector is ageing, without sufficient succession planning in place, particularly in technical roles.

One general manager stated: *"We do struggle to find adequately skilled labour for new technologies implementation or processes improvement".*

"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 industry." (DECC, 2013). A future barrier - **availability of biomass / waste resources for high temperature heat** – was identified by BCC after the evidence gathering phase of the study. This barrier would limit the potential deployment of industrial heat applications of biomass or waste materials since a secure supply of competitively-priced, sustainable feedstock would be essential for the duration of the asset life to justify the significant capital investment.

3.5 Technologies to Reduce Carbon Emissions

While actions of the sector are constrained by barriers and may be promoted by enablers, potential choices of decarbonisation solution are limited by available technologies that are applicable to the sector

Technical options were identified from the literature review, interviews, workshops, discussions with the trade association and input from academia. Data on these options was assembled from these same sources and is presented in appendix C. The energy saving and decarbonisation opportunities have been classified into five categories:

- Conventional improvement options include improved control of combustion, minimisation of heat losses, waste-heat recovery and heat integration, energy monitoring and management and improved process control.
- Ceramic process changes that reduce energy consumption including increased product packing density in kilns, reduction in product weight, development of durable heat exchangers for the kiln exhaust, changes to raw materials to reduce firing temperatures and modifications to eliminate additional firing steps.
- Radical changes to kilns including replacement of batch by continuous kilns (where product ranges and volumes allow this to be feasible and economic) and replacing kilns that are passed their life-expectancy with BAT.
- Options to utilise a lower carbon fuel including the use of biomass gasification to generate gaseous fuels to replace fossil fuels and the application of electrically heated kilns for heavy clay products.
- The application of CC technology to large kilns.

These categories were then grouped in different groups reflecting their ease and timeliness of implementation:

- Existing state-of-the-art technologies with wide deployment: existing and proven technologies, immediate deployment aligned with equipment replacement.
- Major investment technologies: proven technologies already implemented at some sites, but not all; proven technologies that are not yet widely accepted in industry, only a few UK demonstration projects; also some novel technologies included.
- Disruptive changes including radical changes to energy supply and CC.

Three disruptive options applied to kilns in the heavy clay subsector, which have no prior application in the sector, have the potential to reduce carbon emissions significantly:

- Substitution of gasified biomass for natural gas
- Application of electric kilns (using low carbon electricity) to replace gas-fired kilns
- CC applied to gas-fired kilns

In addition to the options that were considered to be sufficiently well advanced to be applied in the period to 2050, several others were identified that could have a significant impact but were not considered sufficiently developed to be included. These options range from improvements to parts of the conventional process e.g.

low energy driers, to radical disruptive changes to replace many steps e.g. ceramic production at less than 100ºC. The following list summarises the main options that were identified but not included in the options register:

1. MIDAR™ technology is an aqueous chemical process, which produces robust ceramics products at <100°C, removing the need to use high temperature processes.
2. The low energy firing uses field enhanced sintering to apply a direct electric field to reduce the peak temperature needed to fire ceramics by up to 600°C and lowers the exposure time to just a few seconds.
3. Microwave assisted drying uses microwave heating to deliver energy more efficiently for drying products, thereby cutting energy consumption for drying.
4. Vacuum drying applies reduced atmospheric pressure to cut the energy consumption required for drying.
5. Electrically heated kilns apply radio frequency (RF) or microwave heating to deliver heat more efficiently to the high temperature sections of kilns, again offering the potential to reduce time, temperature and energy consumption.

Each of these processes are being or have been examined for application in the sector but have not reached the point where their potential is understood adequately to be quantified from literature or by the sector team.

3.5.1 Biomass Carbon Intensity

Pathways including biomass reflect biomass carbon intensity (unless the biomass in the pathway is assumed to be waste biomass). The carbon intensities (below) are applied to two scenarios to help reflect and bound the uncertainties around biomass carbon availability; these are (i) unlimited availability – as deployed in the Max Tech pathway or (ii) no availability.

In all cases, combustion emissions are assumed to be zero (in line with EU Renewable Energy Directive methodology), on the basis that all biomass used is from renewable sources and thus additional CO_2 is removed from the atmosphere equivalent to that emitted on combustion. This means that all biomass is assumed to be sourced from material that meets published sustainability criteria.

Given the wide variation in pre-combustion emissions, a carbon intensity (based on pre-combustion emissions) was derived from a low scenario from the DECC-commissioned Bioenergy Emissions and Counterfactual Model report (published 2014) for modelling purposes. An emission value of 20 kgCO2e/MWh(th) has been used for solid biomass use, and this has been modified to 25 kgCO2e/MWh(th) if the pathways includes pyrolysis, and 30 kgCO2e/MWh(th) if the pathways includes production of biogas.

3.5.2 Cost of Options

Limited information related to the capital cost of technologies was identified in this project as summarised in appendix C. In gathering capital cost-related data, literature and/or engagement with stakeholders – together with expert judgement - were used to establish an initial order of magnitude dataset for use in the cost analysis assessment. The degree of stakeholder engagement in relation to the cost dataset was lower than for the carbon reduction pathways. Operating costs such as energy use changes, energy costs and labour are not included in this analysis, although we recognise that operating costs will have a major impact on the decarbonisation pathways. For example some options (e.g. CC and electrification of firing) will greatly increase energy use and costs of a process plant.

Costs analysis was carried out for the pathways, which is presented in section 4.6.There is a large degree of uncertainty attached to the cost analysis, especially for options which are still in the R&D stage. As well as costs of operation and energy use – other significant costs not included in the analysis are research, development, demonstration, civil works, modifications to plant and costs to other stakeholders, which are significant for many options. Great care must be taken in how these costs are interpreted.

3.5.3 Informing Pathway Development

The interaction of the technical options with the sector enablers and barriers will determine which options are likely to be deployed first, or at all, by the sector. In exploring the potential pathways to decarbonisation, the list of enablers and barriers has informed the selection of technical options deployed in the different pathways. They have also been used to guide the deployment of the different technical options both with regards to time and degree of deployment. For example the enabler ‘replacement need and expansion’, led to a faster deployment of current BAT using state-of-the-art technologies with much reduced carbon emissions compared with the plant being retired.

4. PATHWAYS

4.1 Key Points

The potential future trajectories of carbon emissions in the sector were explored by an analysis of a range of alternative pathways, each comprising different assumptions about the selection, application and timing of technical options for decarbonisation. A spreadsheet model was used to assess the impact of the application of technical options to the sector energy consumption and carbon emissions. The background pattern of growth of the sector to 2050, which affects the underlying fuel consumption and emissions, was represented as a number of alternative scenarios.

The pathways development and analysis shows that the maximum decarbonisation potential of the sector in the current trends scenario is a reduction to 0.5 $MtCO_2$ emitted in 2050 in the Max Tech pathway, which corresponds to a reduction in emissions of 60% compared with emissions in 2012. Significant reductions of 60% and 35% could be achieved under challenging world and collaborative growth scenarios respectively. The reductions have been achieved through a range of options, the most significant 'disruptive' technologies being:

- The replacement of conventional gas fired kilns with electric kilns, applied throughout the sector, cutting gas combustion and using lower carbon electricity
- Decarbonisation of the electricity grid
- Decarbonisation of heat by substituting fossil fuel with biomass, using onsite gasification technology at the larger production facilities
- CC applied to larger heavy clay facilities

'Incremental' and 'Major' technologies have also been applied in the short and medium terms along the pathway, generally using the types of options as follows:

- Replacing older kilns with BAT i.e. new and efficient gas kilns
- Significant process improvements such as heat recovery and regeneration, materials advances for insulation and refractories, improved combustion efficiency
- Significant materials chemistry and technology refinements allowing lower firing temperatures, reduced number of firings, and options such as pre-calcining of clay and reduced product weight
- Incremental improvements extending known solutions

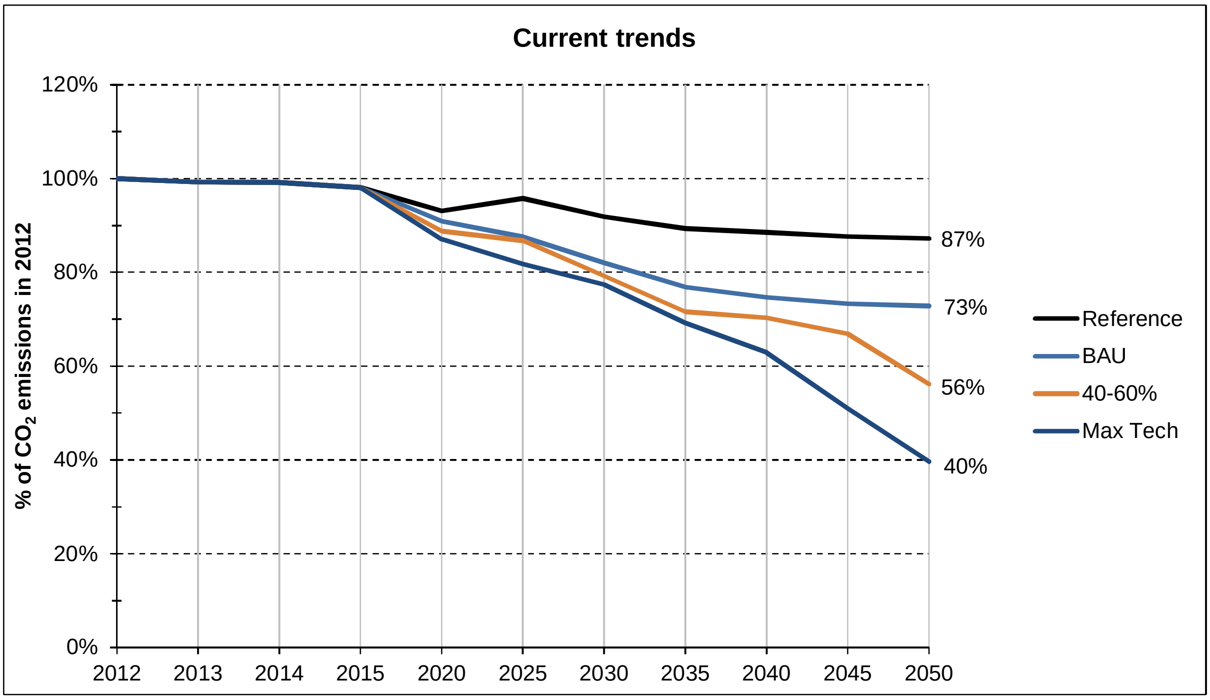

Figure 15: Performance of pathways for the current trends scenario

Figure 15 shows the wide range of decarbonisation and energy efficiency pathways that are possible for the current trends scenario.

- Reference pathway is a hypothetical case in which no sector-specific energy efficiency options are applied but where output and electricity carbon intensity follow their profiles for the current trends scenario.
- BAU represents a pathway in which existing trends in energy efficiency and decarbonisation continue. Incremental options provide reductions earlier in the pathway, and major options including replacement of older kilns using state-of-the-art technology are deployed through the period to 2050. The kiln replacement rate using BAT is assumed to be around 50% of applicable installations by 2040.
- 40-60% pathway builds on BAU with an increased technology replacement rate and also disruptive options start to be deployed in the longer term. Electric kilns and gasification of biomass are deployed from 2040 onward, and CC is applied to a small proportion of larger heavy clay facilities by 2050.
- Max Tech pathway consists of maximum possible deployment of retrofit measures and equipment, and an increased kiln replacement rate. Later in the pathway by 2050, electric kilns are widely adopted across the whole sector to replace 60% of all plants, and gasification of biomass in combination with CC is applied to 40% of fossil fired kilns in the heavy clay subsector.

It is worth noting that the UK Heat Strategy (DECC 2013) considered the application of biomass to be a transitional option, but these pathways have adopted it as a major option late in the period from 2030 onwards. This has implications for potential enabling actions for biomass application, as reviewed later.

The main result of the sensitivity analysis showed that the three disruptive options – application of electric kilns in the heavy clay subsector, the conversion of kilns to gasified biomass, and CC – are all critical to delivering the maximum reduction in carbon emissions. In practice, these options each have restrictions on their deployment and site application, which means they can only replace each other to a limited degree.

4.2 Pathways and Scenarios – Introduction and Guide

The pathways development uses evidence gathered, as set out in Section 3, to create a set of decarbonisation 'pathways', which provide a quantitative component to the roadmap and help inform the strategic conclusions.

A pathway consists of decarbonisation options deployed over time from 2015 to 2050, as well as a reference emissions trend. The analysis covers three: 'scenarios': with pathways developed under a central trend ('current trends' scenario) and alternative future outlooks ('challenging world' and 'collaborative growth' scenarios).

A scenario is a specific set of conditions that could directly or indirectly affect the ability of the sector to decarbonise. Examples of these are: future decarbonisation of the grid, future growth of the sector, future energy costs, and future cost of carbon. Since we do not know what the future will look like, using scenarios is a way to test the robustness of the different pathways. A detailed description of these scenarios is provided in appendix A.

The three generic scenarios were developed, covering a range of parameters. They characterised possible versions of the future by describing assumptions relating to international consensus; international economic context; resource availability and prices; international agreements on climate change; general technical innovation; attitude of end consumers to sustainability and energy efficiency; collaboration between sectors and organisations; and demographics (world outlook). These scenarios were used during the workshop to help decide on deployment rate for the different options.

Quantitative parameters were also part of the scenarios, including production outlook (agreed sector-specific view) and DECC supplied Grid CO_2 intensity profiles which both impact decarbonisation (assuming production and carbon emissions have a linear directly proportional relationship). Other quantitative parameters within the scenarios governed forward price forecasts and technology deployment.

The purpose of the model that underpins this pathways analysis is to bring together the data captured from various sources and to broadly reflect, using a simple 'top down' approach, how emissions might develop to 2050. The model is therefore capable of indicating magnitudes of emission reduction that can be achieved, when various technology options are applied, and also how different deployment timings and high-level economic outlooks for a sector might change the results. A sector model was used to create pathways based on reference emissions and energy consumption in 2012. The model is not intended to give exact results and is not of sufficient detail to account for all mass/ energy/ carbon flows, losses and interactions in a sector (i.e. it is not 'bottom up' and does not use automatic optimisation techniques).

