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

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050

Glass Appendices

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INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – GLASS

APPENDIX A - METHODOLOGY

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

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

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

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

Figure 1 Roadmap methodology

1. Evidence Gathering

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

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

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

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

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

The evidence gathering exercise was subject to inherent limitations based upon the scale of activities and sample sizes that could be conducted within the time and resources available. The literature review was not intended to be exhaustive and aimed to capture key documentation that applied to the UK. The companies interviewed represented over 75% of carbon emissions produced in the UK glass sector and captured UK decision makers and technical specialists in the glass sector. These interviews were conducted to provide greater depth and insight to the issues faced by companies.

The identification of relevant information and data was approached from a global and UK viewpoint. The global outlook examined dominating technologies and process types, global production and CO_2 emissions (in the EU28) and the global outlook to 2050, including the implications for glass producers and consumers, and production and demand uncertainties. The UK outlook examined the sector structure, recent history and context including consumption, demand patterns and emissions, the business environment, organisational and decision-making structures and the impacts of UK policy and regulation. The major UK glass producers and their key sites, dominant technologies and processes were also reviewed.

Options examined were classified into eight categories that represent the principal areas of the glass making process and key cross-cutting areas of potential performance improvement, in order to group similar technology options: raw materials, furnace, improved process control, waste heat recovery, fuel switching, carbon capture, general utilities, recycled glass, and product design.

2. Literature Review

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

The literature review covered over 85 documents. This was not a thorough literature review or Rapid Evidence Assessment (REA) but a desktop research exercise deemed sufficient in its breadth and depth to capture the evidence required for the purpose of this project. Based on the table of contents and a quick assessment (10 to 30 minutes per document), criteria were defined to identify which documents were to be used for the detailed analysis and evidence gathering (see **Error! Reference source not found.** of **Error! Reference source not found.**). Where literature was deemed significant and of good quality, it was read and results were gathered on the principal questions.

The review has drawn on a range of literature (published after 2000, with minor exceptions), that examines energy efficiency and decarbonisation of the sector and also wider reviews, studies and reports deemed relevant to energy-intensive industries overall. Sector-based and academic literature was also added. The documents are listed in section 6 of the main report.

The literature review was conducted in the following phases:

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

	Details
Main focus (all in the glass sector)	Energy efficiency improvements CO_2 and carbon reduction Fuel switching
Secondary focus	Drivers, barriers, policy Carbon capture utilisation and storage (CCUS)
Excluded	Carbon offsetting Energy / CO_2 emissions reduction resulting from use of advanced glass products (e.g. energy efficient double glazing) Non-CO_2 emissions Technologies not applicable to the UK glass manufacturing sector Product switching (from glass to other materials)

Table 1: Scope of review

3. Criteria for including literature

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

	Considerations	Final criteria
Literature value	Preference was given to official publications, such as academic papers or governmental publications. Information from furnace constructors or suppliers (grey literature) was interesting as sector-related info. However, as there is no objective standard with which to compare this information, no extensive search in this domain was executed. The grey literature was used as input to the workshops.	Preference was given to published papers: the main source was ScienceDirect and published official reports.
Time period to be covered	Given the fact that the European Energy Directive (end 2012) is a recent factor in the energy-related political landscape, preference was given to information which was (very) recently published. Some valuable, but older, information was included, as technology penetration is conducted at different speeds throughout the glass sector	No constraint was set on the date of the publication, but older information was given a lower quality rating, due to its lower relevance.
Geographical area	Preference was given to the UK industry, with a broader look to Europe, as the technology competition in this area is the most prominent.	No geographical exclusion criteria were used, but information on the UK glass sector was given a higher quality rating, due to its higher relevance.
sector specifics	Given the specific nature of the UK glass sector, some technologies could be discarded, as there are no plants using them.	Container and flat glass manufacturing were included both qualitatively and quantitatively. Fibre glass was only included qualitatively.
Language	As the majority of information is in English, no special attention was given to publications in other languages.	The search was limited to papers in English, but where easily obtainable qualitative information was found in other languages, this was included[1].

Table 2: High level selection criteria

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

A total of more than 85 papers, official publications and grey literature on glass were collected using this search methodology. The quality, source and objectivity of each document was analysed by reading the abstract (where present), followed by a skim-read of the document.

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

- Category: is the content of the document focusing on technology, drivers/barriers or policy-related aspects;
- Affiliation: what is the source of the document: academia, governance or is it sector-based;

[1] Some valuable references are in Dutch.

- Financial-technical evaluation criteria present (YES/NO);
- Overall quality of the document (+/++/+++);
- Relevance for the UK glass sector (0/+/++/+++);
- Information on technological aspects (0/+/++/+++);
- Information on drivers and barriers: (0/+/++/+++);
- Information on policy/legislation: (0/+/++/+++); and
- Document relevant for developing scenarios: (0/+/++/+++).

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

The approach to selecting and categorising literature is depicted in Figure 2.

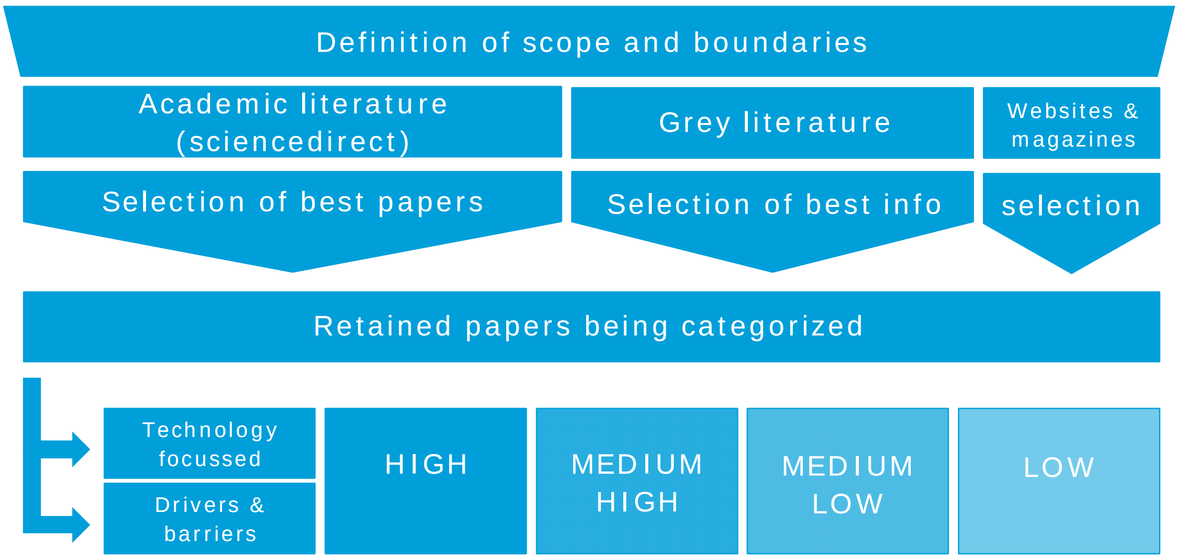

Figure 2: Diagram of the selecting and categorising process

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

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

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

Method of analysing literature

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

1. Reading and noting of the abstract (or summary) followed by review of the document in detail to extract any relevant information on sector description/outlook and information/data on energy savings and decarbonisation measures;

2. Relevant information (if appropriate) was extracted from other sources (or referred to) and document citation trails (if appropriate) were checked for further relevant information/data;
3. Incorporation of the documents into the literature review and collating of the most relevant information/data on energy saving and decarbonisation measures;
4. Energy savings, where possible, were preferably extracted as a percentage, or as a specific energy saving per relevant unit; and
5. For financial savings, the amounts were kept in their original currency.

4. Technical Literature Review

Identifying literature

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

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

Research questions

The evidence review addressed the following research questions:

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

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

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

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

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

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

Information found by the consortium during technical literature review

A number of additional documents were identified during the course of the literature review. These documents were identified through Google / ScienceDirect[2] and through the glass sector team. The search terms used in ScienceDirect and Google were:

- “Glass”
- “Container glass”
- “Flat glass”
- “Glass manufacturing”

[2] http://www.sciencedirect.com/

- “Glass manufacturing” AND “abatement”
- “Glass manufacturing” AND “carbon capture / CCS”
- “Glass manufacturing” AND “driver(s)/barrier(s)”
- “Glass manufacturing” AND “economics”
- “Glass manufacturing” AND “emissions”
- “Glass manufacturing” AND “energy (savings)”
- “Glass manufacturing” AND “energy case study”
- “Glass manufacturing” AND “energy/energy consumption”
- “Glass manufacturing” AND “low-carbon/decarbonisation/carbon”
- “Glass manufacturing” AND “policy/politics”
- “Glass manufacturing” AND “recycle/recycling/cullet”
- “Glass manufacturing” AND “roadmap(s)”
- “Glass manufacturing” AND “scenario(s)”
- “Glass manufacturing” AND “UK”

Other documents in ScienceDirect were found by checking the references of the papers found by the above searches.

The results of the technical literature review are summarised in Figure 3.

Summary of strength of evidence on energy efficiency in glass sector

Division	Number of information sources reviewed					Strength of the evidence			
	Academic searches	Direct website searches	Expert reviewer additions	Grey literature	Total	HIGH	MEDIUM HIGH	MEDIUM LOW	LOW
General	1	6	4	0	11	7	2	1	1
Technologies	11	6	15	6	38	13	13	10	2
CO2 & CCS	2	1	1	0	4	2	0	2	0
Social and Business	4	5	3	11	23	9	4	4	6

Figure 3: Overview of literature review

A complete reference list is available in **Error! Reference source not found.** 6

5. Social and Business Literature Review

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

- We reviewed over 54 documents to create a broad overview of the sector SWOT and identification of drivers and barriers to energy efficiency improvement and decarbonisation, and identification of main uncertainties in generic and business environment;
- Literature reviewed: included documents listed in the ITT as well as grey literature from Trade associations, companies, DECC and BIS. Specific search terms were used which were agreed with DECC to identify the key enablers and barriers;
- We used a systematic and structured approach to the literature review. The criteria for assessing the relevance of the literature were defined to determine whether they address the key principal questions. The literature identified was analysed using a quick assessment process to identify the most relevant information on SWOT, enablers and barriers to decarbonisation; and
- Based on table of contents and a quick assessment we presented the results in a table as below. The analysis resulted in identification of documents to be used for detailed analysis and evidence gathering. Where literature was deemed significant and of good quality (three stars or above), the literature was read and reviewed and results were gathered on the principal question areas.

	Year	Relevance	Quality	Characteristics	SWOT, Drivers and Barriers	Uncertainties future trends	Options	Pathways
Title 1		+++	++	0	++++	++	0	++++
...		++	+++	++	0	+++	+	+
...		+	++	+	0	++++	++	0
Title 10		++	++++	+++	++	+++	+++	++

Table 3: Literature review assessment process

(0= very low, ++++ very high)

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

6. Interviews

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

The ten UK glass manufacturing companies are divided into three subsectors: container (six), flat (three), and continuous filament fibre (one). Although the sector is not homogeneous, the different subsectors have similar manufacturing equipment and are facing the same type of challenges. It was agreed to undertake eight interviews for the glass sector. We identified the proposed interviewees in liaison with British Glass, DECC and BIS, meeting the criteria defined in the methodology.

Eight face-to-face interviews were completed and the following organisations / companies were interviewed:

- British Glass - Technical Director and Chairman of British Glass Energy and Environment Committee and CEO;
- Ardagh Glass - Group Environment and Sustainability Manager (container glass);
- OI - Environment and Risk Manager Europe (container glass);
- PPG - Managing Director (fibre glass);
- Saint Gobain glass - Managing Director (flat glass); and
- Pilkington - Head of Engineering (flat glass).

The manufacturing companies interviewed together represent around 75% of the sector emissions.

Comments collated via British Glass, the workshop and subsequent email correspondence was also used as part of the evidence gathering process.

Interviewees were interviewed using the 'interview protocol' template, developed in liaison with DECC and BIS. The interview protocol was used to ensure consistency across interviews, to ensure that the interviews could be used to fill gaps in the literature review, identify key success stories of decarbonisation, and extract the key social and business barriers of moving to low-carbon technologies. The 'interview protocol' can be found further in this section.

Assumptions

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

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

Interview Template

We identified the proposed interviewees in liaison with British Glass, DECC and BIS in order to give a good coverage of the sector. The methodology of identifying the appropriate number of interviews was the following:

- Identify the number of subsectors by the SIC codes listed in the ITT or another appropriate subsector division;
- Look at ways to combine subsectors based on similarities in products or production techniques to potentially reduce the number of subsectors; and

- Cross validate the subsectors according to the following criteria:
    - Size: medium or large – there are no SMEs in the group of companies that covers 90% of the emissions in the sectors where we are not performing a survey;
    - Innovation level of companies such as front runners or laggards;
    - Whether headquarters is in UK or abroad; and
    - The level of integration of the production units in the supply chain (non-integrated, somewhat integrated, fully integrated).

