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

Chemicals Appendices

MARCH 2015

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – CHEMICALS

APPENDIX A - METHODOLOGY

APPENDIX A METHODOLOGY

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

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

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

An important aspect of the methodology has been stakeholder engagement to ensure that all relevant parties have been invited to participate and contribute. We have worked closely with the Chemical Industries Association (CIA), the Department of Energy and Climate Change (DECC) and the Department for Business Innovation and Skills (BIS) to invite the appropriate industry, academic and other stakeholders, such as financial industry personnel, to participate.

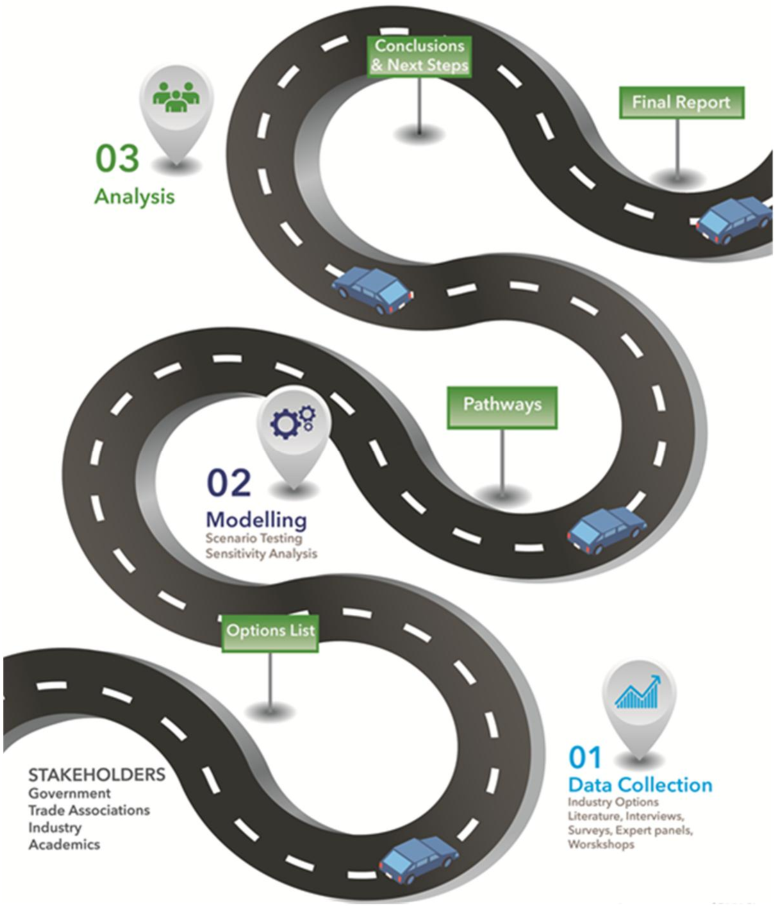

Figure 1 Roadmap Methodology

1. Evidence Gathering

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

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

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

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

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

The evidence gathering exercise was subject to inherent limitations based upon the scale of activities and sample sizes that could be conducted within the time and resources available. The literature review was not intended to be exhaustive and aimed to capture key documentation that applied to the UK. The companies interviewed represented over 35% of carbon emissions produced in the UK chemicals sector and captured both UK decision makers and technical specialists in the sector. These interviews were conducted to provide greater depth and insight to the issues faced by companies. However, because many of the companies in the UK are globally owned, it was difficult to involve senior staff at a global corporate level. This also applied to workshop attendees.

The identification of relevant information and data was approached from a global and UK viewpoint. The global outlook examined dominant technologies and process types, global production and Carbon Dioxide (CO_2) emissions (in the EU27) and the global outlook to 2050, including the implications for chemicals 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 chemicals producers and their key sites, dominant technologies and processes were also reviewed.

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

2. Literature Review

A literature review was undertaken on the chemicals sector. Its aim was to help to identify options, barriers and enablers for implementing decarbonisation throughout the sector. It sought to answer the principal questions and identify 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 150 documents. This was not a thorough literature review or rapid evidence assessment (REA) but a desktop research exercise deemed sufficient by the project team[1] in its breadth and depth to capture the evidence required for the purpose of this project. Based on the table of contents and a quick assessment (10 to 30 minutes per document), criteria were defined to identify which documents were to be used for the detailed analysis and information gathering (see 3 of APPENDIX A). Where literature was deemed significant and of good quality, it was read and results were gathered on the principal questions.