The methodology is summarised in Figure 16

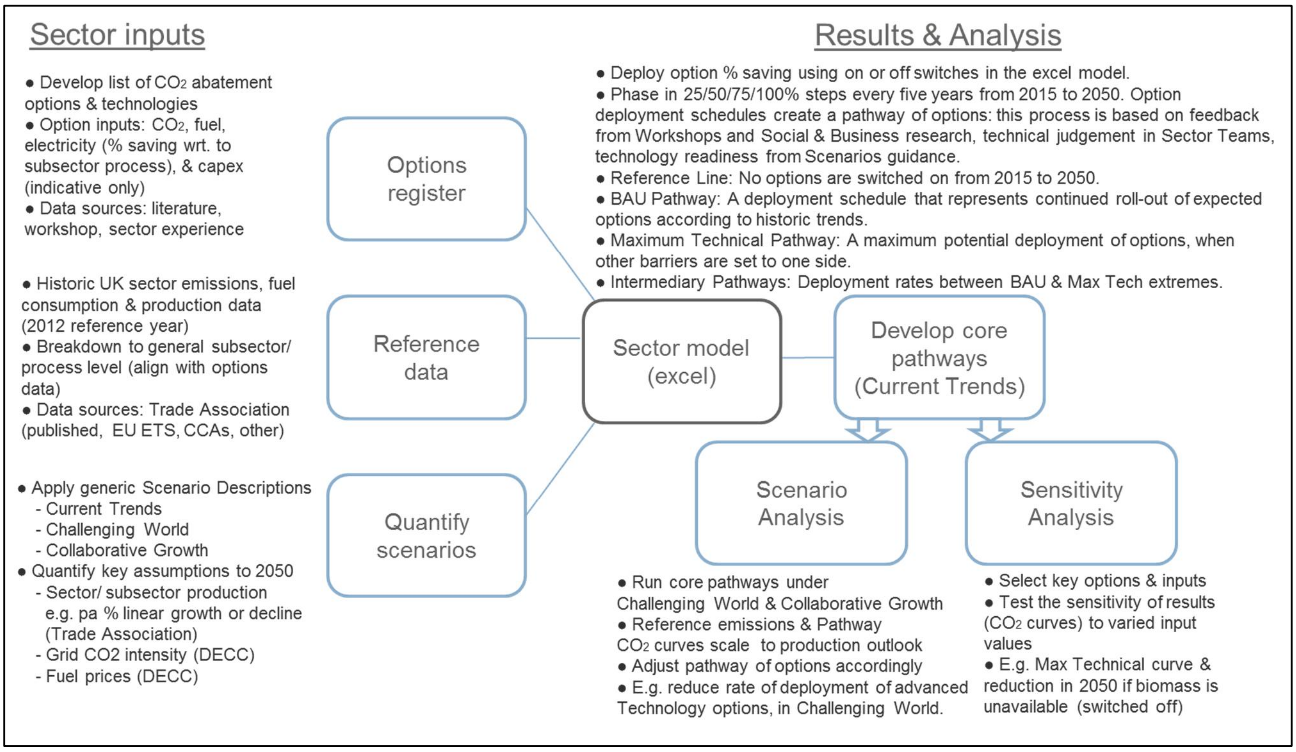

Figure 16: Summary of analysis methodology

This section of the report is structured to present the pathways in the current trends scenario (section 4.4), whilst also briefly describing how the pathways change when modelled under other scenarios. Table 7: Pathways and scenarios matrix illustrates this structure and acts as a guide to the section.

Pathway	Current Trends Scenario	Challenging World Scenario	Collaborative Growth Scenario
Reference Emissions Trend	*Scenario assumptions only linked to production outlook and grid decarbonisation No options deployed in the model*		
BAU	Builds on the reference line by deploying options from 2015 to 2050 in the model, to construct a BAU pathway. Run model under current trends.	Builds on BAU pathway current trends by adjusting option selections and deployment schedule, to reflect the scenario assumptions and technology constraints. Run model under challenging world.	Adjust BAU pathway current trends, i.e. option selections and deployment schedule, to reflect scenario assumptions and technology constraints. Run model under collaborative growth.
20-40% [12]	Builds on BAU for example by: deploying more advanced options, extending further across sector, deploying options earlier. Run under current trends.	Builds on 20-40% pathway current trends in the same way. Run under challenging world.	Adjust 20-40% pathway current trends in the same way. Run under collaborative growth.
40-60%	Builds on 20-40% in the same way. Run under current trends.	Builds on 20-40% pathway current trends in the same way. Run under challenging world.	Adjust 20-40% pathway current trends in the same way. Run under collaborative growth.
60-80%	Builds on 40-60% in the same way. Run model under current trends.	Builds on 40-60% pathway current trends in the same way. Run under challenging world	Adjust 40-60% pathway current trends in the same way. Run under collaborative growth.
Max Tech	Configure a schedule of options from 2015 to 2050 that broadly represents a maximum rate and spread across the sector. Run model under current trends.	Adjust Max Tech pathway current trends in the same way. Run under challenging world.	Adjust Max Tech pathway current trends in the same way. Run under collaborative growth.

Table 7: Pathways and scenarios matrix

Section 4.5 presents results from the sensitivity analysis, which aims to demonstrate the impact of key options and sensitivity of the pathways to critical inputs.

Section 4.6 presents order of magnitude pathway capital costs.

Section 4.7 summarises the enablers and barriers to the options and pathways developed in the modelling, taking account of information gathered from literature and stakeholders.

[12] Intermediary pathways may or may not be developed for a sector, depending on the carbon reductions of the BAU and Max Tech pathways.

4.3 Baseline Evolution - Principal Question 3

This section provides assessment of the range of questions under principal question 3: 'How might the baseline level of energy and emissions in the sectors change over the period to 2050?'

The evolution of the sector was based on a set of outlook assumptions and justifications provided by the BCC, prepared in response to the common scenario definitions used for all sectors in this study. Table 8 presents these assumptions:

Case	Heavy Clay Growth Rate	Reasoning	Other Subsectors Growth Rate	Reasoning
Central Case	+1%/1.5% p.a. to 2025 0% p.a. 2025 to 2050	Expect uplift in housing developments and population growth, but home size is expected to decrease (ONS data). Noted extensive investment in UK factories has not been for over a decade, and EU imports and other global competition is expected to continue. Loss of EU ETS carbon leakage status and exemption from the effects of carbon price underpin on electricity price would affect sector adversely after 2020 vs non-EU.	+1% p.a. to 2025 0% p.a. 2025 to 2050	Global recovery will increase sales for many companies, yet lack of support will reduce sales and increase competitive pressures in refractories, technical ceramics and whitewares. Lack of exemption from the effects of carbon price underpin on electricity price would continue to affect sector adversely after 2020 vs. non-EU.
Upside Case	+3%/4% p.a. to 2025 +1%/2% p.a. 2025 to 2050	Given the above potential market size, difficult to see investment in new factory capacity will yield more than 40-50% increase before 2025 as kilns require a 40 year life. To ensure UK investments over other EU and non-EU countries, it would be necessary to obtain and retain exemption from the effects of carbon price underpin on electricity price plus obtain compensation for renewables on electricity. Imports would still increase.	+1.5% p.a. to 2025 +0.5% p.a. 2025 to 2050	This would increase production volumes beyond pre-recession levels. Relies on continued growth, in particular of tableware, and increased sales in other subsectors. This is contingent on obtaining and retaining compensation for electricity price levy uplift.
Downside Case	0% p.a. to 2025 -2% p.a. 2025 to 2050	Loss of EU ETS Carbon leakage status and lack of exemption from the effects of carbon price underpin on electricity prices would affect sector adversely after 2020 as will rising electricity climate-related charges vs. overseas competitors.	0% p.a. to 2025 -0.5%/-1% p.a. 2025 to 2050	This is an average across the sector, as interpreted for the 'downside' case.

Table 8: Outlook assumptions for sector production (BCC)

Based on the above assumptions and together with BCC, we have developed the following growth estimates for the different future scenarios, split out for the heavy clay (brick) subsector and the other (refractories, technical ceramics, and whitewares) subsectors.

- Current trends – brick subsector: 1.25% annual growth to 2025 and then 0% to 2050. Other subsectors: 1% annual growth to 2025, and 0% to 2050.
- Challenging world – brick subsector: 0% to 2025 and then -2% annual decline to 2050. Other subsectors: 0% to 2025 and -0.75% annual decline to 2050.
- Collaborative growth – brick subsector: 3.5% annual growth to 2025, and then 1.5% annual growth to 2050. Other subsectors: 1.5% annual growth to 2025 and 0.5% annual growth to 2050.

In addition to the growth and decline projections for the different scenarios the following electricity grid emission factors were used in the modelling:

- Current trends: 100g CO_2 per kWh by 2030 and 26g CO_2 per kWh in 2050
- Challenging world: 200g CO_2 per kWh by 2030 and 150g CO_2 per kWh by 2050
- Collaborative growth: 50g CO_2 per kWh by 2030 and 25g CO_2 per kWh by 2050

DECC forward forecasts for energy costs as detailed in appendix D were also selected to reflect the circumstances of the scenarios to permit analysis of levelised costs of applying the various options.

The pathways were developed to meet the desired decarbonisation levels based on the current trends scenario. The deployment of options for current trends was then adjusted when the other scenarios were applied to maintain the desired levels of decarbonisation. This typically resulted in a slower rate of deployment of options in the challenging world scenario and an increased level of option application in the collaborative growth scenario.

4.4 Emission-Reduction Potential and Pathway Analysis – Principal Question 4 and 5

This section provides an assessment of the range of questions under principal questions 4 and 5:

- What is the potential to reduce emissions in these sectors beyond the baseline over the period to 2050?
- What emissions pathways might each sector follow over the period to 2050, under different scenarios?

A detailed description of the pathways development and analysis process is included in appendix A.

The feasibility and cost of decarbonisation in the sector were explored by targeting alternative levels of decarbonisation using a series of pathways. Each pathway comprised different degrees of application and timing of deployment of options. The list of enablers and barriers has informed the list of technical options that are being deployed in the different pathways. They also informed the deployment of the different technical options both with regards to time and degree of deployment.

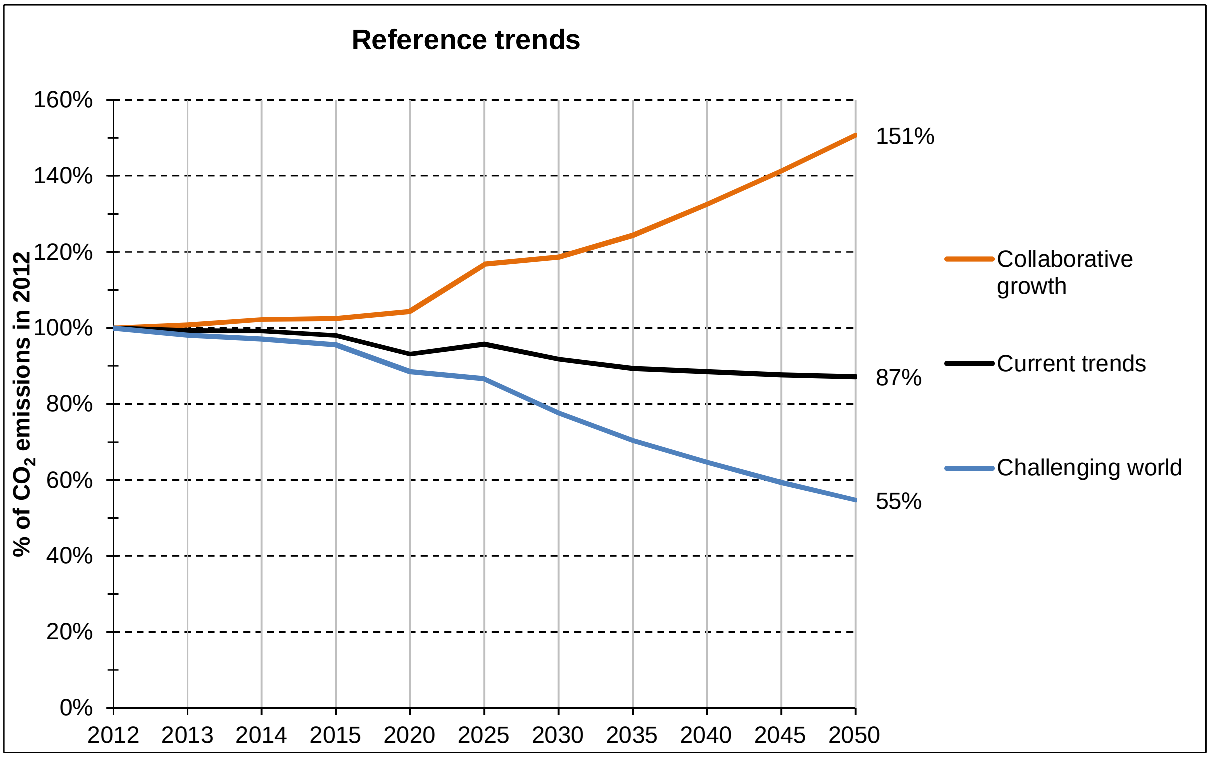

Figure 17: Reference trends for the different scenarios

For all of the pathways, to calculate the total CO_2 reduction of the sector, three key components needed to be accounted for, namely: the growth or decline of the sector, indirect (emissions from using electricity from the electricity grid) and direct emissions. The indirect emissions and growth or decline of the sector are illustrated by the reference trend. In Figure 17, the reference trends for the different scenarios are shown. The shape of the line is linked both to growth or decline of the sector and the different levels of decarbonisation of the electricity grid.

4.4.1 Baseline - Business as Usual Pathway

Pathway Summary

The guiding principle for the BAU pathway was to outline a set of decarbonisation and energy savings options that would be expected if current rates of efficiency improvement in the UK ceramic industry continued without significant intervention or outside support to decarbonise the sector by 2050. Options requiring no policy intervention, compared to today, and only minor changes within the sector were chosen.