Interview Protocol

Preparation

1. Interviewee identification

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

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

***2.* Interview preparation**

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

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

3. Interview format

Introductions

Interviewer sets out the project context and interview agenda.

Goals

Interviewer introduces the goals of the project as follows:

1. To determine the current state, ambitions or plans, successes and problems or challenges of each of the interviewee's organisation or sector with regard to energy use, energy reduction and decarbonisation:
    a. Identify and analyse examples of the implementation of energy efficiency and decarbonisation projects to deliver insight in the problems and barriers at a company level
    b. Develop an understanding of the decision-making processes
    c. Develop an understanding of the relationship between energy/carbon strategy and business strategy
2. To develop insight into the energy efficiency and decarbonisation options available to the organisations or sector and their potential:
    a. As currently deployed by organisations
    b. As an option to be deployed in the future
3. Understanding of the main drivers and barriers for change in general and with regard to energy efficiency and decarbonisation in the sector
4. To develop insight into the specific characteristics (strengths, weaknesses, opportunities and threats) of subsectors (where required)

Existing and future strategy for energy efficiency and decarbonisation

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

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

    Guidance for interviewer: use the prepared options register (prepared by technical lead and sector team) to identify energy efficiency and decarbonisation reduction options. For parts of the list that are not covered, challenge the interviewee to identify options that could be valuable. With front runners place emphasise on more innovative options.

4. How important is energy efficiency and decarbonisation for your organisation? Please address how the carbon and energy strategy fits into wider business strategy and the extent to which it is embedded.

Stories (interviewees not self-identified as leaders)

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

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

Interviewer to lead discussion of a story or example related to an energy efficiency and decarbonisation project using the questions below:

1. What energy efficiency and decarbonisation options have been implemented, why, when and where?
2. Can you tell the story of a project from the initial idea generation until now? Ensure this covers how ideas were generated (i.e. the step before any appraisal of options takes place):
    a What was the timeline, sequence of events?
    b Cover: idea generation, feasibility study (technological, financial, and organisation), decision-making, board presentation, and implementation
    c What was your process for making a case for an investment and who was involved? Consider: key factors during decision-making, required payback, main perceived or actual risks, influence of alternative options for investment, financial and non-financial factors
    d What were the critical moments (breakthroughs, barriers)?
3. What was the original position of the main stakeholders to the energy carbon project? Did their attitudes towards the subject change? How?
4. Why do you consider this story as a success or an area for improvement?
5. What are the main conclusions you can draw from this story - positive and negative?
    a Lessons for future action?
    b Main drivers and barriers for energy efficiency and decarbonisation in your company?
    c Lessons for the way of organising energy efficiency and decarbonisation options within you company?
    d Conclusions regarding potential reduction targets on short-, medium- and long-term?
    e How well did the decarboniation option work in practice, in relation to the anticipated performance?
6. Can any reports or presentations on this innovation be supplied?

Business Environment: value chain and capacity for innovation

Interviewer to ask the following questions:

1. What do you consider to be the main drivers for energy efficiency and decarbonisation in the sector?
    a What are main characteristics of the main parts of the production process? Following the structure of the options register:
        i) Ask specific questions on any elements not covered in the desk research
        ii) Ask specific questions on the characteristics of the subsector (input, process, output, energy use, value chain, competitive forces)
    b What do you perceive as the strengths and weaknesses of your value chain?
    c What have been the main changes in the value chain over the last ten years?
    d What innovations do you expect to see in the value chain in the coming 10/20/30 years?
    e What are possible game changers for the value chain/ or sector?
2. Main innovators or early adopters in the sector:
    a Who influences action (whom or what are they listening to? Why?
        i) Organisations and people within organisations (role or function)?
        ii) Within or outside the sector (other sectors, academics, non-government organisations, politicians, etc.)?

3. Questions on the dimensions of innovations3 . These questions will be on a multiple choice list (answer categories strongly disagree, disagree, neither agree or not agree, agree, strongly agree4). After filling the list, ask for clarifications and examples that underpin answers in the following areas:
   a Technical: networks with other companies, academics, knowledge of competitive and emerging technologies, participation in R&D, pilots, experiments
   b Human capital: improvement projects, multi-disciplinary teams, training on innovation/change/improvement
   c Organisation: horizontal communication lines, clear goals or responsibilities, customer focus
   d Management: clear performance criteria for projects, structural follow up of main improvement projects in management meeting, clear status information on projects
4. (Optional) Please set out a characteristic story of a (successful) sector and subsector that implemented a change/innovation related to energy efficiency and decarbonisation. This question should be asked if consortia or sector teams feel a need to get a better overview of success stories. The question is relevant because in most business environments managers are influenced most by their peers.

Enablers and barriers for sector change

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

1. What do you consider the main drivers for change in the sector?
   a Please state specific drivers in the following fields: social, policy, technical regulatory factors
   b Interviewer to review the pre-prepared list of main driver and check seek further detail from the interviewee
2. What do you consider the main barriers for change in the sector?
   a Please state specific barriers in the following fields: social, policy, technical regulatory factors
   b Interviewer to review the pre-prepared list of main barriers and seek further detail from the interviewee

[3] Questions are asked to get a better (and broad overview of space or possibilities for change (not only including investments but also the change that potential of option will materialise.
[4] This way of working is chosen to be able to just cover the field quickly and get a quick first idea what they consider the important aspects so we can spend as much time as possible on this. We normally don't use the survey results to collect quantitative answers to these.

Function of Interview Template and Protocol:

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

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

Table 4: General interview timeline

7. Surveys

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

The survey was distributed to general managers and energy/environment managers from member organisations of the BG. The questions in the survey were tailored to glass manufacturers, and were developed in consultation with the BG and DECC. These aimed to:

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

Survey questions:
1. What subsector are you working in or what is your relation to the chemical industry?
2. What is the number of employees within your organisation?
3. What is your function within your organisation?
4. How would you describe your company's position in the sector regarding carbon and energy reduction? Please see the definitions below for reference.
5. What impact do the following enablers have in relation to implementing energy efficiency and decarbonisation technologies in your organisation? (A list of 15 enablers identified from the literature review was provided for assessment).
6. Are there any additional enablers that you think are relevant? Please provide details of these and an impact score based on the same scale.
7. What impact do the following barriers have in relation to energy efficiency and decarbonisation technologies in your organisation? (A list of 15 barriers identified from the literature review and interviews was provided for assessment).
8. Are there any additional barriers that you think are relevant? Please provide details of these and an impact score based on the same scale.
9. Please assess to what degree each statement is true for your organisation. • We have well defined goals/objectives and/or targets on energy efficiency and decarbonisation; • Our goals/objectives are translated to targets at site level; • We have a systematic decision-making process for new initiatives with regards to energy efficiency and decarbonisation; • Our decision-making process works well for new energy efficiency and decarbonisation initiatives; • We track progress of energy/carbon improvement projects in management meetings; • We have specific roles or allocated responsibilities within the company with regards to energy efficiency and decarbonisation; • We have strong communication and information sharing channels that support the successful implementation of options with regards to energy efficiency and decarbonisation; • We understand which energy efficiency and decarbonisation technologies can be implemented in our organisation; and • We have sufficiently skilled workforce to implement and handle energy efficiency and decarbonisation technologies.

Table 5: Survey questions

For questions five, six, seven and eight, respondents were given the following impact scale for assessing each enabler and barrier: (-1) negative update, (0) no impact (1) no-to-low impact, (2) low-to-medium impact, (3) medium-to-high impact, and (4) very high impact.

Out of the invited participants, 16 responses were received across the various subsectors.

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

8. Evidence Gathering Workshop

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

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

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

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

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

9. Pathways

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

- 20-40% CO_2 reduction pathway
- 40-60% CO_2 reduction pathway
- 60-80% CO_2 reduction pathway

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

10. Pathways Development and Analysis

Overview

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

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

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

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

Process

1. The gathered evidence (from literature review, sector Team discussions, stakeholder feedback and judgement) was consolidated into a condensed list of options;
2. Timing and readiness of options was developed by the sector Team and during the first workshop, based on evidence from literature, sector knowledge and technical expertise;
3. BAU and Max Tech options were chosen and deployed to the maximum level and rate allowable under the current rends scenario;
4. Options were added to the BAU pathway or reduced or taken out of the Max Tech pathway until each intermediary pathway band was reached;
5. Technical constraints and interactions across the list of options were taken into account when selecting options and deployment;
6. The deployment was adjusted to account for the output of the social and business research as well as current investment cycles;
7. pathways were modelled under the current rends scenario, accounting for changes in production and the carbon emissions of the electricity grid;
8. The results were reviewed and modifications made to the deployment, applicability and reduction potential for any options that appeared to be giving an unexpected or unusual result;
9. Further changes to option choices were made as required through iterations of points 4-8;
10. Revised pathways under current trends were produced for presentation at the second workshop;
11. Feedback on pathways was used to make any further necessary adjustments to the pathways under current rends;

12. The final pathways developed under current trends were used as a basis for the development of pathways under challenging world and collaborative growth scenarios;
13. Deployment of each option under challenging world and collaborative growth was adjusted according to the constraints of each scenario, including the removal of options that would not be likely under challenging world and the deployment of additional options that would become feasible under collaborative growth; and
14. Deployment for each option was adjusted within the technical and scenario constraints in order to reach each pathway band where possible. Note that not all pathway bands are possible under some scenarios.

The options, their constraints and potential interactions are listed in appendix C.

Deployment of Options

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

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

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

Option Interaction

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

- **One option excludes another:** This is taken into account by the user in the deployment inputs in the option selector by ensuring that no exclusive options are deployed to a conflicting level in the same time period. For example, 'electric melting' and 'fuel switching -gas' are options that are mutually exclusive. It can therefore be seen that as 'electric melting' deploys to 75%, 'fuel switching -gas' cannot exceed 25% accordingly;
- **One option depends upon another being adopted:** This is taken into account by the user in the deployment section of the option selector by ensuring that if any option requires a precursor that this precursor is deployed to the appropriate level;
- **Options are independent and act in parallel:** The 'minimum interaction' pathway curve assumes that all options are independent and their effect on energy or emissions are therefore incremental; and
- **Options improve a common energy or emission stream and act in series:** The 'maximum interaction' pathway curve assumes that the saving from each option reduces the remaining energy or emissions for downstream options to act upon.

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

Evidence Not Used in Pathways Modelling

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

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

The adoption rates and applicability rates were used to inform deployment, but without a full bottom-up model implemented on a site-by-site basis, it was difficult to link these parameters directly to investment cycles. The turnaround period of glass furnaces (15 - 20 years) means that only one or two opportunities exist for major option deployment on each furnace. However, with a relatively large number of glass furnaces in the UK, it could be assumed that technologies could be deployed essentially continuously through time, unlike in sectors with a very small number of facilities where deployment can only be made at discrete points in time where individual sites reach turnaround or shutdown dates.

11. Pathways Modelling

Scenarios

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

For each pathway, the following three scenarios were tested: current trends, challenging world and collaborative growth. Scenario parameters are shown in

	challenging world	**current trends**	
International consensus	National self-interest	Modest	C
International economic context	More limited growth, some unstable markets, weakening of international trade in commodities	Slow growth in EU, stronger in world, relatively stable markets	S s
Resource availability and prices	Strong competition, High Volatility High price trends.	Competitive pressure on resources. Some volatile prices Central price trends.	C v C
International agreements on climate change	No new agreements. Compliance with some agreements delayed	Slow progress on new agreements on emission reductions, all existing agreements adhered to.	S e a

	challenging world	current trends
General Technical Innovation	Slow innovation and limited application	Modest innovation, incidental breakthroughs
Attitude of end consumers to sustainability and energy efficiency	Consumer interest in green products only if price competitive. Limited interest in energy efficiency.	Limited consumer demand for green products, efficiency efforts limited to economically viable improvements
Collaboration between sectors and organisations	Minimal joint effort, opportunistic, defensive	Only incidental, opportunistic, short term cooperation
Demographics (world outlook)	Declining slowly in the west Higher growth elsewhere	Declining slowly in the west Modest growth elsewhere
World energy demand and supply outlook	Significant growth in demand with strong competition for resources. High dependence on imported fossil fuels	Balanced but demand growth dependent on supplies of fossil fuels from new fields.
UK Economic outlook	Weaker OBR growth assumption.	Current OBR growth assumption
Carbon intensity of electricity	Weakest trend of electricity carbon intensity reduction 200g/kWh at 2030	Stronger trend of electricity carbon intensity reduction 100g/kWh at 2030
CCS availability	Technology develops slowly, only becoming established by 2040	Technology does not become established until 2030
Low carbon process technology	New technology viability delayed by ten years	New technology economically viable as expected

*Table **6*** below.