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

The literature review was conducted in the following phases:

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

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

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

Table 1: Scope of review

3. Criteria for Including Literature

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

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

Table 2: High level selection criteria

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

A total of more than 150 papers, official publications and grey literature[2] documents on chemicals 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
- Financial-technical evaluation criteria present (YES/NO)
- Overall quality of the document (+/++/+++)
- Relevance for the UK chemicals sector (0/+/++/+++)
- Information on technological aspects (0/+/++/+++)
- Information on drivers and barriers (0/+/++/+++)
- Information on policy/legislation (0/+/++/+++)
- Document relevant for developing scenarios (0/+/++/+++)

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

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

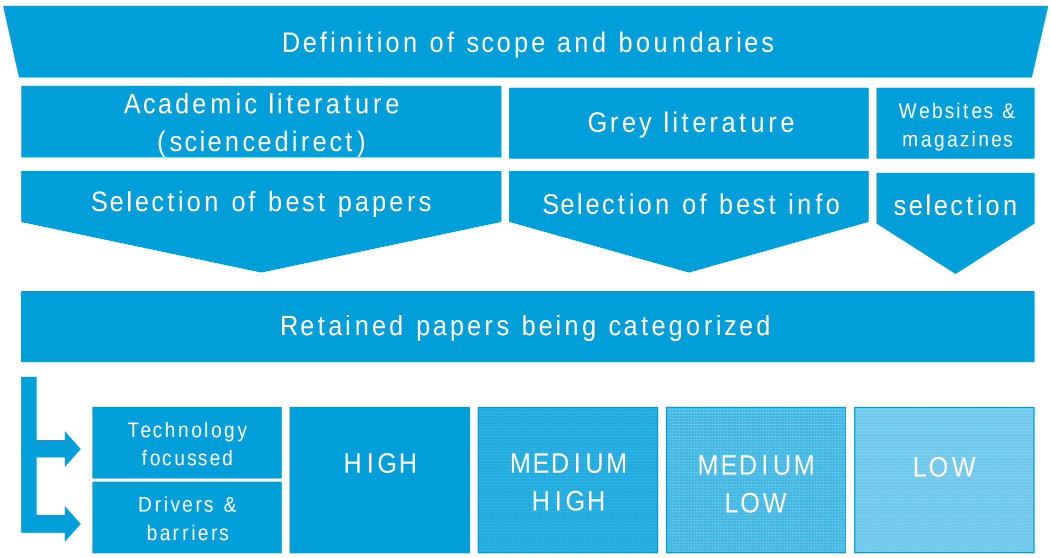

Table 3: Diagram of the selecting and categorising process

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

[2] Grey literature refers to sources such as industry presentations, case study reports etc. that may not have been formally published or peer-reviewed.

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

4. Technical Literature Review

Identifying Literature

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

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

Research Questions

The evidence review addressed the following research questions:

TECHNICAL POTENTIAL: What existing research is there on the technical potential for improving the energy efficiency and lowering the carbon footprint of the chemicals 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 chemicals sector to decarbonise their energy use? What are the perceived benefits for industrial organisations to decarbonise their heat use?

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

PRINCIPAL QUESTIONS: Check for other links to issues raised by principal questions.

Strengths, Weaknesses, Opportunities and Threats (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 and by following up references identified in initial documents or by the chemicals sector team. The search terms used in Google were:

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

In addition, specific sub-sector names (e.g. “olefins”, “titanium dioxide” etc.) were used in place of “chemicals” where required to fill gaps in the data.

The results of the technical literature review are summarised in Table: 4

Summary of strength of evidence on energy efficiency in chemicals 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	3	21	2	1	27	2	11	12	2
Technologies	3	7	2	1	13	2	4	6	1
CO_2 and CCS	0	5	2	1	8	2	5	1	0
Social and Business	7	3	1	7	18	2	9	2	5

Table: 4 Overview of literature review

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

5. Social and Business Literature Review

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

- We reviewed over 20 documents (some of them the same as the technical literature review) to create a broad overview of the sector SWOT and identification of drivers and barriers to energy efficiency improvement and decarbonisation, and identification of main uncertainties in generic and business environment;
- The literature review included documents listed in the Invitation To Tender as well as grey literature from trade associations, companies, DECC and BIS. Specific search terms were used which were agreed with DECC to identify the key enablers and barriers;
- We used a systematic and structured approach to the literature review. The criteria for assessing the relevance of the literature were defined to determine whether they address the key principal questions. The literature identified was analysed using a quick assessment process to identify the most relevant information on SWOT, enablers and barriers to decarbonisation; and
- Based on table of contents and a quick assessment, we presented the results in a table as below. The analysis resulted in the identification of documents to be used for detailed analysis and information gathering. Where literature was deemed significant and of good quality (three stars or above), the literature was read and reviewed and results were gathered on the principal question areas.

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

Table 5: 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.