Option Deployment for the Current Trends Scenario

Figure 18 shows the option deployment for the BAU pathway under the current trends scenario. This figure shows the different technical options on the left, with its relevant subsector identifier:

- All: means option is applied across the total sector
- B: means option is applied to the heavy clay subsector only
- R: means option is applied to the refractories subsector only
- T: means option is applied to the technical ceramics subsector only
- W: means option is applied to the white wares subsector only

The second column categorises the type of investment of each option (incremental, major or disruptive). The third and fourth columns are the estimated actual ADOPT in 2012 and the APP for the option. The APP indicates the maximum potential application of this option to the sector, or its relevant subsector. The breakdowns within the deployment column refer to the remaining applicability of each option. To the right of the APP is the level of additional deployment of the option over time to 2050. Hence an option already adopted at 25% in 2012, with an APP of 65% would have 40% remaining applicability.

The resulting direct CO_2 reductions for the option are scaled for its remaining applicability by percentages in each of the deployment columns. Hence a 50% deployment of our example option for a given five year period would deliver 50% of the remaining 40%, i.e. 20% of its CO_2 reductions potential listed in the options register. Few options affect process emissions, but where they do the process emissions reduction are added to the direct savings in this calculation. Similar calculations are made for the indirect CO_2 reductions.

BAU - current trends

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

Figure 18: Option deployment for the BAU pathway

In this pathway, the principal options that contribute to emissions reductions in 2050 are:

- **Adoption of available lowest carbon process:** in all four subsectors (heavy clay, refractories, technical ceramics, and white wares). This option refers to the replacement of older kilns with BAT kilns at the time of installation. The option is deployed to 50% of remaining applicability in subsectors by 2040, and the new BAT kiln option collectively (over the four subsectors) accounts for around 30% of the total emissions reduction from deployment of options in 2050.
- **Reduction of radiant and convective heat losses and leakage:** in non-BAT kilns across all subsectors. This means improved maintenance practice such as using thermal imaging technology, improving the quality of insulation along the kiln, and ensuring kiln walls and gaps are properly sealed, potentially through development and use of advanced insulation technology and the redesign of kiln cars or kiln car seals. This option is deployed to a further 25% of the sector which have not already adopted the option by 2020 and then 50% by 2035, accounting for 16% of total emissions reduction from deployment of options in 2050.
- **Improving heat use by regenerative processes:** in the heavy clay subsector. It is recognised that a good proportion of large tunnel kilns already have sophisticated designs to minimise energy use; note current adoption of heat recovery of kiln cooling air is high for this option. The BAU pathway assumes a further deployment of heat recovery technology to remaining heavy clay kilns (e.g. recovering kiln drier or exhaust heat), deployed to 25% by 2025, which finally accounts for 11% of total emissions reduction from deployment of options in 2050.
- **Improving combustion efficiency:** in non-BAT kilns across all subsectors. This option consists of adopting new burner technology, burner optimisation and burner control technology to enhance fuel efficiency. This option, deployed to 50% by 2035 of the remaining sector, accounts for 8% of total emissions reduction in 2050.
- **Low mass refractory for kiln cars;** in the heavy clay subsector. This reduces unnecessary thermal mass requiring fuel consumption to heat the kiln cars as they pass through the kiln. Deployment of this option at 25% from 2025 contributes about 5% of the pathway emissions reductions by 2050.
- **Improved process control in all subsectors;** closer monitoring and control of heat-using processes will reduce energy consumption in all subsectors.
- **Reduced air/product mass ratio in the heavy clay kilns**; increases the productive output of heat and hence reduces fuel consumption per tonne of product.

Figure 19 shows the calculated emissions reduction in $MtCO_2$/yr along the pathway trajectory, split out for the principal options, illustrating how they contribute to the trend of falling emissions:

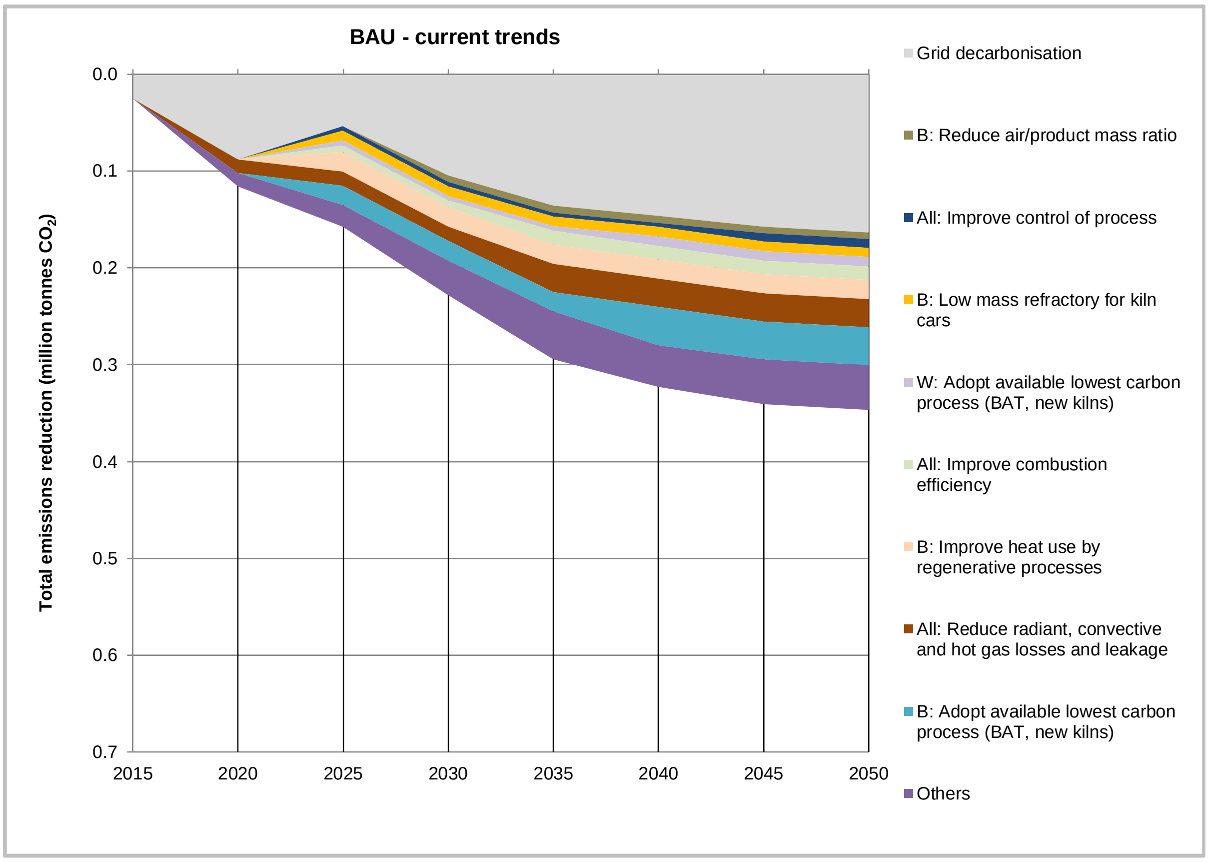

Figure 19: Contribution of principal options to the absolute emissions reductions, for the BAU pathway, current trends scenario

For the current trends scenario, the options deployed in the BAU pathway give an overall reduction of 27% in 2050, compared to 2012. This includes the emission reductions linked to the deployment of options and decarbonisation of the grid. The figure demonstrates that grid decarbonisation, which is a change external to the sector, contributes over 40% to the overall BAU pathway reduction.

The detailed contribution to the pathway emissions reduction in 2050 by each of the principal options applied in the sector is shown in Figure 20.

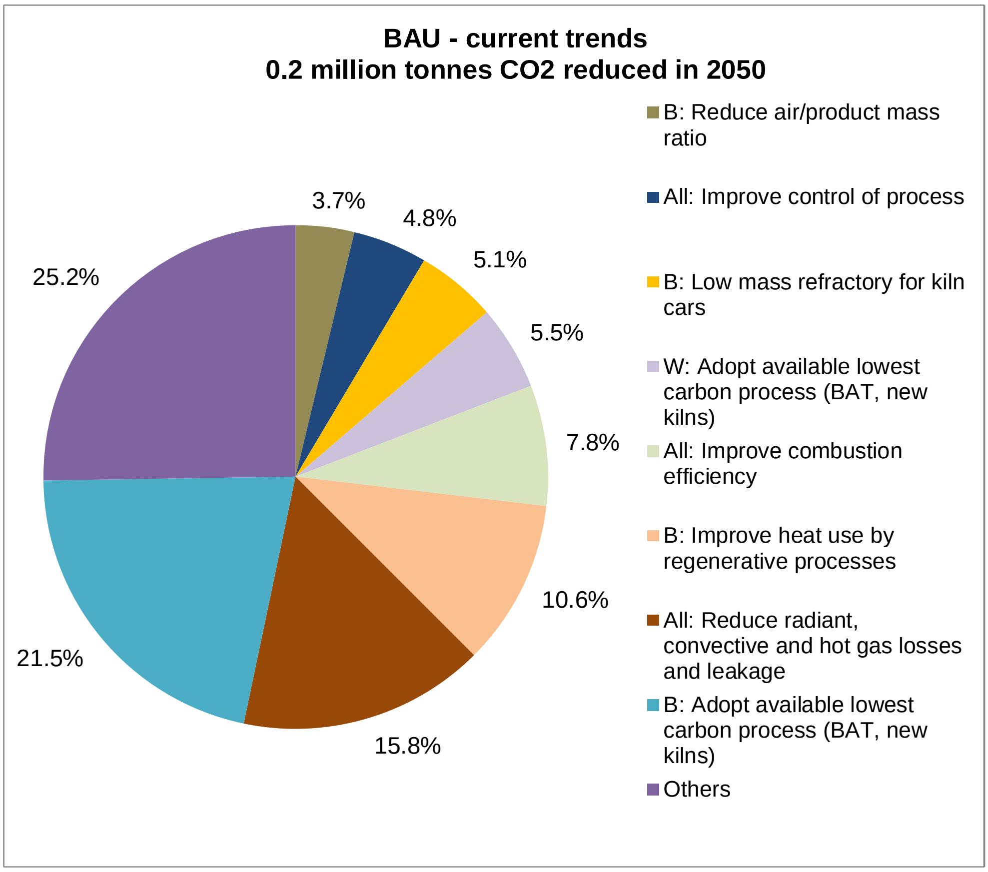

Figure 20: Breakdown of 2050 emissions reduction, for the BAU pathway, current trends scenario

Option Deployment for other Scenarios

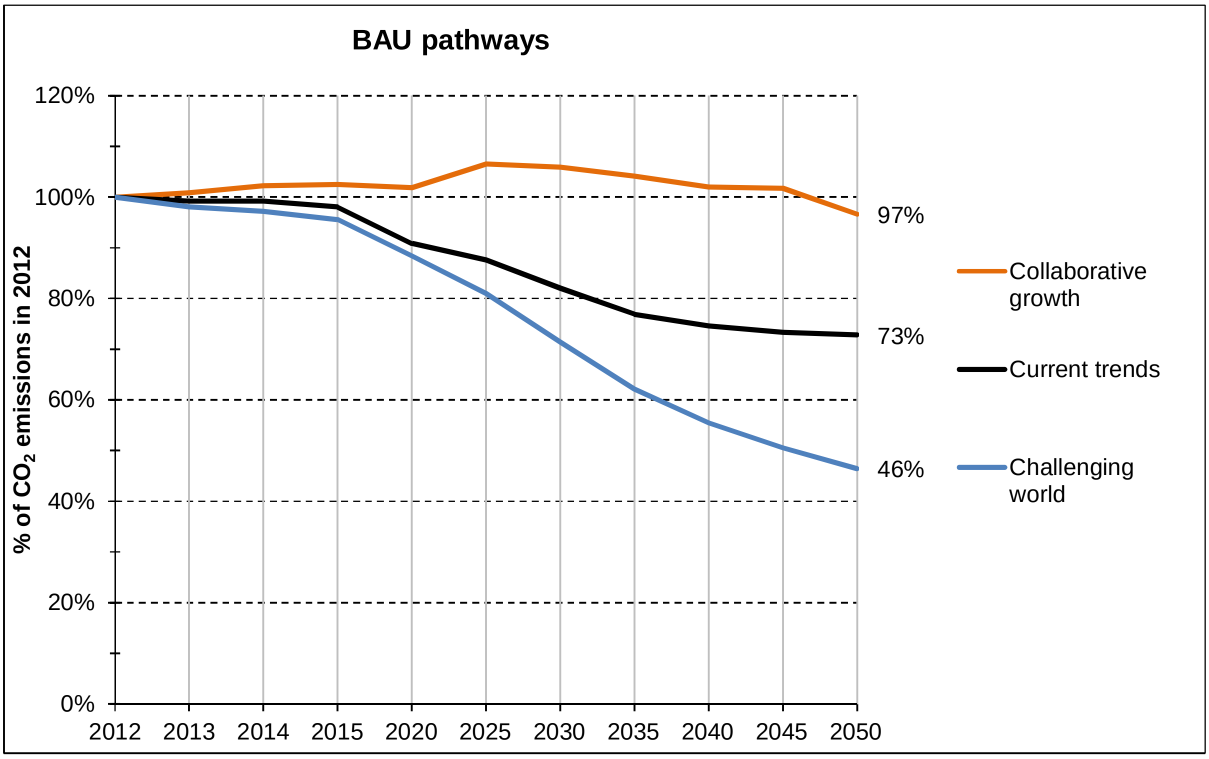

Figure 21: BAU pathways for the different scenarios

Figure 21 shows the BAU pathways for the different scenarios. As can be seen, by 2050 the current trends scenario delivers an overall CO_2 reduction of 27%, the challenging world scenario delivers an overall CO_2 reduction of 54% and the emissions for the collaborative growth scenario a reduction of 3% compared to 2012.

The BAU pathway under challenging world has all options included under BAU in the current trends scenario, deployed at a slower rate. For example there is a reduced replacement rate of kilns, since production capacity is reducing under this scenario. The larger overall reduction for BAU is due to the output decline under this scenario.