Current Trends

The current rends scenario projected moderate UK and global growth. Alongside this, international policies on climate change were assumed to develop, gradually but effectively driving down emissions.

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

Container glass production was assumed to stay constant during the entire period from 2015 to 2050; bur for flat glass an increase in production was estimated. As the UK is coming out of the economic recession, the construction industry is growing, which will result in an increased flat glass production to keep up with this growth. It was assumed that the UK flat glass production will therefore increase by 3.7% annually until 2020 and then stabilise.

Challenging World

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

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

Container glass production was subject to more intense competition from both imports and non-glass alternatives and was assumed to decline by 0.5% annually during the entire period from 2015 to 2050, and flat glass production to decline by 1% annually in that same period due to reduced demand from the construction sector coupled with more intense competition from imports.

Collaborative Growth

The collaborative growth scenario was represented by higher levels of global growth and concerted action to reduce carbon emissions.

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

Container glass production was assumed to increase by 1% annually during the entire period from 2015 to 2050 due to market growth coupled with increasing awareness of the environmental benefits of glass over non-glass alternatives, and flat glass production to increase by 3.7% annually from 2015 to 2020 and by 1% annually for the rest of the period due to increased demand from the construction sector and stronger focus on higher-performance glazing.

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

	challenging world	current trends	collaborative growth
World energy demand and supply outlook	Significant growth in demand with strong competition for resources. High dependence on imported fossil fuels	Balanced but demand growth dependent on supplies of fossil fuels from new fields.	Growing demands balanced by strong growth in supply of renewable energy, slowly declining importance of fossil fuels.
UK Economic outlook	Weaker OBR growth assumption.	Current OBR growth assumption	High OBR growth assumptions
Carbon intensity of electricity	Weakest trend of electricity carbon intensity reduction 200g/kWh at 2030	Stronger trend of electricity carbon intensity reduction 100g/kWh at 2030	Rapid decline in electricity carbon intensity 50g/kWh at 2030
CCS availability	Technology develops slowly, only becoming established by 2040	Technology does not become established until 2030	Technology becomes proven and economic by 2020
Low carbon process technology	New technology viability delayed by ten years	New technology economically viable as expected	New technology viability achieved early

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

12. Options

Classification and Readiness of Options

The options were divided into eight groups representing the principal areas of the glass making process and key cross-cutting areas of potential performance improvement (in order to group similar technology options):

- **Raw materials**: batch pelletisation, batch reformulation, and increased use of recycled glass (cullet);
- **Furnace**: conventional improved furnace construction (end-fired furnace, regenerative furnace, recuperative furnace, increased furnace size, improved furnace insulation, sealed furnace), innovative improved furnace construction (sub-merged combustion melting, hot-oxy glass, SORG LoNOx, Heye melter, Vortec pre-heater and pre-melter, plasma melting, segmented or tailored modular melting, high-speed convection, speed up melting process, and advanced glass melter), and oxy-fuel combustion;
- **Improved process control**: infrared analysis in forehearth, adaptive process controller (APC), continuous gob monitoring system (CGMS), and intelligent glass melting concept (IGMC);
- **Waste heat recovery**: electricity from waste heat, raw materials pre-heating, CHP, waste heat boiler, thermo-chemical recuperator (TCR), organic rankine cycle (ORC) system, and thermo-photovoltaic (TPV);
- **Fuel switching**: fuel switch to electricity (electric melting and electrification or boosting), fuel switching to gas or hydrogen, and renewables generation;
- **Carbon capture**: carbon capture and storage (CCS), carbon capture and utilisation (CCU), and biological carbon capture (BCC) ;
- **General utilities**: overall energy management, compressed air, electric motors and VSD/ASD, heat and steam distribution, and lighting; and
- **Product design**: light-weight containers, energy efficient flat glass, and light-weight flat glass.

Options Processing

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

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

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

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

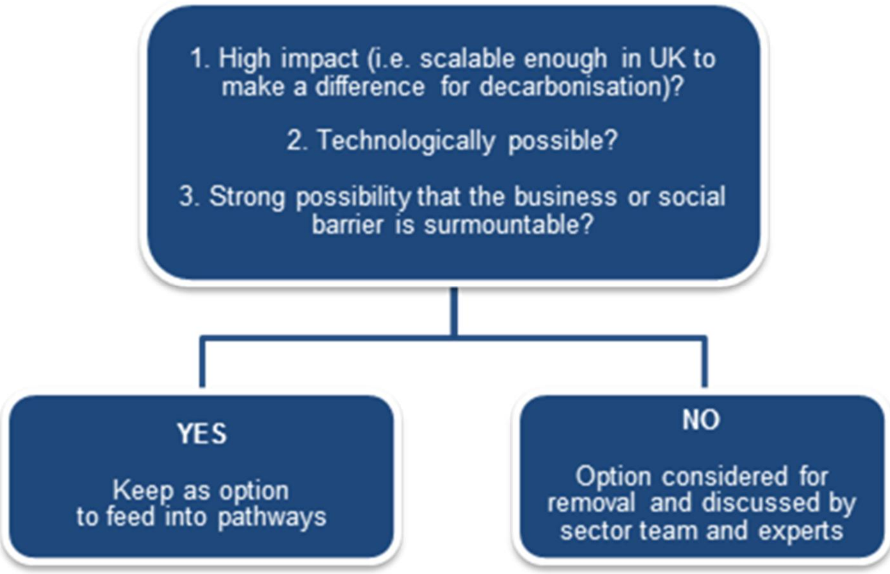

Figure 4: Social and Business pathways impact tree

13. Pathway and Action Plan Workshop

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

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

14. Next Steps

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

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

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

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

- Actions from other glass decarbonisation projects;
- Necessary changes in future markets, product features, business environment to enable the different pathways;
- The outputs of workshops held as part of this project covering decarbonisation pathways and next steps;
- Actions that help maximise the success of a pathway under a range of scenarios;

- Options within the pathways that are necessary for success, e.g. if a particular technology option is necessary for the success of a number of pathways, or an option has a very high decarbonisation potential, actions to implement this option are included; and
- Policy and regulations that could contribute to the removal of barriers and/or enhancement of enablers.

APPENDIX B – FULL SOCIAL AND BUSINESS FINDINGS

APPENDIX B FULL SOCIAL AND BUSINESS FINDINGS

1. SWOT Outcomes

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

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
UK mature and stable market	Glass making is a capital-intensive industry	Bottle light weighting/ UK customer demand for lightweight bottles is high	Competition from alternative packaging materials and from international competitors
Glass sector is highly innovative	Glass company funds are very limited for researching improvements in mature glass processing technology	Opportunity to improve glass recycling in the UK for sorting by glass, colour and quality	High price of energy
Raw materials used to make glass are abundant in nature	Recycling systems are helpful, but sorting processes are not as good as they could be	Collaboration to develop demonstration projects	Uneven playing field/ carbon leakage
Glass is endlessly recyclable	Technology lock-in	Scope for European innovation is large	Regulatory uncertainty
Glass contributes to an efficient and sustainable supply chain	Energy intensive	If additional alternative financing mechanisms were available more advanced technologies with longer paybacks (5-8 years) would be implemented	Lack of alternative financing available threatens the ability of glass sector to deploy technologies with longer payback times

Table: 7 SWOT Analysis

A **SWOT analysis** is a different lens to examine the enablers and barriers and reinforce conclusions and linkages between evidence sources. It identifies how internal strengths mitigate external threats and can be used to create new opportunities, and how new opportunities can help overcome weaknesses. By clustering the various possibilities, we identified key stories from the SWOT analysis which enabled us to describe the business and market story in which companies operate. In order to understand the inter-linkages between the SWOT analysis for the sector and the key enablers and barriers we identified from the literature review, interviews, and workshop, we analysed the root causes of the enablers and barriers and linked it back to the market environment and internal decision-making. The top SWOT outcomes were identified from the literature review, reinforced in the interviews and voted on by workshop participants as the most important.

Other social and business research methods used include system analysis, root cause analysis, causal mapping, Porter's Five Forces analysis, and storytelling. **System analysis** can be used to help decision makers identify a better course of actions and make better decisions. It is a process of studying a procedure or business in order to identify goals and purposes, and to create systems and procedures that will achieve those goals most efficiently. It uses an experimental approach to understand the behaviour of an economy, market or other complex phenomenon. **Root cause analysis** is a method of problem solving that tries to identify the root causes of a problem. A root cause is a cause that - once removed from the problem - prevents the final undesirable event from recurring. **Causal mapping** is a visual representation, showing causalities or influences as links between different nodes. These maps can be used to aid strategic planning and thinking. **Porter's Five Forces** is a framework to analyse the level of competition within an industry and business strategy development. **Storytelling** is a technique that uses a clear and compelling narrative to convey a message or provide context to a conversation with the aim to engage the interviewee and encourage openness.

2. Market Structure

Subsector	Industry Definition	Market share of major companies	Key external drivers
Container glass manufacturing	Firms in this industry manufacture hollow or container glass products by melting silica sand or cullet and fabricating it into finished products. These can include drinking glasses, and glass bottles and jars used to package beverages and foodstuffs.	1. O-I Manufacturing UK Ltd 11.5% 2. Quinn glass Ltd 26.8% 3. Ardagh glass Ltd 36.1% 4. Allied glass Containers Ltd 12.4% 5. Stölzle Flaconnage Ltd 8.1%	• Demand from beer production • Demand from fruit and vegetable processing • Demand from plastic packing goods manufacturing • Demand from spirit production • Real private consumption expenditure • Demand from perfume and cosmetics manufacturing
Flat glass manufacturing	Firms in this industry manufacture flat glass. The majority of this is float glass, but some is rolled glass. Small amounts are drawn and blown flat glass. The industry includes the manufacture of wired, coloured and tinted glass.	1. Guardian Industries UK Ltd. 22.4%, 2. Saint Gobain glass UK 23.4% 3. Pilkington Group 49.2%	• Demand from commercial building construction • Demand from residential building construction • Demand from motor vehicle manufacturing • Demand from building project development
Continuous filament fibre glass manufacturing	Firms in the industry manufacture fibre glass. Fibre glass is a fibre reinforced polymer made of plastic reinforced by glass fibres. The industry includes the manufacture of mat and multi-end roving which can be used in applications such as weaving, knitting, filament winding, and pultrusion. End-use applications include aircraft, boats, automotive, wind turbine blades, bath tubs and enclosures and other applications.	There is only 1 fibre glass company in the UK: PPG Industries representing 100% of UK production.	• Demand from building insulation • Demand from bathroom and kitchen manufacturers • Demand from wind turbine manufacturers • Demand from construction and building manufacturers

Table 8: Market structure description for glass sector

Subsector	Revenue (£M)	Profit (£M)	Wages (£M)	Annual Growth	Imports/ Demand (%)	Exports/ Revenue (%)	Revenue/ Employee (£"000)	Wages/ Revenue (%)	Employees/ establishment (nr.)	Average wage (£"000)	Share of economy (%)	Number of establishments
Container	853.4	70	179.7	0.2% (09-14) 0.6% (14-19)	31	11	187.56	21.06	85.85	39,494.51	0.02	53
Flat	316.0	22.1	58	1.1% (09-14) 3.7% (14-19)	81	25.63	291.24	18.35	120.56	53,456.22	0.01	9

Table 9: Market structure – subsector data within the glass sector

3. Assessing Enablers and Barriers

The first stage in our analysis was to assess the strength of the evidence for the identification of the enablers and barriers. This was based on the source and strength of evidence and whether the findings were validated via more than one information source. If the strength of the evidence was deemed high or medium high, then for the social and business research the enabler and/or barrier was included and information was used to support the answer to the principal question '*What are the main business enablers and barriers to decarbonisation?'*. If the strength of the evidence was deemed high or medium high for the technical options, the uncertainties in the modelling were reduced. The evidence was given a relevance classification of: 'high', 'medium high', 'medium low' or 'low'. The classifications are defined in Table 10 below.

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

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

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

Table 10: Evidence classification definition

The following tables provide a summary of raw data collected relating to enablers and barriers.