6. Interviews

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

The interviews focused on the largest emitters based on information from the EU Emissions Trading Scheme (EU ETS) and the UK Pollutant Release and Transfer Register (UK PRTR) datasets. Of the companies who originally were selected in consultation with DECC and CIA to be interviewed, two declined to participate. Two companies provided input electronically. Interviews were held with:

Company Name	Interviewee role[3]	Sub-sector	Size
INEOS	Director	Olefins, Acrylonitrile, Chlorine	Large (over 500 employees)
GrowHow	Manager and Director	Ammonia	Large
SABIC	Chairman	Olefins	Large
BOC	Manager	Hydrogen	Large
Tata chemicals	Director	Soda ash	Large
BP chemicals	Manager	Acetic acid	Large
Lucite	Manager	Methyl methacrylate	Large
Cristal	Director	Titanium dioxide	Large

Table 6: List of interviewees

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

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

Evidence Gaps

As a number of key UK chemicals producers were not able to participate in the information gathering workshop. A number of additional technical interviews were agreed in order to ensure that options related to these producers’ processes were fully considered. Interviews were held with GrowHow, SABIC UK and Ineos, covering the ammonia and olefins sectors. Discussions also took place with Ineos Nitriles (acrylonitrile) who indicated that they had no further information to add to the generic options presented at the workshop.. These interviews helped to refine the options ahead of the pathway development process.

Assumptions

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

1. Results from the literature review are available and partially or well covered. Well-covered areas are not addressed during the interview. Results may include:
    a. Option register of technical options.
    b. sector and subsector characteristics.
    c. sector SWOT analysis.
    d. Main trends and drivers.
    e. Some hurdles to and barriers for change and/or energy or decarbonisation.
2. Preparation of interviews includes rapid review of website and annual reports information related to business and energy and emissions reduction strategies.

[3] managers include site managers, general managers, energy managers, utility managers

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 CIA, DECC and BIS in order to achieve a good coverage of the sector. The methodology for identifying the appropriate number of interviews was the following:

- Identify the number of subsectors by the SIC (standard industrial classification) codes listed in the invitation to tender (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 (small and medium sized enterprises (SME's) in the group of companies that covers 80% of the emissions in the sectors where we are not performing a survey;
    - Innovation level of companies such as front runners or laggards;
    - Whether headquarter is in UK or abroad; and
    - The level of integration of the production units in the supply chain (non-integrated, somewhat integrated, fully integrated).

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

***2.* Interview preparation**

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

- Social business literature review

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

3. Interview format

Introductions

Interviewer sets out the project context and interview agenda.

Goals

Interviewer introduces the goals of the project as follows:

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

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

    b. Develop an understanding of the decision-making processes

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

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

    a. As currently deployed by organisations

    b. As an option to be deployed in the future

3. Understanding of the main drivers and barriers for change in general and with regard to energy and carbon reduction in the sector

4. To develop insight into the specific characteristics (strengths, weaknesses, opportunities and threats) of subsectors (where required)

Existing and future strategy for energy and carbon reduction

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

1. What is your organisations strategy for energy and carbon reduction? (If the strategy is clear, summarise and ask for confirmation). Cover the following sub-questions:

    a What are the main elements of the strategy?

    b How far in advance are you planning the company's energy efficiency strategy?

c In your opinion, what are the enablers and/or challenges for the strategy?

i) Please specify why:

1. Constrained finance for funding for investments internally or externally
2. Etc.

2. Do you consider your organisation as a leader (innovator or early adopter) or as a follower (early, late majority) on energy and carbon reduction? Cover the following sub-questions:

   a. Can you give one or more example(s) of actions undertaken by members of your organisation that fit with the stated market position?

   b. Do you expect the organisation's position with regard to energy and carbon reduction to change?

   c. Please state why your organisation is or is not a leader.

3. What energy and carbon projects have you implemented the last five years and why? What energy and carbon projects have you not implemented the last five years and why?

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

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

Stories (interviewees not self-identified as leaders)

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

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

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

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

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

   a. What was the timeline, sequence of events?

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

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

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

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

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

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

    a. Lessons for future action?

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

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

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

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

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

Business Environment: value chain and capacity for innovation

Interviewer to ask the following questions:

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

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

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

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

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

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

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

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

2. Main innovators or early adopters in the sector:

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

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

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

3. Questions on the dimensions of innovations[4] . These questions will be on a multiple choice list (answer categories strongly disagree, disagree, neither agree or not agree, agree, strongly agree[5]). After filling the list, ask for clarifications and examples that underpin answers in the following areas:

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

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

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

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

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

Enablers and barriers for sector change

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

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

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

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

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

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

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

Function of Interview Template and Protocol:

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

Intro	5-10 minutes
Current state and plans energy and decarbonisation	20-30 minutes
Stories of energy and decarbonisation	30-45 minutes

[4] 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.

[5] 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.