The BAU pathway under collaborative growth contains the same options deployed at a similar rate but to a larger proportion of the sector, due to the increasing production assumed under this scenario. In addition, disruptive technologies (electric kilns, gasification of biomass to substitute gas fired kilns, CC) were deployed to a portion of the sector from 2040, because (i) the scenario assumes better technology readiness and rate of commercialisation and (ii) disruptive option reductions were required to counteract the increasing reference emissions associated with increased output, to still ensure an overall reduction compared to 2012.

The deployment of options in the challenging world and collaborative growth scenario is shown in appendix D.

4.4.2 20-40% CO_2 Reduction Pathway

Pathway Summary

The objective of this pathway is to apply modest interventions to achieve a CO_2 reduction of 20-40% in 2050. However, as the BAU pathway already achieves a CO_2 reduction in the range of 20-40% under current trends scenario, no separate pathway was developed for this reduction band.

Option Deployment for other Scenarios

The BAU pathway addresses the option deployment for the 20-40% CO_2 reduction pathway in other scenarios.

The BAU pathway achieves over 40% reduction for the challenging world scenario so no additional 40-60% pathway was developed for that scenario. A 20-40% pathway for the challenging world scenario would be achieved by delaying new investments, such as for new BAT kilns, to reduce the level of decarbonisation.

The deployment of options for the collaborative growth scenario for this pathway is shown in appendix D.

4.4.3 40-60% CO_2 Reduction Pathway

Pathway Summary

The intent of this pathway is to apply options more intensively to achieve a reduction in carbon emissions of 40-60% in 2050. The options consist of a similar range of incremental and major process retrofits as the BAU pathway, but with an increased rate of kiln replacement with BAT. Disruptive technologies also start to make an impact, introducing electric kilns across the sector, with biomass and CC technologies in part of the heavy clay subsector later in the period to 2050.

Option Deployment for the Current Trends Scenario

Figure 22 shows the option deployment for the 40-60% CO_2 reduction pathway for the current trends scenario.

40-60% - current trends

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

Figure 22: Option deployment for the 40-60% CO2 reduction pathway

In this pathway, the principal options that contribute to the emissions reduction in 2050 are:

- **Gasification of biomass:** as a substitute of natural gas in larger heavy clay kiln facilities. The option uses gasification technology onsite to process biomass and waste feedstock into syngas, which is then used to co-fire alongside natural gas. The calorific value of syngas is noticeably lower than natural gas, as discussed further in section 4.7.2 below, and therefore complete substitution of natural gas with syngas is not feasible. In the model, a substitution rate of 50% has been utilised and biomass has been assumed to have a carbon intensity of 30kg/MWh, allowing for emissions associated with forestry, transport and the efficiency of gasification processes. The figure shows it is deployed to 25% of the applicable heavy clay subsector in 2040 and then 50% by 2050; although note only 35% of brick kilns are deemed applicable for this technology, so ultimately this pathway assumes 18% (i.e. 50% × 35%) of sites would adopt this technology. The option accounts for 6% of total emissions reduction from option deployment in 2050.
- **Electric kilns**: to replace gas fired kilns with electrically heated kiln technology and is potentially applicable across all subsectors. A proportion of smaller scale kilns already use electrical heating,

however wider-scale adoption of electric kilns would require significant advances in technology and kiln design. For example, an electrically-heated tunnel kiln for brick production would require a radically different design. The saving from this option comes from the fact that gas consumed in direct fired kilns is being replaced by low carbon grid electrical energy. The option is deployed to 25% by 2040 and then 50% by 2050 of applicable kilns (60%), and accounts for 45% of the total reduction from option deployment in 2050.

- **Adoption of lowest carbon process** (kiln replacements using BAT): is deployed to 50% across all subsectors by 2035, and then further to 75% by 2045 in refractories and whitewares. These BAT options collectively account for 13% of the total emission saving from deployment of options in 2050.
- **CC:** in the model the applicability assumption of this technology is limited to 40% of the heavy clay subsector. Similar to gasification of biomass, this assumes that only the larger and geographically suitable brick kilns could be fitted with CC. CC applicability is also dependent on a functioning CO_2 transport and storage infrastructure that can be connected to the industrial site boundary. The option is deployed to 25% of applicable sites by 2050 in this pathway, and accounts for 8% of total emissions reduction from option deployment in 2050.
- **Other options** include the range of incremental and major options listed in Figure 22. They are initially deployed to their respective subsectors, but are then deducted ('undeployed') from 2040 as kilns are being replaced with newer technology (i.e. adoption of lowest carbon process, electric kiln and gasification options). This avoids double counting of CO_2 reductions in the modelling.

Figure 23 shows the calculated emissions reduction in $MtCO_2$/yr along the pathway trajectory, split out for the principal options, illustrating how they contribute to the trend of falling emissions:

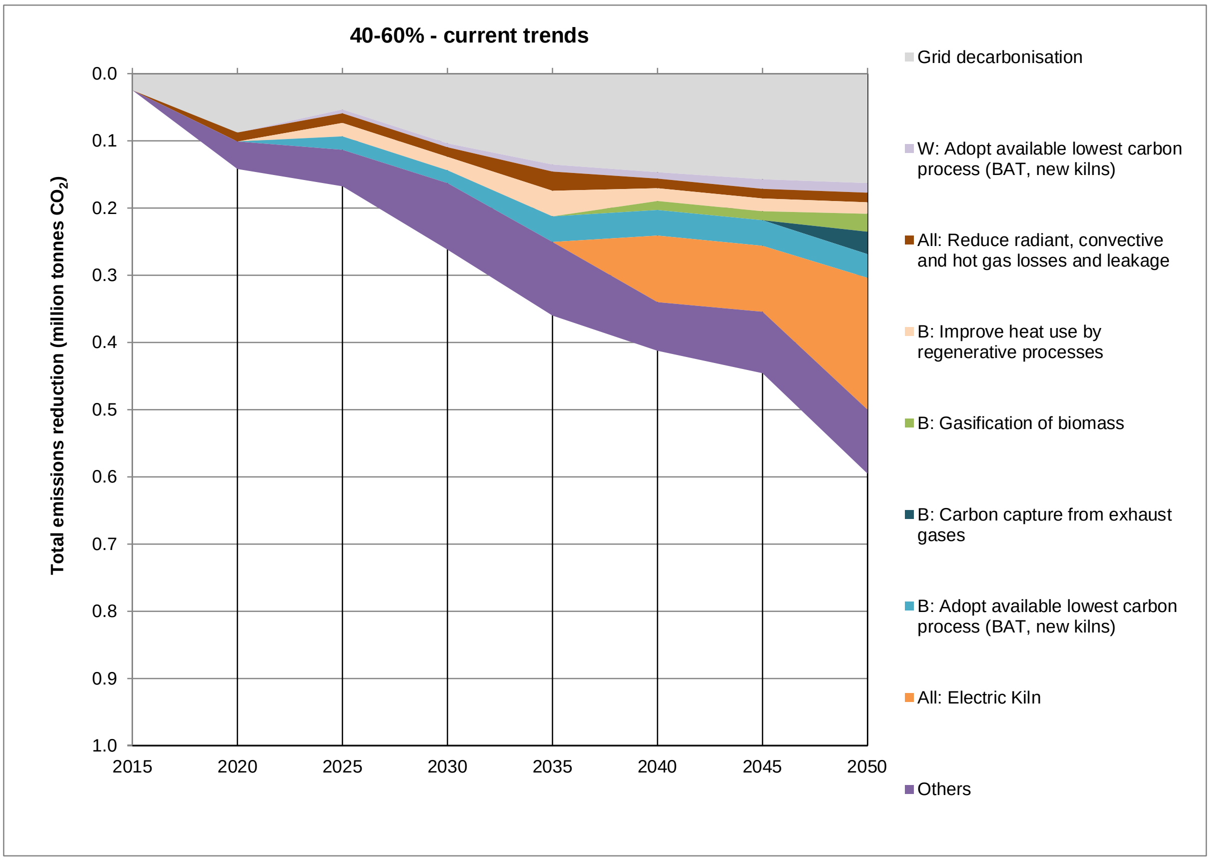

Figure 23: Contribution of principal options to the absolute emissions reductions throughout study period, for the 40-60% pathway, current trends scenario

For the current trends scenario, the options deployed in this pathway give an overall reduction of 44% in 2050, compared to 2012. This includes the emission reductions linked to the deployment of options and indirect emissions reduction (electricity grid decarbonisation). The detailed contribution to the pathway emissions reduction in 2050 by each of the principal options applied in the sector is shown in Figure 24.

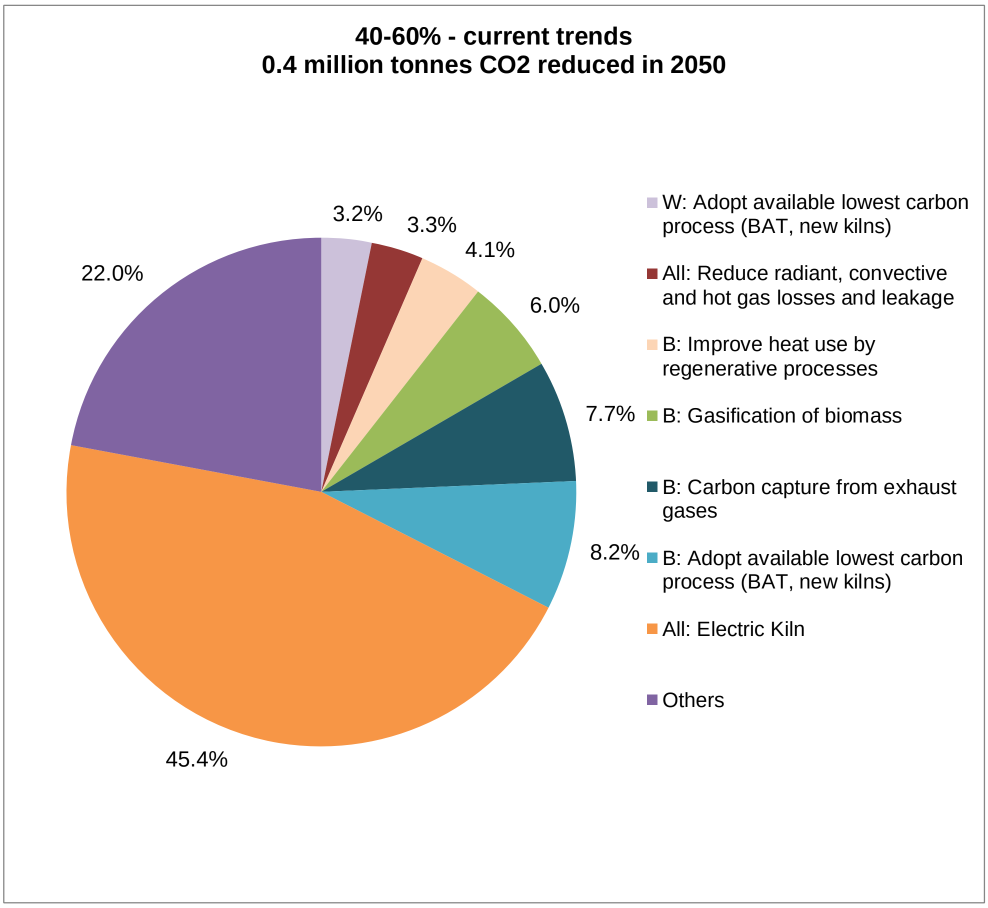

Figure 24: Breakdown of 2050 emissions reductions, for the 40-60% CO_2 reduction pathway, current trends scenario

Option Deployment for other Scenarios

The 40-60% CO_2 reduction pathway when run under the collaborative growth scenario falls into the 0%-20% CO_2 reduction band with a reduction of 18% in 2050 compared to 2012.Under this scenario, it was assumed that option investments and kiln replacements would be accelerated and the deployment of disruptive technologies increased, with particular contributions coming from electric kilns (making use of the low carbon electricity as fuel substitution).

The deployment of options for the collaborative growth scenarios for this pathway is shown in appendix D.

4.4.4 Maximum Technical Pathway

Pathway Summary

The guiding principle for the Max Tech pathway is to select a combination of carbon abatement options and energy savings that are both highly ambitious but also reasonably foreseeable. It is designed to investigate what might be technically possible when uncertain barriers, such as cost and availability of external resources (for example delivering additional power, supplying biomass feedstock or removing captured CO_2 from sites) are set to one side.

The option deployments include all incremental, major and state-of-the-art investment technologies, and maximum deployment of the disruptive technologies that is foreseeable when taking into account practical limitations. The measures imply a complete replacement of all existing kilns by 2050 with either BAT (direct fired) gas kilns, bio-syngas co-fired kilns or electric kilns. CC is also extended across 40% of the heavy clays subsector.

Option Deployment for the Current Trends Scenario

Figure 25 shows the option deployment for the Max Tech pathway in the current trends scenario.

Max Tech - current trends

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

Figure 26: Option deployment for the Max Tech pathway

In this pathway, the principal options that contribute to the emissions reductions in 2050 are:

- **BAT kilns:** with 50% deployment to the applicable heavy clay subsector by 2030 (i.e. 35% of actual sites); 50% deployment to applicable refractories facilities by 2030 rising to 100% by 2050 (50% of sites); 50% deployment to the applicable technical ceramics subsector by 2045 (45% of existing sites); and finally 50% deployment to applicable whitewares installations by 2035, increasing to 100%

by 2050 (which is 50% of existing whitewares sites). The sum across these four subsectors accounts for 8% of the total emissions reduction from deployment of options in 2050.