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

4. Detailed Analysis of Enablers and Barriers

Enablers

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
1	Financial/ Technology	Technological and financial feasibility- if technology is proven and financially viable (less than 2 year payback) it is more likely to be deployed.	**2 Literature Sources** Energetics 2002 found that: "The industry's top need is a cost-effective technology for sorting and separating postconsumer glass." Venmans 2014 found that: "Barriers for investing in energy efficiency and rank: We are waiting to see if the application of the technology but other companies/plants turned (turns) out to be reliable and profitable) 11."	**5 Interviews** Interviewee: "Technology advancement in energy delivery to melt raw materials." Interviewee: "Technology availability – what are the new technologies?" Interviewee: "Quality of technology suppliers to deliver a fully commissioned solution with warranty as opposed to having to implementing it yourself." Interviewee: "Economically viable- low margin business, have to make a lot of bottles to earn our way. Our customers are	52.9% (9) – very high 23.5% (4) – medium-to-high impact 17.6% (3) – low-to-medium impact 0% (0) – no-to-low impact 5.9% (1) – no impact 0% (0) –negative impact 0% (0) - I don't know	Workshop participants indicated that it was difficult to determine when something is proven and viable. Often it is enough for one plant to have demonstrated the technology prior to it being implemented it is best to be the first follower. However, there is a lack of awareness regarding what financing is out there and lack of people available to look at this.	Across the information sources it was clear that technologies that have been successfully trailed previously and with payback periods under 2 years would more likely be implemented over others. This is mainly due to the fact that glass furnaces operate continuously and thus the risk appetite for investing in an unproven technology that could impede production, especially amongst smaller firms who have limited number of furnaces, is low. However, interviews also indicated that if third parties invested in the upfront costs of a technology with a longer payback the investment would likely go through.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
				also low margin business. Not going to pay extra money for greener bottles. Have to work with technology that is economically viable than existing technology or even better." Interviewee: "Payback within 3 years is a key enabler and low CAPEX requirements."			
2	Infrastructure	Strong recycling infrastructure that produces high quality cullet sorted by colour-enables cullet recycling and reduces carbon.	**1 Literature Source** Energetics 2002 found that: "The industry's top need is a cost-effective technology for sorting and separating postconsumer glass."	**2 Interviews** Interviewee: "The best way to reduce emissions in the short term is to increase close loop recycling." Interviewee: "glass was the first industry to be recycled, bottle banks, and recycling. Very little sorting, only bottles and it was nicely sorted. Now everyone else joins the recycling bandwagon, and	47.1% (8) – very high impact 17.6% (3) – medium-to-high impact 11.8% (2) – low-t-medium impact 5.9% (1) – no-to-medium impact 11.8% (2) – no impact 0% (0) – negative impact 5.9% (1) - I don't know When asked which enablers are missing, one respondent added that clear	A strong recycling infrastructure has a high impact on recycling and decarbonisation.	During the workshop, it was evident that there are differences in the quality requirements amongst the glass subsectors. Fibre glass is currently not recycled, flat glass requires the highest quality cullet followed by container glass. Interviewees and workshop participants highlighted the need to return to the bottle bank system, as current recycling system does not produce high enough quality cullet to meet manufacturing needs, especially for clear glass.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
				now our machine will separate everything out. The machine doesn't recycle glass because it's bulky and low cost. So now we are putting glass in a bad recycling system with organics and combustibles."	glass recycling currently could be a mixture of lead crystal, borosilicate/pyrex or container glass, none of which are suitable for flat glass manufacture.		
3	Market and Economy	High and increasing energy prices- enables investment in energy efficiency technologies.	**2 Literature Sources** British Glass Manufacturers Confederation 2014: "The high cost of energy is a strong incentive for reducing energy use (and hence CO_2)." Venmans 2014 found that: "Enablers for investing in energy efficiency and rank: Economic reasons: Increasing energy prices 1."	**5 Interviews** Interviewee: "We would go out of business in months based on the price of electricity compared to fossil fuels." Interviewee: "Cost of energy/ carbon can be an enabler to an extent (taxation on energy can lead to energy reduction and tax reduction, but may not reduce carbon)." Interviewee: "Cost of energy on this site as a fraction of manufacturing cost – driver to reduce	29.4% (5) – very high impact 17.6% (3) – medium-to-high impact 11.8% (2)- low-to-medium impact 11.8% (2) – no-to-low impact 0% (0)- no impact 29.4 .% (5) – negative impact 0% (0) - I don't know	Workshop participants indicated that have more stable energy prices would help planning for the future easier. Participants highlighted that the price of electricity was higher than that of gas which was a barrier to switching to electric furnaces. Participants also mentioned that the Renewables Obligation is affecting the price difference between electricity and gas.	The survey results and interviews indicated that although high and increasing energy prices can act as an enabler, currently the majority of respondents thought it was a barrier. When asked which enablers are missing from the list reduced cost of electricity was listed. Across the information sources, it was highlighted that high energy costs can act as an enabler, but over a certain threshold the cost becomes too high and can act as a barrier.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
				costs."			
4	Operational	Increase lifespan of equipment-investing in furnace energy efficiency technologies.	-	**2 Interviews** Interviewee: "Furnace energy efficiency is a key enabler." Interviewee: "Asset life if Energy reduction-If you use less energy in the furnace, it wears out at a lower rate, so you can use your asset more effectively. It can extend the lifetime of the plant." * Although only two have direct quotes, the basis of discussion for the majority of interviews was the replacement of old equipment.	11.8% (2) – very high impact 35.3% (6) – medium-to-high impact 5.9% (1) – low-to-medium impact 35.3% (6) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 5.9% (1) - I don't know	Equipment that lasts longer justifies larger investments Could also be a barrier: longer lifespan = less new equipment hence less new technology hence possibly less energy savings.	The interviews and survey identified that by reducing energy use in the furnace, the furnace becomes less worn out, and therefore its lifespan increases, which provides a financial incentive for companies to invest in furnace energy efficiency technologies. However, at the workshop, participants indicated that this could be a barrier from the energy savings perspective, as a longer plant life could lead to delays in investing in a more efficient furnace rebuild.
5	Operational	Replacement of obsolete equipment-as equipment becomes obsolete more energy efficient technologies can be deployed.	**1 Literature Source** Venmans 2014 found that: "Enablers for investing in energy efficiency and rank: Replace	**2 Interviews** Interviewee: "We have had continuous improvements in the energy efficiency of the furnaces and have tried one or two new	11.8% (2) – very high 35.3% (6) – medium-to-high impact 35.3% (6) – low-to-medium impact 11.8% (2) – no-	Workshop participants indicated that this was not an enabler rather a standard procedure and that replacements would not make the big difference for decarbonisation. This is included as within the survey, interviews and literature.	Although the majority of survey respondents voted on replacement of obsolete equipment as having an impact of 3 or 4, the workshop and interviews confirmed that replacing old equipment is a normal part of business operations and cost savings, and

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
			obsolete equipment/ production expansion 9."	technologies." Interviewee: "We tore the entire heart of the furnace out because the design was for products we no longer make."	to-low impact 5.9% (1) – no impact 0% (0) – negative impact 0% (0) - I don't know		is unlikely to lead to any radical step change in decarbonisation and will be limited once efficiency limitations have been realised.
6	Financial	Alternative financing (lease back schemes, government grants) - can help share costs/reduce risks of investments with longer payback periods.	**5 Literature Sources** British Glass Manufacturing Association 2014 found that: "However, there are large barriers to implementing further measures and the biggest is often a lack of finance. There must be a strong, clear business incentive to make expensive, disruptive and risky decarbonisation changes. The glass sector should explore the viability of setting up a large-scale demonstration	**2 Interviews** Interviewee: "We haven't received external funding. We are working on a waste heat recovery project, but one of the issues is its quite difficult to understand what financing is available. " Interviewee: "Issue around funding options- can't figure out what is available, lots of strings attached which takes away competitive advantage from the technical improvement."	35.3% (6) – very high impact 35.3% (6) – medium-to-high impact 0% (0) – low-to-medium impact 5.9% (1) – no-to-low impact 11.8% (2) – no impact 0% (0) – negative impact 11.8% (2) - I don't know	It is to find external financing, and that this is difficult to rate as different companies apply for different types of external funding.	When asked which enablers were missing, respondents added, more structured funding of innovative technology developments and research in technical advances in glass making industry to reduce CO2 emissions. Several workshop participants discussed that shared funding of demonstration projects were needed, and several respondents indicated they had difficulties identifying where to obtain outside financing, and that often application processes were complex. During the interviews and workshops, participants indicated that more third party supplier's paying for upfront costs could help share the risk and overcome the payback barrier.

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			facility to prove existing and new technologies and also to reduce risk and encourage uptake." TUC 2012 found that: "The GIB's mandate can make a real, immediate contribution to securing funding for the technological innovations that could make the greatest difference to the EIIs, including lending to small- and medium-sized businesses with scope to innovate but currently facing real barriers to accessing capital." Venmans 2014 found that: "Barriers for investing in				

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
			energy efficiency and rank: Capital availability- other non-energy related investments receive (d) prior financing, 1". TUC 2012, "There are 10 comparatively large companies operating 18 sites across the UK. The GIB's mandate can make a real, immediate contribution to securing funding for the technological innovations that could make the greatest difference to the EIIs, including lending to small- and medium-sized businesses with scope to innovate but currently facing real barriers to accessing				

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			capital." Centre for Low Carbon Futures 2011 found that: "Availability of capital: 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."				
7	Value Chain	Customer demand for more sustainable products	**2 Literature Sources** Glass for Europe found that: "glass	**Interviews 6:** Interviewee: "Our large customers are asking for our	29.4% (5) – very high impact 29.4% (5) – medium-to-high	Consumers will generally choose the low cost option without looking at energy efficiency. It was discussed that builders get	Across the information sources, it was clear that glass products can help reduce lifetime emissions during end use. This can be

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
		(lightweight glass, double glazed windows)- drives innovation and investments in more sustainable products.	can help contribute to zero-energy building stocks, greener vehicles, and photovoltaic modules. The Dutch scientific institute TNO quantified that over 100 million tonnes of CO_2 could be saved annually if this were replaced with advanced glazing. Lighter glass components in vehicles can support the reduction of energy use and CO_2 emissions in vehicles. Coating technologies used in glass can reduce fuel consumption by enhancing comfort and reducing the need for heating or air conditioning or in	sustainability credentials." Interviewee: "Significant portions of the market do accept light weighting." Interviewee: "There has been an absolute interest in sustainability as a whole in the industry. It is more than just energy efficiency, key customers, Coca-Cola and Unilever. It is fundamental to their existence and to our existence." Interviewee: "Our customers in the UK are more interested in sustainability than others. We supply mainly multinationals, and they are more attuned. It is a hotter topic in UK as a result." Interviewee: "The	impact 17.6% (3) – low-to-medium impact 17.6% (3) – no-to-low impact 0% (0) – no impact 0% (0) – negative impact 5.9% (1) - I don't know)	incentivised to increase energy efficiency when building a new house (double/triple glazing), but existing home owners do not. There are differences between flat, fibre, and container glass when it comes to customer demand as the demand comes from different sectors which are under different regulatory and market pressures.	through the use of fibre glass to create a wind turbine blade, triple glazed flat glass to reduce the lifetime emissions of a building or reduce the gas mileage of a vehicle. The research highlighted that for container glass, UK customers have a high demand for light-weighted bottles due to the presence of large multi-nationals who have comprehensive sustainability strategies. Participants discussed the opportunity for government to help spur the demand for more sustainable flat glass through zero carbon building requirements and the like.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
			electric vehicles increases the range it drives. The total CO_2 equivalent generated by an energy efficient double glazing unit throughout its life-cycle is offset on average between 3 to 10 months only." Gordon 2008 "Societal demand- the demand for lightweight bottles. In the K such drive is relatively high through initiatives such as glassrite Projects."	demand may be a little bit greater in the UK as the retailers use sustainability as a marketing tool." Interviewee: "Most of the decarbonisation initiatives are driven by customers in the technical glass domain. There is push to reduce cost and weights (specifically automotive)."			
8	Management and organisation	Commitment by top management to an environmental policy/ climate change strategy- enables top management to sign off on low	**1 Literature source** Venmans 2014 found that: "Enablers for investing in energy efficiency and rank: Commitment by	**2 Interviews** Interviewee: "Energy and decarbonisation is on the first page of our PNL. It is very important." Interviewee: "It's not	23.5% (4) – very high impact 35.3% (6) – medium-to-high impact 5.9% (1) – low-to-medium impact 23.5% (4) – no-	The main driver therefore is finance, not from a solely environmental perspective. One participant indicated there is a barrier to the willingness of managers to tackle energy culture systematically.	Although workshop participant indicated that top management do not at the end of the day care about decarbonisation or climate change, rather they care about the bottom line, the interviews and survey indicated that top management commitment to invest in risk energy efficiency

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		carbon technologies as they align with the company's strategies and policies.	top management to an environmental policy".	a show stopper, but requires personal engagement and commitment from the top. Need buy-in because it may impact KPIs such as cost, quality, etc."	to-low impact 5.9% (1) – no impact 0% (0) – negative impact 5.9% (1) - I don't know		projects and management commitment to an environmental policy or strategy can help companies to sign off on energy efficiency projects. This is especially the case in small companies, where the top executive, makes the final decisions.
9	Legislation	Political certainty-stable energy efficiency and carbon regulatory framework enables investments in low carbon energy as it creates a stable investment environment.	-	**4 Interviews** Interviewee: "Solar panels on roof – FIT is going backwards. The prospect of doing it is becoming less and less." Interviewee: "Political certainty and level playing field with overseas competition are key enablers." Interviewee: "We were 9/10 of the way of getting a solar project, but then the FIT subsidy was cut in half, making our project no longer viable." Interviewee: "Long-term planning security is a key	23.5% (4) – very high impact 29.4% (5) – medium-to-high impact 5.9% (1) – low-to-medium impact 23.5% (4) – no-to-low impact 11.8% (2) – no impact 0% (0) – negative impact 5.9% (1) - I don't know	Whilst the UK government's commitment to 80% CO_2 reduction by 2050 had helped businesses to understand the long -term decarbonisation goals, it was still thought that political certainty is not currently enabling investment, chiefly because there is not currently thought to be enough stability and for this reason the enabler was scored as a barrier (score = -1). Changes to policy options in the past included: • Changes to FiT rates • Switch from revenue neutral to full purchase for CRC • Delay in building targets (zero carbon homes) • Backloading within the ETS • Future uncertainty over carbon leakage provisions in the ETS (both 2015-2019 and post 2020) coupled with CSCF element. However, it was also recognised that political certainty could be an enabler. Such as in the electricity	The interviews highlighted that several renewables projects which could have been used to supply a significant amount of electricity to the plant, failed due to unexpected changes in FiT regulations. This is reflected in the divided workshop score.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
				enabler."		generation sector where the government has provided 'contracts for difference' which allows low carbon investments to be made with relative certainty of return on investment and this would score fairly highly as an enabler (score = 3).	
10	Legislation	Regulations encouraging energy efficiency and taking account of life cycle emissions-create more demand for sustainable glass and therefore more revenues to invest in advanced technologies.	**1 Literature Source** Glass for Europe found that: "National energy efficiency action plans include economic and fiscal incentives to consumers to replace standard glazing with energy efficient glazing. Energy performance of building directive will require all new constructions to achieve nearly zero energy standards by 2020."	**2 Interviews** Interviewee: "Government needs to take a lifecycle view on regulations." Interviewee: "Regulations to produce green buildings can help create demand."	23.5% (4) – very high impact 29.4% (5) – medium-to-high impact 17.6% (3) – low-to-medium impact 11.8% (2) 5.9% (1) 0% (0) 11.8% (2) - I don't know	If regulations take account for life cycle emissions through Life Cycle Assessments (LCA) and are done correctly for products, this would stimulate product and process improvements. However, if the energy efficiency legislation was applied to the glass manufacturer, it is unlikely to drive energy efficiency as this would take funds away from possible capital investments and therefore a (-1) score was given. There are challenges to using LCA as it is complex, where the boundaries are drawn, and what methodology is used can change the results.	Across the information sources, regulations that could incentivize the sustainable use of glass and identify and apply a robust LCA methodology that rewards or takes account of glass's end-use not just the emissions during its manufacture, would be a strong enabler to help reduce emissions overall and can help other sectors achieve their reductions such as the buildings and automotive sectors.
11	Legislation	Legislative compliance-Companies must meet government	**1 Literature source** Venmans 2014 found that: "Enablers for	**1 Interview** Interviewee: "Responsibility is mainly on compliance	23.5% (4) – very high impact 35.3% (6) – medium-to-high impact	Discussions on legislative compliance were split on this enabler. Whilst requirements for IED meant that the various abatements were purchased, it	Legislative compliance was seen as both an enabler (maintain environmental license to operate) and barrier to decarbonisation (costs of legislative compliance

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
		regulations and it is a driver of investment decisions.	investing in energy efficiency and rank: Comply with legal obligations (e.g. environmental license) 13".	investment, pollution reduction."	17.6% (3) – low-to-medium impact 17.6% (3) – no-to-low impact 0% (0) – no impact 5.9% (1) – negative impact 0% (0) - I don't know	was doubtful whether these actually achieved an overall environmental benefit (NOx versus CO_2) and there was also a chance that, if costs were too high, closure may follow. There was a need for balance between regulatory compliance, and costs thereof, versus cost of moving abroad.	too high and move manufacturers elsewhere).
12	Market and Economy	Production expansion-increases revenues to invest in decarbonisation.	-	**2 Interviews** Interviewee: "Container glass is a low margin business- need to make a lot of bottles to earn our way." Interviewee: "We are our own best enablers- we free the cash and capital to make the improvement. We create our own business class independently from government funding or other incentives."	5.9% (1) – very high impact 23.5% (4) – medium-to-high impact 23.5% (4) – low-to-medium impact 29.4 %(5) – no-to-low impact 17.6% (3) – no impact 0% (0) – negative impact 0% (0) - I don't know	Decarbonisation (relative) can only be achieved if there are glass manufacturers in the UK left to decarbonise, and therefore revenues are needed to be able to invest.	Although not discussed in the workshop as key enablers, and overlooked by the literature, the interviewees and workshop participants highlighted the obvious that without increased productions and healthy revenues, manufacturers will not have the capital to invest in new technologies.
13	Organisational	Reputation building-low carbon projects help build a company's	Venmans 2014 found that: "Enablers for investing in energy efficiency	**3 Interviews** Interviewee: "Some customers don't care about sustainability but	23.5% (4) – very high impact 29.4% (5) – medium-to-high impact	There are limitations and power that brand owners have on the light weighting potential of premium alcohol brands, but that for some premium brands and	Reputation building was seen as an important activity for container glass companies whose customers are some of the world's leaders in sustainability. The

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and interpretation
		reputation for marketing purposes.	and rank: Environmental image building towards clients 3."	others in the commercial scene do care. Architects or providers of social housing are interested in your credentials. Sustainability is about responsible sourcing." Interviewee: "Own 'green' agenda as a marketing differentiator – classic marketing, differentiate against competitors." Interviewee: "The demand may be a little bit greater in the UK as the retailers use sustainability as a marketing tool."	17.6% (4) – low-to-medium impact 11.8% (2) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 11.8% (2) - I don't know	non-premium brands, light weighting is a useful marketing tool that can enhance both the glass manufacturer's and beverage customer's reputation with the final consumer.	interviews also indicated that sustainability can help flat glass company's win government contracts for social housing, and can help fibre glass company's explain the end use value of their product better to customers and other stakeholders.
14	Market and economy	Cost of carbon-EU ETS encourages investment in energy efficiency to achieve cost savings.	-	**4 Interviews** Interviewee: "EU ETS carbon price-it's a cost but not significant cost to us in terms of carbon price." Interviewee: "In the future we won't be	11.8% (2) – very high impact 5.9% (1) – medium-to-high impact 29.4% (5) – low-to-medium impact 29.4% (5) – no-to-low impact	Cost of carbon could potentially be an enabler if it was high enough and applicable to all industries and/or glass manufactures globally. The cost is not high enough to be an enabler or key driver, therefore the division in scores given.	Cost of carbon could potentially be an enabler, but the current cost is too low. Future increases to the cost of carbon may become a greater driver for decarbonisation, but it can also lead to increased costs and therefore be seen as a barrier if costs become too high.

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				able to meet our CO_2 allowances, and therefore CO_2 will have a value and drive decision-making in the future. It will save on CO_2 bill and energy bill." Interviewee: "Carbon floor pricing will make it more difficult to invest in the UK." Interviewee: "CO_2 is always a lower value consideration."	11.8% (2) – no impact 11.8% (2) – negative impact 0% (0) - I don't know		The survey, interviews, and workshops discussed that the cost of carbon is leading to carbon leakage and a reduction in exports, and therefore negatively impact the UK glass manufacturers.
15	Value chain	Availability of natural soda ash as opposed to synthetic soda ash reduces carbon emissions.	-	**1 Interview** Interviewee: "Using natural soda ash instead of synthetic can have a double digit impact on carbon."	0% (0) – very high impact 17.6% (3) – medium-to-high impact 17.6% (3) – low-to-medium impact 23.5% (4) – no-to-low impact 23.5% (4) – no impact 0% (0) – negative impact 17.6% (3) - I don't know	This was discussed as a pathway option and highlighted the availability of natural soda ash and whether switching to natural soda ash would actually reduce carbon when taking into account the transport emissions from importing from Wyoming and/ or Turkey where natural ash quarries are located.	One interviewee had success in reducing its emissions and costs by switching to natural soda ash, yet the workshop questioned whether the transport of natural soda ash would indeed mean the emissions reduction was less. The future availability of natural soda ash was also raised as a concern. The survey results demonstrated mixed views on this enabler.

Barriers

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
1	Financial	Long payback periods (5-8 years) and high costs. Return on investment too small- surpasses companies' investment criteria (less than 2 years) and therefore technologies with longer paybacks are less likely to be implemented.	**1 Literature** British Glass Manufacturers Confederation 2014 found that: “However, there are large barriers to implementing further measures and the biggest is often a lack of finance. There must be a strong, clear business incentive to make expensive, disruptive and risky decarbonisation changes.”	**7 Interviews** Interviewee: “Cost of technology to meet government emission regulations.” Interviewee: “ROI and payback period are crucial. It gets harder to justify smaller projects. If it doesn’t have a minimum of 2 year backpack.” Interviewee: “The study found that there is sufficient wind to make electricity from a wind turbine but payback over 5 years.” Interviewee: “Most important barriers are high CAPEX requirements, long payback times.” Interviewee: “This year, we have capital/cash anything that has a 2 years payback or less we can move on. Anything longer we	76.5% (12) – very high 5.9% (1) – medium-to-high impact 5.9% (1) – low-to-medium impact 0% (0) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 5.9% (1) - I don’t know	Workshop participants indicated that payback was more important than capital costs.	Payback periods for advanced technologies were seen as the most important barrier across the information sources. Many of the options discussed in the interviews and workshop such as waste heat recovery had paybacks over 7 years. The interviews revealed that decision-making criteria usually included payback of 2 years or less or in some instances 3 years or less. There may potentially be an opportunity for cross sector sharing to finance large demonstration projects to overcome payback and third party financing.

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				can consider." Interviewee: "Long payback periods for a lot of cases that can't come close to our payback criteria." Interviewee: "Payback on some of projects not fitting financial guidelines – thus own corporate finance a blocker."			
2	Financial	Lack of capital–competition for funds internally.	**5 Literature Sources** British Glass Manufacturing Association 2014 found that: "However, there are large barriers to implementing further measures and the biggest is often a lack of finance. There must be a strong, clear business incentive to make expensive, disruptive and risky decarbonisation changes. The glass sector should explore the viability of setting up a	**4 Interviews** Interviewee: "Cost justification for energy efficiency projects over other projects more aligned to core business." Interviewee: "We have good R&D but it's limited in number." Interviewee: "We are owned and funded in such a way that there are limits to the amount of CAPEX that we can spend." Interviewee: "Core problem is availability of CAPEX."	52.9% (9) – very high impact 0% (0) – medium-to-high impact 17.6% (3) – low-to-medium impact 17.6% (3) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 5.9% (1) - I don't know	Workshop participants indicated that competition for capital can be separated out from lack of capital. Lack of capital is different for different companies; small companies may struggle with availability of capital.	Multi-national companies highlighted that it is difficult to obtain funds for UK energy efficiency projects, when there may be more profitable investments more closely aligned to the core business in other plant locations outside the UK. Interviews highlighted that R&D funding has become more limited in size and number, or R&D funding available is not earmarked for process efficiency innovations. In some instances there is no capital available, and in others, the capital is limited due to governance structure of the company or expenditure limited to a percentage of turnover. The cost justification of energy efficiency projects over other projects was seen as an additional internal

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			large-scale demonstration facility to prove existing and new technologies and also to reduce risk and encourage uptake.” TUC 2012 found that: “The GIB’s mandate can make a real, immediate contribution to securing funding for the technological innovations that could make the greatest difference to the EIIs, including lending to small- and medium-sized businesses with scope to innovate but currently facing real barriers to accessing capital.” Venmans 2014 found that: “Barriers for investing in energy efficiency and rank: Capital				decision-making barrier.

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			availability- other non-energy related investments receive (d) prior financing, 1." TUC 2012, "There are 10 comparatively large companies operating 18 sites across the UK. The GIB's mandate can make a real, immediate contribution to securing funding for the technological innovations that could make the greatest difference to the EIIs, including lending to small- and medium-sized businesses with scope to innovate but currently facing real barriers to accessing capital." Centre for Low Carbon Futures 2011 found that: "Availability of				

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			capital: 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."				
3	Infrastructure	Insufficient quantities of cullet- due to inefficient recycling system.	**3 Literature Sources** Environmental Protection Agency 2008 found: "It is also evident that cullet going back into remelt, at home or abroad, has a significantly reduced carbon impact than using it in domestic	**3 Interviews** Interviewee: "Volume of 'cullet' available to recycle- collection and distribution in cycle not mature or deeply established across demolition/usage chain." Interviewee: "Availability of glass in the quantity and	47.1% (8) – very high impact 17.6% (3) – medium-to-high impact 11.8% (2) – low-to-medium impact 5.9% (1) – no-to-low impact 0% (0) – no impact 0% (0) – negative impact 17.6% (3) - I don't	Workshop participants indicated the recycling system was a key barrier to receiving large quantities of cullet.	Glass is infinitely recyclable, and using cullet reduces emissions, however; current recycling system does not produce sufficient amounts of cullet to reduce emissions further.