- **Electric kilns:** are rapidly deployed in steps from 25% in 2035 up to 100% in 2050. This implies that all applicable kilns (60% of total) are electric by 2050. Although electric kilns are seen to be challenging for large heavy clays units, the technology is assumed to have been widely developed in the pathway; given it is the Max Tech case. Also, the main impetus for investment and commercialisation of electric kiln technology in the analysis is due to the grid decarbonisation assumption in the scenario modelling. The option accounts for 41% of total emissions reduction from option deployment in 2050.
- **Carbon Capture:** is deployed on a similar schedule from 25% up to 100% by 2050 to applicable kilns in the heavy clay subsector. This implies that 40% of actual heavy clay sites would be fitted with CC; with main limiting constraints being that only larger sites might be economically suitable and have access to CO_2 transport and storage infrastructure. It should be noted that CC is the only option in the model assumed to abate process emissions (as well as fuel emissions). The option accounts 23% of total emissions reduction from option deployment in 2050.
- **Gasification of biomass onsite**: is also deployed to 25% and then up to 100% by 2050. The applicability assumption of this option is 35% of the heavy clay subsector, implying that around a third of heavy clay sites might adopt this technology under the Max Tech pathway. Similar to CC, the limiting factors might be the size of facility at which this option might prove economic, and also system level constraints such as availability of biomass feedstock in the UK. The option accounts for 11% of total emissions reduction from option deployment in 2050.

Figure 27 shows the calculated emissions reduction in $MtCO_2$/yr along the pathway trajectory, split out for the principal options, illustrating how they contribute to the trend of falling emissions:

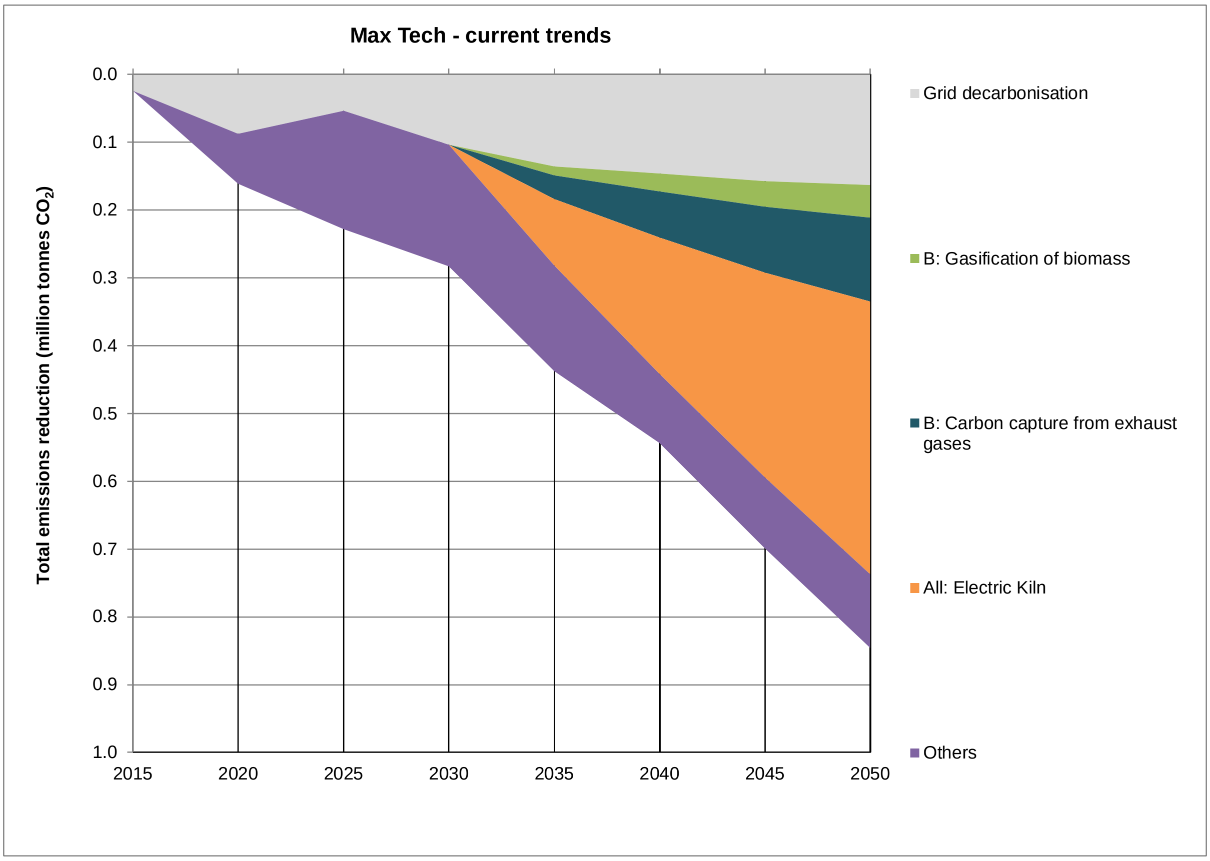

Figure 27: Contribution of principal options to decarbonisation throughout the study period, for the Max Tech pathway, current trends scenario

For the current trends scenario, the options deployed in this pathway give an overall reduction of 60% in 2050, compared to 2012. As shown in Figure 27 grid decarbonisation contributes significantly to this overall reduction result as well as the direct reduction from deployment of options.

The level of reduction achieved in the Max Tech pathway may be considered to be lower than expected. However the ceramic sector has substantial process emissions, representing over 20% of total CO_2 emissions. These are not reduced by energy efficiency options and are only affected by technical options that reduce product weight or by CC. These options have restricted maximum impact due the properties of the raw materials, the small scale of the installations, the dilution of CO_2 in exhaust streams and their wide geographical distribution.

The detailed contribution to the pathway emissions reduction in 2050 by each of the principal options applied in the sector is shown in Figure 28

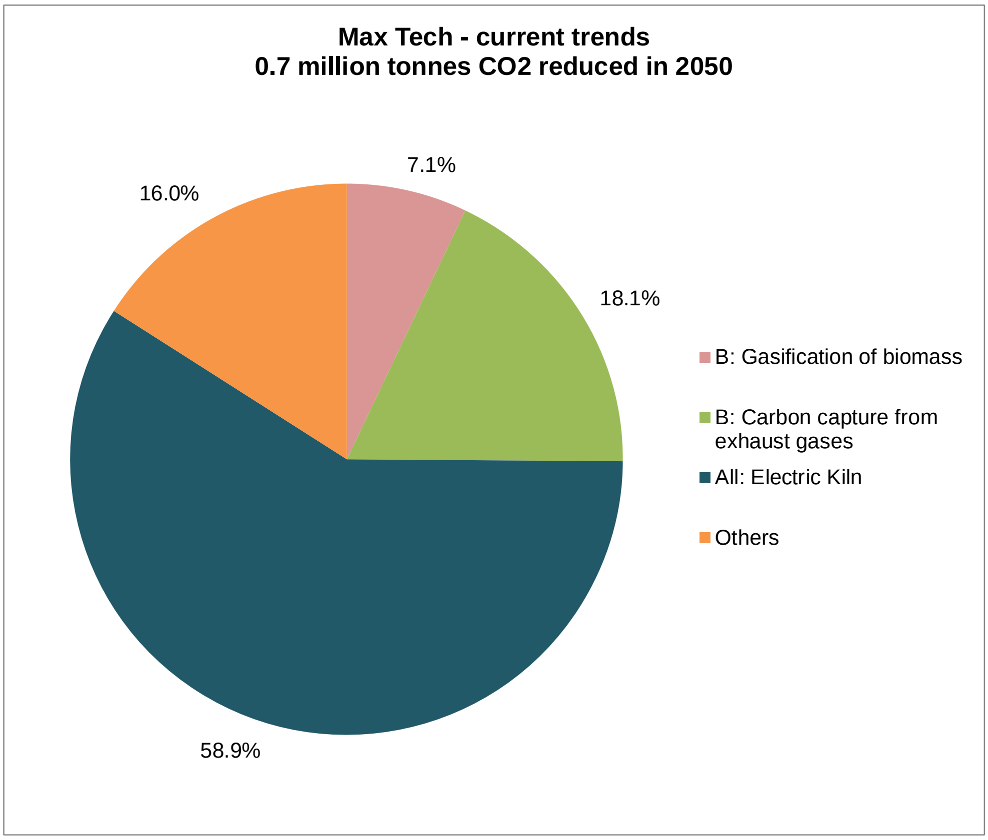

Figure 28: Breakdown of 2050 emissions reductions, for the Max Tech pathway, current trends scenario

Interaction between these options was an important consideration when configuring the pathway. An electric kiln would have to replace and substitute a conventional kiln, and could not overlap. Gasification of biomass could not technically be applied to electric kilns, but would complement direct fired (BAT) gas kilns. CC could technically be used to capture both process and fuel emissions from conventional (BAT) kilns (with or without use of biofuel), and could also potentially capture process emissions from large capacity electric kilns, although there are considerable uncertainties in this application.

When modelling the Max Tech pathway, two key assumptions about company decision making were made:

- All existing kilns are replaced with new technology by 2050 (hence 'Existing gas kilns: Retrofit opportunities' reach 0% in all subsectors – in Table 9 below)
- 40% of ceramic companies retain fuel (natural gas or co-firing natural gas and syngas) as their primary energy source and 60% embrace electric kiln technology

A kiln replacement programme was then formulated to act as a basis for the Max Tech pathway, as agreed with the BCC. The programme assumed to be applied to the heavy clays subsector is shown in Table 9.

Year	Existing gas kilns: Retrofit opportunities	New gas kilns: BAT	Syngas co-firing	Existing electric kiln	New electric kiln
2020	95%	5%	0%	0%	0%

2030	60%	40%	0%	0%	0%
2040	20%	30%	20%	0%	30%
2050	0%	5%	35%	0%	60%

Table 9: Kiln replacement programme for heavy clay subsector, as a basis for the Max Tech pathway

Retrofit options are assumed to be the option of choice from 2020-2030 but from 2040 onwards the number of retrofits drop as new kilns are installed. New gas BAT kilns will be installed rapidly in the lead up to 2030 then the rate of new installations will slow, but the number of new installations will continue to rise overall. Simultaneously, some of the new kilns will have syngas retrofitted from 2030 onwards. The use of syngas co-firing was assumed to increase between 2030 and 2050. 60% of kilns were assumed to be electric by 2050, but with deployment starting after 2030.

Option Deployment for other Scenarios

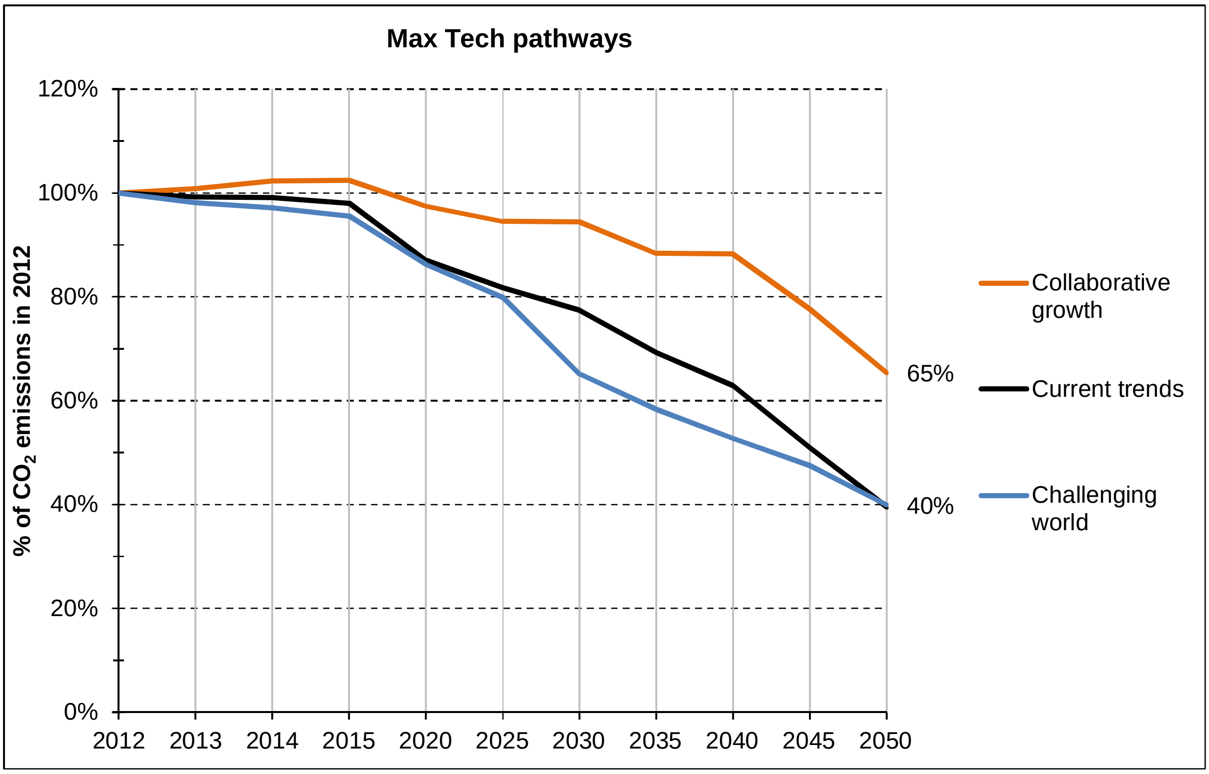

Figure 29: Max Tech pathways for the different scenarios

Figure 29 shows the Max Tech pathways for the different scenarios. As can be seen both the current trends and challenging world scenarios deliver a CO_2 reduction of 60%, while the collaborative growth scenario delivers CO_2 reduction of 35% compared to 2012.

For the challenging world scenario, short and medium-term investments that extend known solutions and process improvements are delayed by five years and Major plant replacements are also reduced. Deployment of electric kilns was reduced because grid decarbonisation is not as ambitious and effective under this scenario. CC and gasification of biomass are deployed to their maximum potential by 2050, ensuring a total reduction of CO_2 emissions for this pathway remains at 60% in 2050 compared to 2012.

In the collaborative growth scenario, the Max Tech pathway just reaches the 40-60% CO_2 reduction band. The total reduction of CO_2 emissions for this scenario is 41% in 2050 compared to 2012. In this scenario, the options and deployment rate are the same as the current trends case already discussed. Since the key options for electric kilns and driers in heavy clay, large scale application of CC and gasification of biomass are already deployed to the maximum level considered feasible by BCC, the shortfall in CO_2 reduction in this scenario could not be reduced.

The deployment of options for the challenging world and collaborative growth scenarios for this pathway is shown in appendix D.

4.5 Sensitivity Analysis

A set of sensitivities were run in the model to test the significance of key options on pathway outcomes and to highlight their importance in defining potential actions. All these cases were run in the current trends scenario to explore their impact in the base case.

First, the pathways were re-run with a reduced rate of deployment of best available kiln technology with deployment only to 25% in 2030. The sensitivity resulted in the 40-60% and Max Tech pathways performing worse in the medium term from 2025 to 2035, but regaining a similar reduction in the long term towards 2050. This is because the disruptive options (electric kilns, biomass gasification and CC) make larger reductions from 2040 onwards. Only in the case of the BAU pathway was final sector saving in 2050 degraded. However the impact was small, being only a reduction of around 2%. This shows that BAT kiln replacement does not significantly affect the pathway outcomes in 2050, although a reduction of the deployment of this option would delay decarbonisation of all pathways.

Secondly, the pathways were run with no additional deployment of electric kilns, particularly into the heavy clay subsector. The results showed a significant impact on the 40-60% pathway (12% less reduction by 2050) and the Max Tech pathway (23% less carbon saving by 2050); although there was no change for BAU. This moved the Max Tech pathway down by two reduction bands, i.e. from 60-80% to 20-40%. Since the alternative options for large scale reduction of CC and gasification of biomass were already deployed to the maximum level considered feasible by BCC, this impact could not be corrected. This sensitivity demonstrates the significant importance of large scale electric kilns to the more ambitious decarbonisation and energy efficiency pathways.

Thirdly a sensitivity was run to test the influence of reduction coming from biomass substitution options; i.e. no deployment of gasification of biomass onsite, across all pathways

The results showed lower long-term reductions in the period 2040-2050 for the 40-60% and Max Tech pathways; with 2% less overall reduction for 40-60% and 3% less for Max Tech pathway in 2050. The options that would be available to restore this lost reduction in the sector would be the increased application of large electric scale kilns or CC in the heavy clay subsector. However these two technologies are mutually exclusive, operating on different kiln types, so that they cannot be applied further.

Finally 0% deployment of CC to the heavy clay subsector was run in the model across all pathways. The Max Tech pathway reduction was cut by 8%, resulting in 52% CO_2 saving compared to 2012, moving the Max Tech pathway into a lower reduction band. The 40-60% pathway saving moved down by 2% in 2050 and the BAU was unaffected. Again, the alternative large impact options are already deployed to the maximum feasible extent in this pathway so the adverse impact of removing CC cannot be restored.

The main conclusion of the sensitivity analysis is that the application of electric kilns across the sector is the most critical option to delivering the maximum reduction in carbon emissions by the ceramic sector, the second being CC in the heavy clay subsector, with the use of gasified biomass also contributing. These options each have restrictions on their application which means they can only replace each other to a limited degree.

The implications of the pathways analysis and these sensitivity findings are that the higher CO_2 reduction pathways all depend upon novel, disruptive technologies to achieve the desired results. This finding lends significance to the potential actions necessary to overcome the barriers to implement these essential technologies.

All resulting graphs and pathway curves for these sensitivity tests can be referred in appendix D.

In the option interaction calculation, the ‘no interaction’ case adds approximately 5% to the carbon reduction in 2050 in the Max Tech pathway.

4.6 Pathway Costs

4.6.1 Introduction

Estimates of the costs of new technologies and/or capital improvements with a time horizon to 2050 is fraught with difficulties; any long term forecasts should be treated with caution. The cost analysis presented in this report is intended to provide a high level estimate of the total capital cost of each pathway to the UK as a whole, in a form which is consistent with the government’s approach to assessing the relative capital costs of alternative decarbonisation options from a social perspective[13]. It is based on an analysis of ‘order of magnitude’ option capital costs. The purpose of developing and presenting this cost analysis is to provide an indication of the capital costs for the pathways, which could form a basis for further work.

In gathering capital cost-related data, literature and/or engagement with stakeholders were used to establish an initial dataset for use in the cost analysis assessment. Operating costs such as energy use changes, energy costs and labour are not included in this analysis, although we recognise that operating costs resulting from the decarbonisation pathways will have a major impact any economic assessment. For example some options (e.g. CC and electrification of firing) greatly increase energy use and/or operating costs of a process plant.

4.6.2 Calculation of Pathway Costs

The pathway costs and CO_2 reductions are measured with respect to the reference trend, i.e. they are calculated as the difference between costs and emissions under the decarbonisation pathway and those under the reference trend. This means the costs represent the additional capital costs for the pathway compared to a future in which there was no deployment of options. The pathway costs have been assembled from the estimated costs of the combination of decarbonisation and energy efficiency options, in accordance with each carbon reduction pathway including the selected deployment rates of each option. The methodology for calculating the total discounted capital costs which produce the CO_2 reductions for each pathway can be summarised as follows:

13 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360316/20141001_2014_DECC_HMT_Supplementary_Appraisal_Guidance.pdf

1. Capital costs of deployment for each decarbonisation and energy efficiency option are calculated based on the order of magnitude capital costs to deploy that option at one site (or installation or unit of equipment). This is then deployed to the applicable number of sites (or installations or units of equipment) for the (sub) sector in the pathway as defined by the model.
2. Capital costs reflect the additional cost of delivering the CO_2 and/or energy reduction options compared to continuing production without deploying the options. For a number of major investment options, including replacement of life-expired assets with BAT (for a list of options in this category see appendix C), only a proportion of the cost is assumed to be attributed to CO_2 emission or energy reduction, as a significant factor for the investment in this case would be to replace retiring production capacity and to recognise that options may be implemented for reasons other than decarbonisation / energy efficiency. In the absence of detailed information this proportion (attributed to the capital cost calculation in this analysis) is assumed to be 50%. For all other technology options the entire capital cost (i.e. 100%) is attributed to energy / carbon reduction. Capital costs are applied at the year of each deployment step (as modelled in the carbon reduction pathways), and adjusted in cases where the asset life defined in the option register would extend beyond 2050 to reflect their residual value on a linear depreciation basis.
3. The annual capital expenditure of each pathway is calculated from the capital cost and deployment of each of the options selected. Capital costs are presented in present day value (i.e. 2015) and assumed to remain constant throughout the period. The discount rate for costs has been chosen to be 3.5% to value the costs from a social perspective and in accordance with standard HM Treasury methodology for this type of assessment. In other words, all proposed capital expenditure on the various pathways are adjusted for the time value of money, so costs (which occur at different points in time) are expressed on a common basis in terms of their 'net present value' using the discount rate of 3.5%. The effect of this standard methodology is to reduce the apparent cost of large investments that are deployed in the pathways later in the study period.

The following specific assumptions apply:

i. Asset replacement is assumed to take place at end of the life of an existing asset. No allowance has been made for loss of production during the shutdown period associated with the implementation of major and/or disruptive technology options. Similarly no allowance has been made for loss of EU ETS allowances or civil works associated with a major shutdowns and plant rebuilds. Although costs may be incurred in a case where a plant is written off before the end of its life, this has not been taken into account in this analysis.
ii. It has been assumed that minor incremental improvements would be implemented in the shadow of other rebuild or maintenance work so that no additional costs for shutdown would be incurred.
iii. No allowance has been made for the costs of innovation and it is assumed that the costs of development of breakthrough technologies would be funded separately and not be charged to subsequent capital investments. Technology licensing costs are assumed to be included in the capital costs.
iv. No carbon price or other policy costs are included in the calculations.
v. Changes in other operating costs including labour, maintenance or consumables associated with the deployment of options have not been included (although it is noted these will be significant for many options).
vi. This analysis covers capital costs for carbon reduction; changes to energy use and energy costs (as a result of deployment of the options) has not been quantitatively included although it will be significant for many options.

4.6.3 Limitations

The project methodology for cost data collection and validation did not deliver a complete dataset for the capital cost of options, and where data was available, it was qualified at low confidence levels. Further, estimates based on expert judgement have been made where data gaps remained. Also, the degree of stakeholder engagement in relation to this cost analysis was lower than for the carbon reduction pathways.

All costs in the data input tables are subject to wide variation, for example between sites and sub-sectors and for technology options that have not been demonstrated at commercial scale. Hence, the cost data represent 'order of magnitude' estimates that require extensive further development and validation prior to any further use, including with sector stakeholders.

Moreover, the assumptions and constraints on confidence levels limit the valid uses for the results of this cost analysis, therefore the following applies to use of this analysis:

- The values are a starting point to help assess relative benefits of different technologies over the long term.
- The cost analysis results should not be used in isolation to compare decarbonisation technologies or decide on priorities for their development – additional techno-economic analysis should be carried out on individual options or groups of options.
- The cost analysis is part of a process of research and exploration and is being shared in a transparent way to support the development of broader strategy. The results are effectively provisional order of magnitude estimates which need to be developed further on the basis of thorough research before they can be used to inform decisions.

4.6.4 Cost Analysis Results

The results of the cost analysis of decarbonisation for the various pathways within the current trends scenario are summarised in Table 10 below.

Results can be used for relative comparison between pathways in a sector. No cost moderation process between the eight sectors has been carried out and therefore in the absence of further data validation and analysis comparison between sectors is not recommended.

The CO_2 emission abatement offered by each pathway has been totalled for each year to present a **cumulative** carbon abatement figure for the period from 2013-2050 compared to the reference pathway.

Although this analysis of discounted capital cost does not include energy costs, it should be noted that energy cost changes will be subject to the uncertainties of future energy cost projections and the significant divergence between energy costs applicable to the different levels of energy consumption. A high level qualitative assessment of the impact of energy use and cost is presented in the table below.

Pathway	Total Discounted Capital Cost 2013-2050 £m[14]	Cumulative Carbon Dioxide Abated 2013-2050 ($MtCO_2$)[15]	Projected Impact on Fuel / Energy use and Fuel / Energy cost
BAU	300	4.1	This pathway includes deployment of options that increase overall energy efficiency and reduce overall fuel use. In the study period from 2013 – 2050, this pathway would result in a substantial saving in energy and fuel used. The projected value of this saving will depend on the fuel cost forecast adopted.
40-60%	500	5.7	The increase in fuel costs from the substitution of natural gas with electricity for electric kilns is off-set by the reduced cost of natural gas consumption from energy efficiency measures. The overall net effect depends on the fuel cost forecast adopted.
Max Tech	700	8.1	The main characteristic of this pathway is a very significant transfer of energy use from natural gas to electricity resulting in a projected large overall increase in energy use and costs. The scale of the increased cost will depend on the fuel cost forecast adopted.

Table 10 Summary costs and impacts of decarbonisation for the pathways

4.7 Implications of Enablers and Barriers

From the pathways described above, there are a number of options or groups of options that will make significant contributions to decarbonisation under some or all of the pathways and scenarios. These are:

- Adopt lowest carbon process (BAT kilns)
- Gasification of biomass
- Large scale electric kilns
- CC from exhaust gases
- Low and Low-Medium cost options

From the evidence gathered during the project (from literature, interviews, survey and workshops) a number of enablers and barriers which could affect these options were identified. The barriers were primarily access to investment, new technology risks and limitations of expertise and skills within the sector, as detailed in section 3.4.5 above. Enablers were also identified by the evidence gathering process and the significance of these enablers to promoting the adoption of the individual options was assessed. The relationships between the enablers and barriers and the options are discussed below.

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[14] Model output rounded to 1 significant figure to reflect ‘order of magnitude’ input data
[15] Model output rounded to nearest million tonnes of CO_2

4.7.1 Adopt Lowest Carbon Process

A major contributor to decarbonisation in the Max Tech case is the adoption of BAT kilns, especially in the heavy clay and whitewares subsector. The application of enhanced kiln designs to replace existing units will produce a step improvement in energy consumption through improved design of heat recovery and combustion of fuels with the application of advanced refractory and insulation materials. Decisions on such an investment will be based on wider business considerations such as sustaining production, extending plant life, labour savings (robotics) and waste reduction rather than savings from improved fuel efficiency.

Barriers to adoption of BAT kilns are primarily related to capital cost and investment decisions made between sustaining production capacity in the UK and expanding overseas where energy, carbon and labour costs may be lower. These decisions will be driven by confidence in ROI and assessment of risks rather than considerations of decarbonisation. High future fuel costs would enhance savings offered by new plant but could make a UK based plant less competitive, would increase risks to returns on the investment and reduce the ability of firms to invest. Uncertainty on energy, climate and environmental policy and perceived risks to energy security also undermine investment decisions.

A particular barrier for larger plants, which are obliged to participate in the EU ETS, is loss of ETS allowances if the project lasts more than 6 months. Restoration of full allowances is impossible under the current interpretation of the rules and reduced allowances will be granted only after 6 months or a year of new plant operation. This loss of relief and increased uncertainty is a major disincentive to investment. Reform of the EU ETS would support investment in major capital projects that improve energy and carbon efficiency but which might take longer than 6 months to complete.

Enablers for the option would be confidence in the future UK demand for products and a long-term commitment to UK based production by plant owners coupled with a supportive and stable, long-term regulatory framework. Reduced and more predictable gas prices (short and long term), would strengthen the business case for new investment.

In each scenario the application of BAT kilns affects all pathways in the period 2025 to 2040, delivering a significant proportion of early CO_2 reductions, enabling the sector to make a significant change before the disruptive options can be deployed.

Enablers	Reduced and more predictable gas prices (short and long term) Stable long-term regulatory environment Senior management commitment to sustained UK production
Barriers	High capital costs and long payback periods Uncertainty about return on capital Limited availability of capital including global competition for funding from group headquarters Rising UK energy and, or carbon prices Regulatory uncertainty Perceived energy security risks EU ETS treatment of extended shutdown for energy and carbon efficiency improvement

4.7.2 Gasification of Biomass

This option would substitute a large part of the natural gas consumed by a large scale kiln by a syngas generated by gasification of biomass or waste. Complete replacement of the natural gas was not considered to be viable by the sector specialists as this would require synthetic natural gas production by a more complex and less efficient gasifier using costly oxygen instead of air. Syngas substitution technology offers the advantage that it can be applied to existing heavy clay kiln designs with some burner and control system modification.