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			aggregate manufacture. In terms of CO_2 reduction, domestic remelt is the best option, with short haul foreign remelt, being a close second. Multi-loop recycling would further favour remelt applications and as indicated above, this is currently most prevalent in container manufacture. The quality of the cullet being produced from MRFs falling short of that required for use in remelt, container glass in particular. This represents a CO_2 saving opportunity loss, as such material is currently suitable only for less environmentally beneficial end-uses such as	quality is not there in the UK. Alternative routes (aggregates) for glass are too attractive." Interviewee: "Need more cullet from packaging market."	know		

#	Category	Barriers	Literature review	Interviews	**Surveys** (distribution of responses - % and number)	Workshops	Analysis and interpretation
			aggregates. The lack of economic incentives to produce good quality cullet fit for container remelt. o Simplistic weight based recycling targets being the basis of legislative drivers. Meeting the recovery targets in 2008 will divert approximately 1.6 million tonnes of waste glass from landfill with a consequent saving of 1.8 million tonnes of virgin material, essentially irrespective of which end-use is considered – container remelt, fibre remelt, or aggregates use. That is, landfill diversion and raw material savings are not key environmental differentiators				

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			between the different end-uses.” Energetics 2002 found that: “The industry’s top need is a cost-effective technology for sorting and separating postconsumer glass.” Wood and Balhuizen 2013 found that: “To produce the same products with fewer inputs is a no brainer for business. But unfortunately within the recycling industry, as colours of glass must be separated, a lot of recycled glass ends up in asphalt production, rather than as new glass products. This is a huge challenge to the industry and one that must be				

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
			tackled if glass is to live up to its potential as an environmentally friendly option.”				
4	Value chain	Low quality of available cullet-prevents cullet from being used for remelt.	**2 Literature Sources** Ricardo AEA 2013 found that: “The availability of good quality cullet will determine the degree to which melting energy can be reduced further. While container glass melting may be more accepting of mixed recyclate, flat glass manufacture is far more exacting in the origin of cullet. Further increases in the use of cullet may require glass manufacturers to intervene in the glass recycling business in order to secure cullet of the required quality, and the author, through his communications with British Glass,	**3 Interviews** Interviewee: “glass was the first industry to be recycled, bottle banks, and recycling. Very little sorting, only bottles and it was nicely sorted. Now everyone else joins the recycling bandwagon, and a machine separates everything out. The machine doesn’t recycle glass because it’s bulky and low cost. So now we are putting glass in a bad recycling system with organics and combustibles. If we picked the glass out you have recycled.5 tonnes, and now it’s not reusable because it has all kinds of organic matter on it.” Interviewee: “Quality is a big issue when it comes to	41.2% (7) – very high impact 23.5% (4) – medium-to-high impact 17.6% (3) – low-to-medium impact 5.9% (1) – no-to-low impact 0% (0) – no impact 0% (0) – negative impact 11.7% (2) - I don’t know	Workshop participants indicated that this was a high impact barrier and enabler if high quality cullet were available.	The quality of cullet currently produced was a major barrier to reducing emissions further. The quality requirements for clear glass for flat and container are high. All information sources confirmed a return to bottle banks would improve the quality of cullet.

#	Category	Barriers	Literature review	Interviews	**Surveys** (distribution of responses - % and number)	Workshops	Analysis and interpretation
			is aware of two container glass manufacturers doing this. Availability of recycled glass of the required quality (including colour). Availability of clear cullet can be particularly problematic. Batch and cullet pre-heating." Butler, 2005 found that: "For example, in the case of waste glass (or cullet) the imbalance between the colour mix in a rising of household and commercial glass container waste in the UK, and demand from UK glass container manufacturers, presents a significant barrier to closing the loop on this material flow."	cullet. More and more cost associated with cullet processing process, this cost being added to the price of cullet. Raw feed stock being collected from recycling schemes, the last 10 years quality has gotten worse to. That is linked to government policy- this is a significant barrier." Interviewee: "Availability of glass in the quantity and quality is not there in the UK. Alternative routes (aggregates) for glass are too attractive."			

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
5	Market and economy	High and fluctuating electricity prices- makes it difficult to calculate return on investment on new technologies and makes some technologies such as electric furnaces cost prohibitive.	**1 Literature Source** Centre for Low Carbon Futures 2011 found that: "Price of energy: 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."	**7 Interviews** Interviewee: "Importers can really undercut us because they don't have the same energy and carbon implications and can produce cheaper." Interviewee: "The electricity prices are rising and making us non-competitive against Europe." Interviewee: "Big issue around forecast for electricity cost and current state of electricity price." Interviewee: "Energy costs/ energy price fluctuates rapidly in the UK. It is difficult to judge price it is between 20 to 30% of OPEX costs." Interviewee: "Energy reduction is a key cost driver." Interviewee: "With energy it's a bit different the energy price level isn't high	41.2% (7) – very high impact 29.4% (5) – medium-to-high impact 17.6% (3) – low-to-medium impact 11.8% (2) - 5.9% (1) 0% (0) – negative impact 0% (0) - I don't know	Workshop attendants indicated that high and increasing energy prices can be perceived as both an enabler and barrier. High and increasing energy prices might force companies to focus more on energy efficiency **(4) – very high impact,** but if energy prices get too high then production moves elsewhere. **(-1)- negative impact).**	Fluctuating energy prices makes it difficult for glass manufacturers to plan the return on their investments, and are a major operational cost. Interviewees and workshop participants believed the electricity grid would become more decarbonised, but that the price of electricity is too high and thus does not encourage a switch to electric furnaces. There is concerned about UK's competitiveness in relation to Europe and other markets due to the higher energy prices in the UK.

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
				enough to create a concern But the variability of energy prices is a concern as it makes it hard to plan." Interviewee: "With energy prices going up, the business case for heat recovery and energy reduction technologies is getting less economically feasible."			
6	Legislation	Unlevelled playing field with overseas competition due to differences in climate change and energy policies.	**1 Literature Source** Glass for Europe found that: "In the context of the EU ETS, the exposure of flat glass manufacturing to external trade has been assessed by DG Enterprise of the European Commission. This assessment revealed that the industry's exposure to external trade equalled 21% during the period 2005 to 2007. This reality coupled with	**6 Interviews** Interviewee: "If they continue to charge us for CO_2 and we are competing with plants in Egypt, who don't have the costs of CO_2, we will move to Egypt. Carbon leakage outside the EU and outside the UK is an issue." Interviewee: "Importers can really undercut us because they don't have the same energy and carbon implications and can produce cheaper."	41.2% (7) – very high impact 17.6% (3) – medium-to-high impact 23.5% (4) – low-to-medium impact 11.8% (2) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 0% (0) – I don't know	Participants indicated that EU ETS carbon leakage measures for the glass sector are working, but there has still been some leakage already. Since 80% of large glass companies operating in the UK are owned from overseas, investment has large potential to go elsewhere Carbon leakage is being experienced most notably through higher imported glass	Although the industry is impacted by carbon leakage, glass exemptions for the EU ETS and the economic recession have limited the impact of carbon leakage on the sector. There was some indication that companies are beginning to experience carbon leakage and are seeing a reduction in exports and increase in imports as a result.

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
			a high energy intensity ratio means that our industry is exposed to risks of carbon leakage.”	Interviewee: “The industry is impacted by carbon leakage.” Interviewee: “On an EU basis, there is a growing disparity between electricity cost including in countries in Germany and France, where published prices are similar to the UK, but they compensate their industries more, which is a competitive issue especially when exporting into EU.” Interviewee: “Political certainty and level playing field with overseas competition are key enablers.” Interviewee: “Is there a threat of carbon leakage? Yes, absolutely no doubt. Investment of new plants has been outside of Europe. We will see leakage in two ways. One leakage losing business to furnaces being build		from Algeria and edges of Europe especially for automotive. Carbon leakage not yet a problem for flat glass in UK. Carbon leakage was also thought to have been mitigated by the recession. Participants highlighted that filled glass was not counted as glass and therefore number of glass bottles being imported into the UK is underestimated by around 90%.	

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
				outside EU, North Africa, Turkey, Ukraine. Flat glass is seeing this even more heavily. We will lose investment into the EU." Interviewee: "More on the Southern European front. We have seen a reduction in Exports of glass. It impacts on exports before imports. The scheme currently misses the impact downstream. Using spirits, 80% of spirits are exported, mainly EU, North America and Asia. It will become more expensive to trade. If it isn't our exports it will be our customer's balance of trade. The Term carbon leakage is narrowly defined within the EU ETS. You have to look at different levels."			
7	Technology	Chemical and process efficiency limitations- there are limits to energy	**1 Literature Source** Centre for Low Carbon Futures	**1 Interview** Interviewee: "Understanding that for every plant	41.2% (7) – very high impact 35.3% (6) – medium-to-high	Workshop participants highlighted that efficiency	Glass manufacturers in the UK have been decarbonising and improving their energy efficiency over the last 50 years. There are concerns that

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
		efficiency of furnaces.	2011 found that: "Technology limitations: For many industries, much has already been done to improve the efficiency of the processes involved; there are efficiency limitations on current processes. Cross industry infrastructure: Some respondents noted the need for investment in national level infrastructure, particularly in relation to carbon capture and storage, and electricity decarbonisation and recycling."	manager is to have process stability because we have a thermal energy process, we have a huge tank firing a long of energy at the end a reactor, there is a chemical process going on continuously. If you have any process instability you end up with cost and regulatory issues."	impact 11.8% (2) – low-to-medium impact 0% (0) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 5.9% (1) - I don't know	limitations are a matter of equal playing field. They become a barrier when energy and CO_2 costs increase because UK companies are reaching their improvement limits and will hence move abroad.	manufacturers have nearly reached the highest efficiency limits possible, however; better plant level efficiency data could help ascertain whether this is indeed the case.
8	Operational	Long plant life (longevity of current equipment)/ investment cycle- allowing limited opportunity to invest in major technological	**1 Literature Source** Ricardo AEA 2013: "Implementation of opportunities requiring retrofit will either have to wait until furnace rebuild or	**3 Interviews** Interviewee: "We have an investment cycle of 15-20 years. A decision we make now, we will have to live with for 20 years. We can't gamble, we could cause problems	29.4% (5) – very high impact 47.1% (8) – medium-to-high impact 11.8% (2) – low-to-medium impact 11.8% (2) – no-to-low impact	Workshop participants indicated that feasibility studies and pilot projects are needed to prove and thereby lower risks of new more innovative	Due to the long plant lives of glass furnaces, there are limited opportunities to rebuild by 2050 and therefore limited opportunities to invest in an advanced technology that can significantly reduce a company's carbon emissions. The workshop highlighted that rebuild feasibility studies can help reduce the risk and

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
		manufacturing changes (15-20 years).	experience unplanned downtime and lost production."	for our customers, and make a good plant uneconomically viable, and create job loss. Using technology that already exists." Interviewee: "There is a distinct lack of understanding of the investment cycles for manufacturing we really think 20 years not 2 years. There has to be recognition that we can't turn things around in 5 years. There are limited step changes." Interviewee: "There is a furnace repair, once every 15 years; you have the opportunity to make major changes. At this time, the plant looks at new furnace, machines, major repair of furnace, inspection technology. It is critical at that time; the planning of any environmental abatement equipment is done with the	5.9% (1) – no impact 0% (0) – negative impact 0% (0) - I don't know	plant rebuilds.	test out more innovative rebuild designs with higher emission reduction potentials

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
				operational planning of the production facilities."			
9	Financial	Difficulty to find external financing (grants, funds for R&D etc.)-limits adoption of technologies with longer paybacks.	**2 Literature Sources** Venmans 2014 found that: "Barriers for investing in energy efficiency and rank: Difficulties in finding internal or external financing for investments 4". Centre for Low Carbon Futures 2011 found that: "Lack of financial support for R&D: Some respondents commented on the difficulty of accessing government support to promote industry R&D. Regulatory uncertainty: Long-term clarity was seen as vital to underpin high cost, long-term technology investment."	**2 Interview** Interviewee: "Application processes for grants are complex, and have many caveats." Interviewee: "We really believe in the glass industry, we are asking government for money to do waste heat recovery. The whole burden is currently on us, R&D, and it is a high risk investment."	17.6% (3) – very high impact 41.2% (7) – medium-to-high impact 11.8% (2) – low-to-medium impact 5.9% (1) – no-to-low impact 11.8% (2) – no impact 0% (0) – negative impact 11.8% (2) - I don't know	Workshop participants stated that it is difficult to convince people to implement non-technical innovative procedures through alternative finance models, since it is more difficult to foresee benefits on paper. Participants indicated a general reluctance to go out of conventional CAPEX method and that there is limited financial innovation. Engagement is needed to educate people to move away from conventional financing.	Lack of resources deployed to identifying the funding available, and reluctance to move to third party financing are seen as additional barriers to finding external financing. There is a lack of collaboration on financing demonstration projects as this is seen as a competitive advantage and thus sharing the financial burden amongst manufacturers is limited. One interviewee indicated that they would go through with a renewable energy investment if a third party invested in upfront costs to share the risk of a longer payback.
10	Operational	Retrofit capability-	**2 Literature**	**2 Interviews**	5.9% (1) – very	Workshop	Glass manufacturers are highly risk