There are several barriers to the adoption of this technology. Financial support for the development of breakthrough technologies will be necessary, including for industrial research, development and demonstration of pre-commercial technologies. The availability of a secure supply of competitively-priced, sustainable feedstock will be essential. The large capital cost of the technology and its potential risks means that it will face strong competition for funding from head office. The uncertainty of biomass availability and price together with the technical risks increase the uncertainty around ROI. The additional vehicle movements to deliver the fuel and regulatory uncertainty over the exact legal treatment of CO_2 emissions from biomass expose the option to additional regulatory risks. The new process also has potential impacts on product quality.

Enablers for the application of gasification of biomass would be clarity over the security of supply and price and carbon rating of biomass feedstock, incentives for renewable fuels used for industrial process heating and demonstration of the new process at commercial scale to reduce new technology risks. Senior management buy-in for decarbonisation would also enhance the take-up of this option.

For the current trends scenario, the gasification of biomass option has a significant impact on Max Tech and the 40-60% CO_2 reduction pathways.

Enablers	Prior demonstration of the technology at scale Security of supply of biomass Assured biomass price or other incentives for renewable fuels used in industrial processes Senior management buy-in and formal business commitment
Barriers	Lack of support for new technology development and demonstration High capital cost and global competition for funding from group headquarters Uncertainty about return on capital Uncertainty in biomass secure availability and price Regulatory uncertainty for emissions and fuel supply Uncertainty about the performance and reliability of a new process Uncertainty about product quality impacts

4.7.3 Large Scale Electric Kilns

This option is to replace fuel burned in kilns by electrical heating. While electrically heated kilns are used for a limited number of firing processes in the sector, there is no experience of large scale continuous kilns being electrically heated as their energy costs would be radically higher than for a gas-fired kiln. The use of electrical heating would necessitate a substantially different kiln design to use the different heat source and would only be implemented as a replacement for a kiln at the end of its life. The option would be adversely affected by electricity energy prices which are currently four to five times that of gas. Given the UK's current and predicted electricity prices, this option would be viable only with very substantial incentives to reduce carbon emissions. In other respects an all-electric kiln would have reduced local environmental impacts and might offer improved product quality.

Barriers to the deployment of large scale electric kilns are dominated by the high energy cost for the option which would typically at least double product costs without incentives. In addition the scale and cost for new technology all-electric equipment would be seen to present significant risks to the industry which could hamper its deployment. In addition, substantially increasing electricity feeds to factories, which are often located in rural locations, is also perceived to be problematic. These risks would be seen to adversely affect returns on investment in such an option.

An important enabler would be incentives to avoid emissions from fossil fuels. Another enabler would be large scale demonstration of the technology to largely eliminate technology risks. The recognition of decarbonisation as being an important company objective would enhance senior management buy-in as would formal business commitment to decarbonisation.

This option contributes strongly to the Max Tech and the 40-60% pathways.

Enablers	Development and demonstration of the technology at scale Incentives to reduce fossil fuel use or increase use of low carbon electricity Senior management buy-in and formal business commitment Decarbonisation of electricity supplies as projected
Barriers	Large multiple increase in energy cost over gas Rising electricity prices Lack of support for new technology development and demonstration (new kiln design) High capital cost and global competition for funding from group headquarters Uncertainty about return on capital Uncertainty of local capacity to meet increased electrical demand

4.7.4 Carbon Capture

This option would apply CC technology to the flue gases from the largest heavy clay kilns to capture a high percentage of fuel and process carbon emissions. This is the only technology able to reduce the significant level of process emissions from the heavy clay subsector. The process equipment could be added to new and existing kilns and would have no impact on the production process. The site would however need to have space for the necessary equipment for capture and export of the CO_2 along with additional facilities to manage the operation and any hazards presented by the processes. The process plant would be subject to additional regulations, typically those for the chemical industry that could complicate the management of the site.

Export of the captured CO_2 could be pipeline, as liquid CO_2 in tankers or to an adjacent chemical plant using the gas as a feedstock. Any of these alternatives adds requirements and may restrict the application of this technology to suitably located plants. The remote location of these plants away from likely national carbon capture and storage (CCS) infrastructure adds substantially to costs.

Barriers to this option include substantial capital cost without any corresponding saving from fuel consumption reduction and added costs for energy consumption by the CC process itself. This will unavoidably have an adverse effect on ROI. The necessary investment for such development and demonstration will need to be supported as the technology offers no financial return to the sector. The process and equipment will be demanding of space that will be challenging to find on many sites. The addition of new hazards on site will require changes of site management and will face some regulatory uncertainty to obtain planning consent for changes to the site and for its subsequent operation. Without strong incentives the investment would not be financially viable.

Technology development for application in the ceramic sector will be necessary to address specific challenges of the contaminants in the exhaust gas stream and the low concentration of CO_2 in the exhaust stream. Furthermore, the volume of emission at each site is comparatively small and the sites are widely-dispersed geographically, with proximity to local raw material reserves currently being a key locational consideration

Enablers for the option would be formal commitment to decarbonisation and corresponding senior management buy-in, appropriate policies to provide incentives to develop, demonstrate and apply a process that requires investment for no other return. The development of a carbon storage infrastructure will be necessary to minimise cost for such an option, while regulatory clarity would be necessary for the development and operation of the plant.

This option impacts the Max Tech and 40-60% pathways.

Enablers	Incentives to invest in a decarbonisation technology with no business benefits

	The development of carbon storage infrastructure to kiln sites Clarity of regulatory position for CCS application Senior management buy-in and formal commitment to decarbonisation
Barriers	Substantial capital cost with adverse return on capital Need for substantial incentives to overcome adverse impact on costs Lack of support for new technology development and demonstration Availability of space for additional equipment on production sites Regulatory difficulty for planning consent and operating licences High capital cost and global competition for funding from group headquarters Location of sites away from CCS infrastructure

4.7.5 Low and Low-Medium Cost Options

This is a group of options that requires only low or low-medium capital investment. These are largely the current state-of-the-art technologies such as energy management, improved insulation levels, better control of combustion, process refinements, increased density of kiln setting etc. They have been grouped together for the purposes of this section as they have similar enablers and barriers. Small incremental investment was identified as an enabler as the site typically has access to a capital budget for small works that it can control itself. The low capital cost options are likely to fall into such a category. For the low-medium capital cost options with longer payback, costs might be spread over several years, otherwise funding from head office may be difficult to obtain and external grants and borrowing may not be readily accessible, restricting the application of such options.

Even lower investment costs are sensitive to the lower profit margins in the marketplace. Some of these options are more concerned with organisational changes rather than technical changes. Successful implementation would require both evidence gathering to support the understanding of technical issues as well as a willingness to address changes in practice and the development of new skills.

These options would have an impact on all pathways, but would influence the BAU the most.

Enablers	Small incremental investments
Barriers	Lack of funds or incentives for projects with medium-longer term paybacks Competitive marketplace with lower profit margins Lack of awareness and information imperfections Lack of skilled labour

5. CONCLUSIONS - PRINCIPAL QUESTION 6

This section provides assessment of the questions under Principal Question 6: 'What future actions might be required to be taken by industry, government and others to overcome the barriers in order to achieve the pathways in each sector?'

This section is structured as follows:

- Eight 'strategic conclusions' or themes have been developed by analysing the main enablers and barriers. Example next steps/potential actions are also included for each strategic conclusion.
- Six key technology groups are discussed, many of which link to the themes above. As described in section 4, a small group of technologies make a significant contribution to decarbonisation in 2050[16]. Example next steps are included to assist with developing, funding and implementing the technologies. A seventh 'other' group covers technologies that are specific to the ceramic sector and/or in the sector's control.

It is intended that government and industry use the roadmap to develop the example actions further in order to achieve decarbonisation while maintaining competitiveness of the sector.

5.1 Key Points

During the development of potential pathways to decarbonisation, the barriers to their implementation and the enablers to promote them were summarised in sections 3.4.5. In combination with other enablers and barriers identified during the study, these were grouped into the following themes to be addressed by the sector, government and other stakeholders:

- Strategic Issues
    - Challenging investment climate
        - Creation of a long-term energy-intensive industry strategy
        - Development of a supportive, stable, long-term policy framework to underpin investments in new equipment and innovation
        - Ease access to funding, grants or allowances to increase the uptake of a range of energy efficiency and decarbonisation technologies within heat intensive sectors
        - Promote level playing field compared with EU and global competitor markets
        - Promote internationally competitive and stable energy and carbon price by mechanisms accessible to all heat-intensive industrial users e.g. actions to extend strategic gas storage to avoid seasonal gas price spikes, support for low cost fuel imports
        - Minimise regulatory change and uncertainty in existing and new regulation (e.g. EU ETS)
        - Ease Local Authority planning approval for industrial renewable energy and low carbon projects
        - Investigate consumption-based emissions reporting
    - Need for low carbon energy supplies
        - Establish an energy strategy that establishes affordable, long-term security of supply
        - Incentivise decarbonised electricity as an economically viable low carbon energy source
        - Clarity on biomass cost, availability, carbon emissions rating and regulatory position
        - Prioritise biomass use for heat production rather than electricity generation

[16] These six technology groups apply to the ceramics sector and also the other seven sector roadmaps.

        - Carbon storage infrastructure

Understand interactions between decarbonisation actions by different sectors (i.e. a lifecycle approach view of emissions that assesses more than the carbon emitted in the production phase).

- Innovation and skills
    - Support RD&D, innovation and early application of a portfolio of new low carbon technologies for heat-using sectors
    - Strengthen skills retention and development in the sector
- Specific sectorial decarbonisation technologies
    - Work to make lower carbon products acceptable to market
    - Undertake key specific sectorial technology developments and apply them

5.2 Strategic Conclusions

5.2.1 Strategy, Leadership and Organisation

In order to take this agenda forward, it is considered critical that the ceramic sector, the government and other stakeholders recognise the importance of strategy and leadership in the context of decarbonisation, energy efficiency and international competitiveness for the sector.

This links to all other conclusions below, including RD&D, technology deployment, energy supply and financing.

A possible action to address this issue is to establish a long-term energy-intensive industry strategy with sector-specific working groups. The UK would benefit from a long-term strategy that recognises the strategic economic benefits of maintaining EIIs within the UK. Given their importance to the UK economy in terms of gross domestic product (GDP) contribution, direct and indirect employment and as drivers for research and innovation, the vision should be to develop and grow the world's most carbon-efficient EIIs. This will require open and on-going dialogue and partnership between government (various departments), industry and other stakeholders, such as technology developers and, or academics, trade unions etc. This EII strategy also needs to be linked to energy policy, environmental policy and other industrial policies (e.g. construction). The ceramic sector working group could bring:

- Leadership and vision to the UK sector, emphasising how ceramic production adds strategic value for the UK and why it is important to face the challenges and develop the opportunities for the sector. This vision could encompass the ambition, drive, passion and creativity required to maximise future opportunities for the sector and in doing so help to continue to spread a positive message and image.
- An approach to the need to drive forward the joint priorities of maintaining competitiveness of the existing ceramic operations (recognising the challenges of operating in the markets within which they reside) and also the need to increase RD&D activity and support technology and product innovation in the sector
- A high-level link between industry, the government and the EU and a clear framework within which production, technology, energy efficiency and decarbonisation agendas can be taken forward. Members of the working group could engage with executives in corporate headquarters (both Original Equipment Manufacturers (OEMs) and ceramic production companies) to address the current lack of activity and engagement between the UK and the international sector community (for example in RD& D).
- A practical means e.g. targeted funding, to take forward the roadmap agenda with shorter-term action plans, for example, in five-year intervals.

This ‘strategy’ conclusion is also applicable to individual companies, which have a key role in overcoming barriers and strengthening enablers – this links to a number of strategic conclusions, for example, management commitment to decarbonisation and energy efficiency, value chain opportunities, and shortage of skilled labour. As none of the companies interviewed has a strategy that looks further than 2025 in terms of carbon-reduction targets, it is important to link longer term conclusions from this project into shorter-term company-level plans.

5.2.2 Business Case Barriers

One of the most important barriers to decarbonisation and energy efficiency, based on the literature, interviews and workshops, is lack of funding for such projects as the ROI is not attractive enough or there is a lack of capital available. While this is not the only barrier to implementation of decarbonisation and energy efficiency projects (others include risk of implementing new technology, lack of skills, lack of management time, lack of certainty of business case), it is an important issue.

Significant improvement in the investment environment is required to permit and drive the necessary surge of investment likely to be required in the sector to deliver changes contributing to decarbonisation from 2025. The following potential actions have been identified to improve the climate for investment in the UK ceramic sector:

- Ease access to funding, grants or allowances to increase the uptake of a range of energy efficiency / decarbonisation technologies within heat intensive sectors
- Investigate working with OEMs/ energy service companies (ESCOs) and their financial support
- Financial innovation – off balance sheet
- Waste heat recovery incentive
- Establish an industrial energy efficiency dedicated fund which incentivises energy efficiency
- Use of third-party funds, for example ethical investment funds

5.2.3 Future Energy Costs, Energy Supply Security, Market Structure and Competition

Low carbon energy supply is critical to the ceramic sector and actions are required to maintain a competitive position for the UK. This strategic conclusion links to a number of external factors that influence the business environment in which the sector operates. These include energy security and energy cost comparison to other regions (both reality and perception), as these factors are important when investment decisions are made. There is a role for government in recognising the importance of and the link between long-term plans on energy security to investment decisions made by companies in the sector. Moreover, the UK energy supply system will influence company decisions to invest in the sector (especially those investments that rely on secure competitive energy supply).

The following potential actions have been identified in relation to this theme:

- Implement an energy strategy that establishes affordable long-term security of supply.
- Establish a means by which decarbonised electricity can be made cost competitive with fossil fuel, e.g. progressively for the existing operations of the sector and more strongly to support large scale conversion of facilities to electric firing no later than 2035 for the 40-60% pathway and 2030 for the Max Tech pathway. Enable the sector to obtain relief from the costs of decarbonising the grid.
- Implement the development of a broad range of low carbon technologies. Key technologies with cross-sectorial applicability include: further waste heat recovery developments, switching to low carbon fuels, electrification of heat, product reformulation and CCS or carbon capture and utilisation (CCU)

technologies for high temperature industries (including the necessary developments and infrastructure for CO_2 transport to storage or reuse to be available for timely application in the ceramic sector).