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
		new technologies can only be implemented if they can be retrofitted on the furnace with limited production disruption limiting the low carbon technological options available.	**sources** Ricardo AEA 2013: "Implementation of opportunities requiring retrofit will either have to wait until furnace rebuild or experience unplanned downtime and lost production." Venmans 2014 found that: "Barriers for investing in energy efficiency and rank: Technology lock in: Technique was/is incompatible with other elements of the plant 10".	Interviewee: "Risk associated with step change technology on melting furnace." Interviewee: "Retrofit capability- if we want to put waste heat recovery in, you are adding it after you started the plant, more difficult to add in when plant is running. You can implement it, but with great difficulty."	high impact 41.2% (7) – medium-to-high impact 29.4% (5) – low-to-medium impact 5.9% (1) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 11.8% (2) - I don't Know	participants indicated this was a major barrier, as often new legislation requires unproven technologies. No one wants to take the first risk.	averse and are not likely to implement technologies that might lead to production disruptions due to malfunctioning retrofits. Therefore, technologies that have been tried before are more likely to gain traction.
11	Operational	Risk of production disruption- hassle, inconvenience	**3 Literature sources** Ricardo AEA 2013: "Implementation of opportunities requiring retrofit will either have to wait until furnace rebuild or experience unplanned downtime and lost	**3 Interviews** Interviewee: "We can't gamble, we could cause problems for our customers, and make a good plant uneconomically viable, and create job loss. Using technology that already exists." Interviewee: "Don't	23.5% (4) – very high impact 17.6% (3) – medium-to-high impact 23.5% (4) – low-to-medium impact 17.6% (3)- no-to-low impact 11.8% (2) – no impact 0% (0) – negative	Workshop participants indicated that no one wants to take the first risk. If anything goes wrong during retrofit this can create financial loss.	Risk of production disruptions from retrofit technologies is an even larger concern for small companies with limited production capacity. Management commitment is needed for any energy efficiency retrofit project as if anything goes wrong, it impacts on plant level employee performance KPIs. Interviewees were concerned about retrofits/ installing new technologies, and its implications on quality and being able to continue

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
			production." European Commission - Joint Research Centre 2013 found that: "In general, container glass furnaces operate continuously, or with one or two minor repairs, for over 20 years, after which time they are rebuilt with either partial or total replacement of the structure depending on its condition." Venmans 2014 found that: "Barriers for investing in energy efficiency and rank: Risk of production disruptions, hassle, inconvenience, 8".	want to create major change that causes major issues. Incremental change is the way ahead." Interviewee: "The industry doesn't have as high of an incentive to push for these technologies. For every equipment you put on top of your core installation you will cause instabilities."	impact 5.9% (1) - I don't know		to meet customer demands. Demonstration of new technologies, for example at test facilities, could reduce the risk of damage to commercial plants and encourage uptake.
12	Market and economy	Low demand risk-efficiency investments entail fixed costs that may be cost	**1 Literature Source** Venmans 2014 found that: "Barriers for	-	5.9% (1) – very high impact 35.3% (6) – medium-to-high impact	Workshop participants scored low demand risk a 3. Participants indicated this was	Companies may not be able to recover fixed investment costs if demand for glass products and therefore revenues decline. However, container glass sector for example

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
		inefficient when there is overcapacity during economic downturns	investing in energy efficiency and rank: Low demand risk: efficiency investments entail fixed costs that may be cost-inefficient when there is overcapacity during economic downturns, 2".		17.6% (3) – low-to-medium impact 11.8% (2) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 23.5% (4) - I don't know	down to the economy, variable costs, demand, and taking investment risks. Participants highlighted that low demand risk is linked with growing competition.	was not hit that heavily by the recession, whereas flat glass was impacted more. This risk varies on the local economies, and it was difficult to identify a solution to overcome this barrier.
13	Financial	Contract arrangements- may prevent using other suppliers or technologies.	-	**2 Interviews** Interviewee: "We are not allowed to implement some of the energy efficiencies on the technology that would lead to energy efficiency because some of them are trailing it and patenting it." Interviewee: "Current contract arrangements – some of our contracts say that we can't do things that are further up the list. You have to get all of your supply from specific companies."	5.9% (1) – very high impact 35.3% (6) – medium-to-high impact 17.6% (3) – low-to-medium impact 11.8% (2) – no-to-low impact 5.9% (1) – no impact 0% (0) – negative impact 23.5% (4) - I don't know	**-**	Certain contractual arrangements with existing furnace suppliers or technology suppliers may lock a glass manufacturer in to buying all technologies from that supplier rather than the best technology available.
14	Management and Organisation	Shortage of skilled labour.	**1 Literature source** VNG 2012 "There	**1 Interview** Interviewee: "Skilled workers are a key	Survey respondents when asked whether	One workshop table indicated having the right	The glass sector is already responding to this barrier through the establishment of the glass Academy

#	Category	Barriers	Literature review	Interviews	Surveys (distribution of responses - % and number)	Workshops	Analysis and interpretation
			is likely a shortage of skilled glass technologists, awareness in media , government and the Dutch general public for the social consequences terms of leakage of knowledge transfer production elsewhere at higher environmental costs , transport , loss of employment , etc. seem to be missing."	barrier- you are as good as your workforce. Need to become globally competitive and that we can invest in being as good as we can be. Need to stay ahead of the curve."	they have a sufficiently skilled workforce to implement and handle energy and decarbonisation, 47.1% said strongly agree, and 35.3 % agreed.	people was a key enabler. Or not having the right people a key barrier to decarbonisation. A second workshop table stated that there are enough sufficiently skilled employees, but they are ageing, and thus there is a threat of losing valuable knowledge.	and other institutions to ensure that graduates and skilled engineers required for the implementation of advanced technologies are secured.

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – GLASS

APPENDIX C – FULL TECHNOLOGY OPTIONS REGISTER

APPENDIX C FULL TECHNOLOGY OPTIONS REGISTER, INCLUDING DESCRIPTIONS

Option	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex per site[7]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
BATCH PELLETISATION	8	0%	100%	£200,000	Expert judgement (PB/DNV GL consortium)	5% (C)	Adapted for this project based on the following references (VNG, 2012; van Celsian, 2012; Rongen et al., 2013) and review by sector team
BATCH REFORMULATION	7	0%	100%	£200,000	Expert judgement (PB/DNV GL consortium)	5% (C)	Adapted for this project based on the following references (VNG, 2012; US EPA, 2008; Thiery et al., 2007; ETSU, 1994; Beerkens et al., 2008) and review by sector team

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

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

Option	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex per site[7]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
CARBON CAPTURE[8]	6[9]	0%	100%	£40,000,000	Factored from data in Element Energy (2014)	65% (C)	Expert judgement (PB/DNV GL consortium) with review from trade association and their members
ELECTRIC MELTING	8	0%	100%	£40,000,000	Expert judgement (PB/DNV GL consortium) – assumed same cost as conventional furnace	100% (C)	Provided by trade association with review by sector team and PB/DNV GL
ELECTRICITY FROM WASTE HEAT	9	0%	100%	£3,500,000	Directly from literature (Carbon Trust, 2005) and review by sector team	40% (E)	Provided by trade association with review by sector team and PB/DNV GL
FUEL SWITCHING - GAS	8	0%	100%	£30,000,000	Factored from capex developed by ceramics sector for biomass gasification	84% (C)	Provided by trade association with review by sector team and PB/DNV GL
FUEL SWITCHING - HYDROGEN	4	0%	100%		Option not included in pathways	0% (C)	Option not included in pathways

[8] All costs are for CO_2 capture alone, including CO_2 purification and compression. Costs associated with transport and storage/utilisation are excluded.
[9] Element Energy, 2014 (Note – for oxy-combustion capture; post-combustion TRL 7)

Option	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex per site[7]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
GENERAL UTILITIES	9	0%	100%	£200,000	Provided by trade association with review by sector team and PB/DNV GL	0% (C)	Provided by trade association with review by sector team and PB/DNV GL
IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL	8	0%	100%	£1,100,000	Expert judgement (PB/DNV GL consortium) with review from trade association	5% (C)	Provided by trade association with review by sector team and PB/DNV GL
IMPROVED FURNACE DESIGN - INNOVATIVE	5	0%	100%	£40,000,000	Factored from capex developed by ceramics sector	25% (C)	Adapted for this project based on the following references (US EPA, 2008; Ross and Tincher, 2004; BCS, 2008; Beerkens et al., 2008) and review by sector team
IMPROVED PROCESS CONTROL	8	0%	100%	£150,000	Directly from literature (US EPA, 2008) and review by sector team	2% (C)	Adapted for this project based on the following references (VNG, 2012; US EPA, 2008; ETSU, 1994; Beerkens et al., 2008) and review by sector team
INCREASED USE OF RECYCLED GLASS -	9	56%	100%	£140,000	Expert judgement (PB/DNV GL	61% (C)	Provided by trade association with

Option	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex per site[7]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
CONTAINER					consortium) with review from trade association		review by sector team and PB/DNV GL
INCREASED USE OF RECYCLED GLASS - FLAT	9	28%	100%	£140,000	Expert judgement (PB/DNV GL) with review from trade association	43% (C)	Provided by trade association with review by sector team and PB/DNV GL
OXY-FUEL COMBUSTION	8	0%	100%	£3,300,000	Adapted for this project based on the following references (IIP, 2014; US EPA, 2008) and review by sector team	20% (C)	Adapted for this project based on the following references (British Glass, 2014; IIP, 2014; US EPA, 2008; Kobayashi et al., 2005; ETSU, 1994; Celsian, 2014) and review by sector team
RAW MATERIALS PRE-HEATING	8	0%	100%	£1,500,000	Adapted for this project based on the following references (Ricardo AEA, 2013; IIP, 2014; US EPA, 2008; American Ceramic Society, 2009; Ardagh, 2014) and review by sector team	15% (C)	Adapted for this project based on the following references Ricardo AEA, 2013; IIP, 2014; US EPA, 2008; Ardagh, 2014; Zippe, 2012; van Celsian, 2012; ETSU, 1994) and review by sector team

Option	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex per site[7]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
RENEWABLE GENERATION	9	0%	100%	£2,000,000	Factored from capex developed by refining sector	25% (E)	Provided by trade association with review by sector team and PB/DNV GL
WASTE HEAT RECOVERY	8	54%	100%	£1,500,000	Expert judgement (PB/DNV GL consortium) – assumed same cost as 'raw materials preheating'	15% (C)	Expert judgement (PB/DNV GL consortium) – assumed same cost as 'raw materials preheating'

Table 11: Technology options for decarbonisation for the glass sector

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – GLASS

APPENDIX D – ADDITIONAL PATHWAYS ANALYSIS

APPENDIX D ADDITIONAL PATHWAYS ANALYSIS

1. Option Deployment for Pathways under Different Scenarios

Challenging World

Pathway: Business As Usual   Scenario: Challenging World (CW)

OPTION	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 BATCH PELLETISATION	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
02 BATCH REFORMULATION	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
03 CARBON CAPTURE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 ELECTRIC MELTING	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 WASTE HEAT RECOVERY - ELECTRICITY FROM WASTE HEAT	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
06 FUEL SWITCHING - GAS	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 FUEL SWITCHING - HYDROGEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 GENERAL UTILITIES {From 2012 level}	0%	100%	0%	0%	0%	25%	25%	50%	50%	75%	75%
09 IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL {From 2012 level}	0%	100%	0%	0%	0%	25%	25%	50%	50%	50%	75%
10 IMPROVED FURNACE DESIGN - INNOVATIVE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 IMPROVED PROCESS CONTROL {From 2012 level}	0%	100%	0%	0%	0%	25%	25%	50%	50%	50%	75%
12 INCREASED USE OF Recycled glass - Container	56%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13 INCREASED USE OF Recycled Glass - Flat	28%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
14 OXY-FUEL COMBUSTION	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15 WASTE HEAT RECOVERY- RAW MATERIALS PRE-HEATING	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
16 RENEWABLE GENERATION	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
17 WASTE HEAT RECOVERY - other	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 5: BAU pathway, challenging world scenario

Pathway: Max Tech no CCS   Scenario: Challenging World (CW)

OPTION	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 BATCH PELLETISATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
02 BATCH REFORMULATION	0%	100%	0%	0%	0%	0%	0%	0%	25%	25%	25%
03 CARBON CAPTURE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 ELECTRIC MELTING	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 WASTE HEAT RECOVERY - ELECTRICITY FROM WASTE HEAT	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
06 FUEL SWITCHING - GAS	0%	100%	0%	0%	0%	0%	0%	25%	25%	60%	60%
07 FUEL SWITCHING - HYDROGEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 GENERAL UTILITIES {From 2012 level}	0%	100%	0%	0%	0%	25%	25%	50%	50%	75%	75%
09 IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL {From 2012 level}	0%	100%	0%	0%	25%	25%	25%	50%	50%	50%	38%
10 IMPROVED FURNACE DESIGN - INNOVATIVE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	13%
11 IMPROVED PROCESS CONTROL {From 2012 level}	0%	100%	0%	0%	25%	25%	25%	50%	50%	50%	75%
12 INCREASED USE OF Recycled glass - Container	56%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
13 INCREASED USE OF Recycled Glass - Flat	28%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
14 OXY-FUEL COMBUSTION	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15 WASTE HEAT RECOVERY- RAW MATERIALS PRE-HEATING	0%	100%	0%	0%	0%	0%	0%	10%	10%	10%	10%
16 RENEWABLE GENERATION	0%	100%	0%	0%	0%	0%	0%	10%	10%	10%	10%
17 WASTE HEAT RECOVERY - other	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 6: Max Tech pathway without CCS, challenging world scenario

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

OPTION	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 BATCH PELLETISATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
02 BATCH REFORMULATION	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	25%
03 CARBON CAPTURE	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	25%
04 ELECTRIC MELTING	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 WASTE HEAT RECOVERY - ELECTRICITY FROM WASTE HEAT	0%	100%	0%	0%	0%	0%	0%	13%	13%	13%	13%
06 FUEL SWITCHING - GAS	0%	100%	0%	0%	0%	0%	0%	25%	25%	50%	50%
07 FUEL SWITCHING - HYDROGEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 GENERAL UTILITIES {From 2012 level}	0%	100%	0%	0%	0%	25%	25%	50%	50%	75%	75%
09 IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL {From 2012 level}	0%	100%	0%	0%	25%	25%	25%	50%	50%	50%	38%
10 IMPROVED FURNACE DESIGN - INNOVATIVE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	13%
11 IMPROVED PROCESS CONTROL {From 2012 level}	0%	100%	0%	0%	25%	25%	25%	50%	50%	50%	75%
12 INCREASED USE OF Recycled glass - Container	56%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
13 INCREASED USE OF Recycled Glass - Flat	28%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
14 OXY-FUEL COMBUSTION	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15 WASTE HEAT RECOVERY- RAW MATERIALS PRE-HEATING	0%	100%	0%	0%	0%	0%	0%	10%	10%	10%	10%
16 RENEWABLE GENERATION	0%	100%	0%	0%	0%	0%	0%	10%	10%	10%	10%
17 WASTE HEAT RECOVERY - other	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 7: Max Tech pathway with CCS, challenging world scenario

Collaborative Growth

Pathway: Business As Usual   Scenario: Collaborative Growth (CG)

OPTION	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 BATCH PELLETISATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
02 BATCH REFORMULATION	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
03 CARBON CAPTURE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 ELECTRIC MELTING	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 WASTE HEAT RECOVERY - ELECTRICITY FROM WASTE HEAT	0%	100%	0%	0%	5%	5%	10%	10%	25%	25%	25%
06 FUEL SWITCHING - GAS	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 FUEL SWITCHING - HYDROGEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 GENERAL UTILITIES {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	75%	75%	100%	100%
09 IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	75%	75%	100%	58%
10 IMPROVED FURNACE DESIGN - INNOVATIVE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	13%
11 IMPROVED PROCESS CONTROL {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	75%	75%	100%	100%
12 INCREASED USE OF Recycled glass - Container	56%	100%	0%	0%	0%	0%	25%	25%	25%	50%	50%
13 INCREASED USE OF Recycled Glass - Flat	28%	100%	0%	0%	0%	0%	25%	25%	25%	50%	50%
14 OXY-FUEL COMBUSTION	0%	100%	0%	0%	0%	5%	10%	10%	10%	20%	20%
15 WASTE HEAT RECOVERY- RAW MATERIALS PRE-HEATING	0%	100%	0%	0%	0%	0%	10%	10%	25%	25%	25%
16 RENEWABLE GENERATION	0%	100%	0%	0%	0%	0%	10%	10%	25%	25%	25%
17 WASTE HEAT RECOVERY - other	0%	100%	0%	0%	5%	5%	10%	10%	10%	10%	10%

Figure 8: BAU pathway, collaborative growth scenario

Pathway: 20% - 40% Scenario: Collaborative Growth (CG)

OPTION	ADOP.	APP.	DEPLOYMENT								
			2014	2015	2020	2025	2030	2035	2040	2045	2050
01 BATCH PELLETISATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
02 BATCH REFORMULATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
03 CARBON CAPTURE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 ELECTRIC MELTING	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
05 WASTE HEAT RECOVERY - ELECTRICITY FROM WASTE HEAT	0%	100%	0%	0%	0%	0%	10%	25%	25%	25%	50%
06 FUEL SWITCHING - GAS	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 FUEL SWITCHING - HYDROGEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 GENERAL UTILITIES {From 2012 level}	0%	100%	0%	0%	25%	50%	75%	75%	100%	100%	100%
09 IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL {From 2012 level}	0%	100%	0%	0%	25%	50%	75%	75%	75%	75%	63%
10 IMPROVED FURNACE DESIGN - INNOVATIVE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	13%
11 IMPROVED PROCESS CONTROL {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	75%	75%	100%	100%
12 INCREASED USE OF Recycled glass - Container	56%	100%	0%	0%	0%	0%	25%	25%	25%	50%	50%
13 INCREASED USE OF Recycled Glass - Flat	28%	100%	0%	0%	0%	0%	25%	25%	25%	50%	50%
14 OXY-FUEL COMBUSTION	0%	100%	0%	0%	0%	5%	10%	10%	10%	20%	20%
15 WASTE HEAT RECOVERY- RAW MATERIALS PRE-HEATING	0%	100%	0%	0%	0%	0%	10%	10%	25%	25%	25%
16 RENEWABLE GENERATION	0%	100%	0%	0%	0%	0%	10%	10%	25%	25%	25%
17 WASTE HEAT RECOVERY - other	0%	100%	0%	0%	5%	5%	10%	10%	10%	10%	10%

Figure 9: 20-40% CO_2 reduction pathway, collaborative growth scenario

Pathway: 40% - 60% Scenario: Collaborative Growth (CG)

OPTION	ADOP.	APP.	DEPLOYMENT								
			2014	2015	2020	2025	2030	2035	2040	2045	2050
01 BATCH PELLETISATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
02 BATCH REFORMULATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
03 CARBON CAPTURE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 ELECTRIC MELTING	0%	100%	0%	0%	0%	25%	50%	50%	50%	50%	50%
05 WASTE HEAT RECOVERY - ELECTRICITY FROM WASTE HEAT	0%	100%	0%	0%	0%	0%	10%	25%	25%	25%	25%
06 FUEL SWITCHING - GAS	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 FUEL SWITCHING - HYDROGEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 GENERAL UTILITIES {From 2012 level}	0%	100%	0%	0%	25%	50%	75%	75%	100%	100%	100%
09 IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	50%	50%	25%	25%
10 IMPROVED FURNACE DESIGN - INNOVATIVE	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	25%
11 IMPROVED PROCESS CONTROL {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	75%	75%	100%	100%
12 INCREASED USE OF Recycled glass - Container	56%	100%	0%	0%	0%	0%	25%	25%	50%	50%	75%
13 INCREASED USE OF Recycled Glass - Flat	28%	100%	0%	0%	0%	0%	25%	25%	25%	50%	50%
14 OXY-FUEL COMBUSTION	0%	100%	0%	0%	0%	5%	10%	10%	10%	20%	20%
15 WASTE HEAT RECOVERY- RAW MATERIALS PRE-HEATING	0%	100%	0%	0%	0%	0%	10%	25%	25%	25%	50%
16 RENEWABLE GENERATION	0%	100%	0%	0%	0%	0%	10%	10%	25%	25%	25%
17 WASTE HEAT RECOVERY - other	0%	100%	0%	0%	5%	5%	10%	10%	10%	10%	10%

Figure 10: 40-60% CO_2 reduction pathway, collaborative growth scenario

Pathway: Max Tech no CCS Scenario: Collaborative Growth (CG)

OPTION	ADOP.	APP.	DEPLOYMENT								
			2014	2015	2020	2025	2030	2035	2040	2045	2050
01 BATCH PELLETISATION	0%	100%	0%	0%	0%	25%	25%	25%	50%	50%	75%
02 BATCH REFORMULATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
03 CARBON CAPTURE	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 ELECTRIC MELTING	0%	100%	0%	0%	0%	25%	50%	50%	50%	50%	50%
05 WASTE HEAT RECOVERY - ELECTRICITY FROM WASTE HEAT	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
06 FUEL SWITCHING - GAS	0%	100%	0%	0%	0%	0%	0%	25%	25%	50%	50%
07 FUEL SWITCHING - HYDROGEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 GENERAL UTILITIES {From 2012 level}	0%	100%	0%	0%	25%	50%	75%	75%	100%	100%	100%
09 IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	50%	25%	25%	0%
10 IMPROVED FURNACE DESIGN - INNOVATIVE	0%	100%	0%	0%	0%	0%	0%	0%	25%	25%	50%
11 IMPROVED PROCESS CONTROL {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	75%	75%	100%	100%
12 INCREASED USE OF Recycled glass - Container	56%	100%	0%	0%	0%	0%	25%	50%	50%	75%	80%
13 INCREASED USE OF Recycled Glass - Flat	28%	100%	0%	0%	0%	0%	25%	25%	50%	50%	75%
14 OXY-FUEL COMBUSTION	0%	100%	0%	0%	0%	25%	25%	25%	25%	50%	50%
15 WASTE HEAT RECOVERY- RAW MATERIALS PRE-HEATING	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
16 RENEWABLE GENERATION	0%	100%	0%	0%	0%	0%	10%	10%	25%	25%	50%
17 WASTE HEAT RECOVERY - other	0%	100%	0%	0%	5%	5%	10%	10%	10%	10%	10%

Figure 11: Max Tech pathway without CCS, collaborative growth scenario

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

OPTION	ADOP.	APP.	2014	2015	2020	2025	2030	2035	2040	2045	2050
01 BATCH PELLETISATION	0%	100%	0%	0%	0%	25%	25%	25%	50%	50%	75%
02 BATCH REFORMULATION	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
03 CARBON CAPTURE	0%	100%	0%	0%	0%	25%	25%	50%	75%	75%	100%
04 ELECTRIC MELTING	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 WASTE HEAT RECOVERY - ELECTRICITY FROM WASTE HEAT	0%	100%	0%	0%	0%	0%	0%	13%	13%	13%	13%
06 FUEL SWITCHING - GAS	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 FUEL SWITCHING - HYDROGEN	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 GENERAL UTILITIES {From 2012 level}	0%	100%	0%	0%	25%	50%	75%	75%	100%	100%	100%
09 IMPROVED FURNACE CONSTRUCTION - CONVENTIONAL {From 2012 level}	0%	100%	0%	0%	25%	50%	75%	75%	75%	75%	50%
10 IMPROVED FURNACE DESIGN - INNOVATIVE	0%	100%	0%	0%	0%	0%	0%	0%	25%	25%	50%
11 IMPROVED PROCESS CONTROL {From 2012 level}	0%	100%	0%	0%	25%	50%	50%	75%	75%	100%	100%
12 INCREASED USE OF Recycled glass - Container	56%	100%	0%	0%	0%	0%	25%	50%	50%	75%	90%
13 INCREASED USE OF Recycled Glass - Flat	28%	100%	0%	0%	0%	0%	25%	25%	50%	50%	75%
14 OXY-FUEL COMBUSTION	0%	100%	0%	0%	0%	25%	25%	50%	50%	75%	75%
15 WASTE HEAT RECOVERY- RAW MATERIALS PRE-HEATING	0%	100%	0%	0%	0%	0%	0%	13%	13%	13%	13%
16 RENEWABLE GENERATION	0%	100%	0%	0%	0%	0%	10%	10%	25%	25%	50%
17 WASTE HEAT RECOVERY - other	0%	100%	0%	0%	5%	5%	10%	10%	10%	10%	10%

Figure 12: Max Tech pathway with CCS, collaborative growth scenario

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