- Promote internationally competitive and stable energy and carbon by mechanisms accessible to all heat-intensive industrial users, e.g .actions to extend strategic gas storage to avoid seasonal gas price spikes, support for low cost fuel imports.
- Promote level playing field compared with EU and global competitor markets.

5.2.4 Industrial Energy Policy Context

The need for long-term energy and climate change policy is key to investor confidence, according to literature. We identified an increasing cost of carbon as a potential enabler for low carbon investment as it can increase the financial benefits of energy efficiency and/or decarbonisation investment. At the same time regulatory uncertainty has been identified to be a barrier. Investments commensurate with the more ambitious pathways will require long-term commitment to policy support, as changes in policy can be damaging, particularly when the business case for investment is marginal and is highly dependent upon factors such as (fluctuating) energy prices.

Possible actions as next steps to address this conclusion are as follows:

- Development of a supportive, stable, long-term policy framework to underpin investments in new equipment and innovation.
- Minimise regulatory change and uncertainty in existing and new regulation (e.g. EU ETS)
- Ease Local Authority planning approval for industrial renewable energy and low carbon projects.
- Establish clear policy decisions on decarbonisation of the electricity grid to provide cost clarity for industrial consumers.

5.2.5 Life-Cycle Accounting

While manufacturing can account for up to 90% of some ceramic products' carbon footprint, the inherent energy savings during the use phase together with the durability of ceramic products give them long lifespans over which time the environmental impact of the production phase is significantly reduced. Further development of standard tools for evaluating life-cycle 'cradle-to-grave' carbon impacts, from original raw material and feedstock through to final product disposal could be carried out – to enable appropriate value to be put on this type of carbon benefit and therefore easing the investment in decarbonisation.

The interaction between sectors is also significant with the carbon emissions of the ceramic sector being necessary for products contributing to minimising carbon emissions in other sectors (e.g. refractories which are used in other high-temperature processes – glass, cement, ceramics, iron and steels and chemicals manufacture). A proper 'lifecycle' analysis of such activities is necessary to ensure that policies and investments are focussed on the most effective decarbonisation measures overall. The analysis methodology needs to be developed in the short term and its application across the industrial sectors needs to be completed by 2018 to inform investment and policy decisions in a timely manner.

Finally, consumption-based emissions reporting could be investigated and consider how climate policy could benefit from a broader approach which also takes into account embedded emissions in imported products in order to ensure that the UK is not decarbonising by deindustrialising.

5.2.6 Value chain collaboration

The carbon emissions of the ceramic sector are significantly affected by the expectations of consumers, the business needs of builders and other industrial users of ceramic products together with product standards and the requirements of building regulations. Collaboration across the value chain could enable products with lower lifecycle carbon emissions to be developed and adopted.

Promotion of value chain collaboration requires development of a market demand for low carbon products. This can be enhanced by better exchange of information between suppliers and users, regulatory change e.g. in building regulations, to reward the use of long life and lower carbon building products. Education will be needed for the public to recognise and value low carbon products and services.

Support mechanisms for RD&D on lower lifecycle carbon products and processes would accelerate value chain collaboration. Discussion with users and end customers to increase the market accessibility of less carbon intensive products may highlight future opportunities, for example assessing potential benefits of lighter products, lower firing products and products eliminating firing steps. This action needs to commence in the near term and continue as a dialogue to promote and recognise the potential benefits of lower carbon ceramic production over the following decades.

5.2.7 Research, Development and Deployment

The ceramic sector needs to explore and apply new technologies to reduce energy consumption and carbon emissions. The costs and uncertainties of RD&D are challenging and the cost of commercial scale demonstrator facilities needed before new technologies can be deployed often represent too large a risk for an individual company to fund. Collaboration would be a solution but companies are constrained where it might be interpreted as 'collusion' between competitors.

Possible actions within this theme, based on stakeholder engagement and assessment of the technologies in the pathways, include:

- Increased collaboration in order to join up industry needs and academic research areas.
- Industry and government to further develop and support centres of excellence and technology 'catapults'.
- Pre-competitive joint funding of RD&D projects.
- Collaboration and joint action by industry and government on technology demonstration to drive down capital and operating costs and ensure performance is demonstrated before mass adoption.
- Identify areas of possible RD&D collaboration between companies, potentially via existing local industry and new cross-sectorial groups. Key areas for research could include new heat exchanger technologies to permit heat recovery from kiln exhaust gases, the development and application of gasification of biomass to continuous kilns and the design and testing of large capacity continuous electric kilns.
- Incentivise early adoption of new technologies in order to drive down costs and demonstrate performance. Successful technology demonstration would reduce risks and encourage wider deployment.
- Advances in materials development and production technology to enable less energy intensive processes to be employed, e.g. shorter, lower temperature or reduced number of firing steps and additional heat recovery

Further details are provided in the specific technology sections below.

5.2.8 Employees and Skills

The ceramic sector faces significant issues in migrating towards a low carbon future. Innovation in technology and strengthening of skills within the sector will be essential. Potential actions for strengthening of skills retention and development in the sector could include:

- Better sharing of expertise and skills across the sector
- Enhanced training and development of skills in existing staff and new entrants
- Promoting the future economic viability of the sector in the UK

These actions need to be initiated in the near term and sustained throughout the following decades to permit and maintain momentum for development and decarbonisation.

5.3 Key Technology Groups

5.3.1 Electricity Grid Decarbonisation

Decarbonisation of this key source of energy supply could provide a significant contribution to the overall decarbonisation of the sector. Actions will be required to ensure that this takes place while maintaining cost-competitiveness (see also section 5.2.3 above). The Government's reforms of the electricity market are already driving electricity grid decarbonisation, and this report uses assumptions of a future electricity decarbonisation trajectory that is consistent with Government methodology and modelling.

5.3.2 Electrification of Heat

Ceramic sector energy use is dominated by fossil fuels. The pathway analysis has demonstrated that migration to low carbon electricity is an essential option for decarbonisation. The heavy clay subsector has the largest energy consumption and carbon emissions but there are currently no large scale continuous kiln designs available to meet the needs of the subsector. A large scale continuous electric kiln, that provides efficient and cost-competitive electrical heating for large tunnel kilns, would be very different to one designed to be heated by gas combustion and significant development will be required in collaboration with manufacturers to produce and prove a suitable product for widespread application (see also RD&D above).

5.3.3 Fuel and Feedstock Availability (Including Biomass)

As investigated in several of the pathways, substitution of gas derived from biomass gasification for natural gas in kilns is a potential technology for decarbonisation in the ceramic sector.

The availability and cost of biomass is a potential issue for sector decarbonisation, given its importance to the pathways (although the no biomass Max Tech pathway has shown that significant decarbonisation can be achieved without it). This availability issue is critical in view of the long-term investment associated with kiln upgrades. The security of biomass supply is particularly affected by competition between sectors, for example with large scale biomass use for power generation. The challenges are to understand where the greatest decarbonisation potential can be achieved with a limited resource, as well as to maximise the availability of the resource (links to *Life-cycle carbon accounting* above).

5.3.4 Energy Efficiency / Heat Recovery

The pathways demonstrate that the largest early improvements in carbon emissions result from the application of energy efficiency and heat recovery techniques, to both existing and new kilns. The improvement to energy efficiency by a range of measures related to combustion and reduction of heat losses is complemented by the application of increased heat recovery to kiln and drier exhaust streams. New BAT kilns include these features, although improvements in heat recovery technology to handle the challenging application will need further progressive development to maximise its potential on both new and existing kilns.

Specific technical issues that could be addressed by sectorial research, development and application include assessment of improvements in refractory and insulating materials to reduce heat consumption across all heat-intensive sectors.

5.3.5 Clustering

The benefits of clustering for example through integrated industrial manufacturing parks are well known in other industrial sectors. While this type of approach is a possibility in the ceramic sector in theory, it has not been considered in this study due to the current geographic distribution of manufacturing sites in the sector.

5.3.6 Carbon Capture

Individual ceramic sites are not considered to be of a sufficient scale to justify their own CO_2 pipeline and storage infrastructure. Collaboration is necessary to establish the networks, along with the availability of sources of funding appropriate to this type of shared infrastructure. In addition, while even large ceramic sites produce exhaust flows for which proven CC technology exists, there are challenges of low CO_2 concentration and the presence of aggressive acid gases in the exhaust stream that are unprecedented. Work is therefore necessary to develop and demonstrate economic CC technology appropriate to commercial application in the sector at this scale (links to *Research and Development* theme).

5.3.7 Specific Sectorial Decarbonisation Technologies

High temperature transformation of materials is characteristic of ceramic products. However the sequence and details of processing steps for each product can be refined for different purposes – to reduce costs, increase throughput, minimise rejects or reduce energy – and adjustments made to benefit one aspect may adversely affect another. There are therefore a range of improvements to ceramic processes that can be optimised or traded-off to reduce emissions, preferably in conjunction with reduced costs or increased throughput. These include changes to the composition of raw materials to permit lower firing temperatures to be achieved, changes in manufacturing processes to permit the omission of firing steps and adjustments to improve energy utilisation by closer kiln packing. Some of these improvements are inherently highly specific to products and production facilities, while others relate to materials properties that are generic. As a result some of these improvements can only be made at a company level, while others are perhaps best addressed in collaboration; in either case these relate to the *Research and Development* theme above.

5.4 Closing Statement

This roadmap report is intended to provide an evidence-based foundation upon which future policy and actions can be built. The way in which the report has been compiled is designed to ensure it has credibility with industrial, academic and other stakeholders and is recognised by government as a useful contribution when considering future policy. It will be successful if, as a result, the government and the ceramic sector are able to build on the report to deliver significant cuts in carbon emissions, increased energy efficiency and a strong on-going competitive position of the UK ceramic industry in the decades to come.

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7. GLOSSARY

Adoption

The percentage of sector production capacity to which a carbon reduction option has already been applied. Therefore, of the list of options being assessed, this is a measure of the degree to which they have already been deployed in the sector.

Applicability

The percentage of the sector production capacity to which a particular option can be applied. This is a measure of the degree to which a carbon reduction option can be applied to a particular part of the sector production process.

Barrier to Decarbonisation or Energy Efficiency

Barriers are factors that hinder companies from investing in and implementing technologies and initiatives that contribute to decarbonisation

Business as Usual

A combination of carbon abatement options and energy savings that would be expected with the continuation of current rates of deployment of incremental improvement options in the sector up to 2050 without significant intervention or outside support.

Decarbonisation

Reduction of CO_2 emissions (in $MtCO_2$) – relative to the reference trend for that scenario. When we report carbon dioxide – this represents CO_2 equivalent. However, other GHGs were not the focus of the study which centred on both decarbonisation and improving energy efficiency in processes, combustion and indirect emissions from electricity used on site but generated off site. Also, technical options assessed in this work result primarily in CO2 emissions reduction and improved energy efficiency. In general, emissions of other GHGs, relative to those of CO2, are very low.

Carbon reduction band or bins

The percentage ranges of CO_2 reduction achieved for a given pathway in 2050 relative to the base year e.g. 20-40% of the base year emission.

Carbon reduction curve or profile

A quantitative graph which charts the evolution of sector carbon emissions from 2014 to 2050

Competition Law

The UK has three main tasks:

- Prohibiting agreements or practices that restrict free trading and competition between business entities. This includes in particular the repression of cartels.
- Banning abusive behaviour by a firm dominating a market, or anti-competitive practices that tend to lead to such a dominant position. Practices controlled in this way may include predatory pricing, tying, price gouging, refusal to deal and many others.

- Supervising the mergers and acquisitions of large corporations, including some joint ventures. Transactions that are considered to threaten the competitive process can be prohibited altogether, or approved subject to ‘remedies’ such as an obligation to divest part of the merged business or to offer licences or access to facilities to enable other businesses to continue competing.

Deployment

Once the adoption and applicability of an option has been taken into account, each option can be deployed to reduce part of the sector’s CO_2 emissions. Hence, the deployment of the option from 2015 through to 2050 is illustrated in our analysis by the coloured matrix on the pathway presentations.

Enabler for decarbonisation or energy efficiency

Enablers are factors that that make an investment feasible or would either help overcome a barrier.

Grid CO_2 emission factor

A specific scenario assumption relating to the average carbon intensity of grid electricity and projection(s) of how this may evolve to 2050

Maximum Technical Pathway (‘Max Tech’)

A combination of carbon abatement options and energy savings that is both highly ambitious but also reasonably foreseeable. It is designed to investigate what might be technically possible when other barriers are set to one side. Options selected in Max Tech take into account barriers to deployment but are not excluded based on these grounds. Where there is a choice between one option or another, the easier/cheaper option is chosen or two alternative max tech pathways are developed.

Option

A carbon reduction measure, often a technical measure, such as a more efficient process or technology

Option Register

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, asking participants at the information gathering workshop which options they would consider viable, and through engagement with members of the relevant trade associations.

Pathway

A particular selection and deployment of options from 2014 to 2050 chosen to achieve reductions falling into a specific carbon reduction band

Projection of Production Changes

A sector specific scenario assumption which defines the changes in production as an annual percentage change to 2050

Reference trend

the carbon dioxide emission trend that would be followed if the 2012 base year emissions were affected by production change and grid decarbonisation in accordance with the sector specific scenarios

Scenario

A specific set of conditions external to the sector which will affect the growth and costs of production in the sector and affect the timing and impact of options on carbon emissions and energy consumption

Scenario assumptions

A set of specific cost and technical assumptions which characterise each scenario. These include forward fuel and carbon price projections, grid CO_2 factor projection and background economic growth rate. The assumptions may include sector forward production projections.

Sensitivity case

The evaluation of the impact of changes in a single assumption on a pathway e.g. the availability of biomass

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