Business environment and innovation power	15-20 minutes
Drivers and hurdles for sector change (to test survey/workshop questionnaire)	If time left

Table 7: General interview timeline

7. Survey

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

The survey was distributed to general managers and energy/environment managers from member organisations of the CIA. The questions in the survey were tailored to chemicals producers, and were developed in consultation with the CIA 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 and decarbonisation technologies of 15 enablers and 15 barriers identified from the literature review and interviews;
c. Prioritise top 5 Strengths, Weaknesses, Opportunities and Threats of the sector; and
d. Assess current conditions and capacity of the organisations to respond to decarbonisation.

Survey Questions:
1. What Subsector are you working in or what is your relation to the 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 and decarbonisation technologies in your organisation? (A list of 15 enablers identified from the literature review was provided for assessment).
6. Are there any additional enablers that you think are relevant? Please provide details of these and an impact score based on the same scale.
7. What impact do the following barriers have in relation to implementing energy 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 select the 5 strengths that are the most relevant to your organisation. (A list of 15 strengths identified from the literature review and interviews was provided for assessment).
10. Please add any other strengths of your organisation that are not included in the list.
11. Please select the 5 weaknesses that are the most relevant to your organisation. (A list of 12 weaknesses identified from the literature review and interviews was provided for assessment).
12. Please add any other weaknesses of your organisation that are not included in the list.
13. Please select the 5 opportunities that your company could potentially explore to maximise the implementation of energy and decarbonisation technologies. (A list of 15 opportunities identified from the literature review and interviews was provided for assessment).
14. Please add any other opportunities of your organisation that are not included in the list.
15. Please select the 5 threats that will potentially hinder your organisation in implementing energy and decarbonisation technologies. (A list of 15 threats identified from the literature review and interviews was provided for assessment).

16. Please add any other threats of your organisation that are not included in the list.
17. Please assess to what degree each statement is true for your organisation.
    - We have well defined goals/objectives and/or targets on energy 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 and decarbonisation;
    - Our decision-making process works well for new energy 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 or decarbonisation;
    - We have strong communication and information sharing channels that support the successful implementation of options with regards to energy and decarbonisation;
    - We understand which energy and decarbonisation technologies can be implemented in our organization; and
    - We have sufficiently skilled workforce to implement and handle energy and decarbonisation technologies.

Table 8: List of survey questions

For questions 5, 6, 7 and 8, respondents were given the following impact scale for assessing each enabler and barrier: (-1) negative impact, (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, 17 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 information gathering stage of the project also involved Workshop 1, the 'Information Gathering Workshop'.

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

The workshop was divided into four key activities:

The first activity focused on reviewing the potential generic technological options for decarbonisation and identifying the enablers, barriers, advantages, and disadvantages of each. Workshop participants were divided into four groups. In order to allow time for reasonable discussion of individual options, the generic options were divided before the workshop into either 'Top 10' or secondary decarbonisation technology options. Each group received half of the 'top 10' options for discussion, as well as all the secondary options. The participants at each group were encouraged to separate into two subgroups: one to discuss the 'top 10' generic options and another to act as 'hunter gatherers' checking the secondary options. After the initial discussions, all of the participants reconvened at each group in order to provide a summary of their discussions and vote on the technologies that each individual felt would help the sector to decarbonise the most, and on the technologies that they felt would significantly impact on the energy efficiency of the sector.

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

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

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

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

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

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

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

9. Pathways

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

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

In addition, two purely technology-driven pathways were developed: a Business as Usual (BAU) pathway and a Maximum Technical (Max Tech) pathway.

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

Max Tech represents a pathway where all technically feasible options are deployed when they become available without cost being a limitation, but while also being reasonably foreseeable. Reasonably foreseeable in this context means that the technology has been demonstrated at least at pilot scale and that the envisaged deployment is not based on unrealistic requirements e.g. the installation of a CO_2 pipeline network connecting every chemical plant in the country.

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

10. Pathways Development and Analysis

Overview

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

The principal vehicle for developing the pathways was a pathways development meeting held between Parsons Brinckerhoff, the CIA and DECC in early September 2014. Logic reasoning (largely driven by option interaction and scenario constraints), sector knowledge and technical expertise were applied when selecting options for the different pathways under each scenario. For example, incremental options with lower costs and higher levels of technical readiness were selected for the lower decarbonisation bands, whereas more “disruptive” options were selected for the higher decarbonisation bands in order to reach the desired levels of decarbonisation. These pathways were challenged by the sector team, modelled and assessed under the three scenarios and finally challenged by the stakeholders participating in the second workshop. This workshop feedback was then taken into account and final pathways were developed. All quantitative data and references were detailed in the options register and relevant worksheets of the model.

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

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

Process

1. The gathered evidence (from literature review, sector team discussions, stakeholder feedback and judgement) was consolidated into a condensed list of options.

2. Timing and readiness of options was developed by the sector team and during the first workshop, based on evidence from literature, sector knowledge and technical expertise.
3. BAU and Max Tech options were chosen and rolled out to the maximum level and rate allowable under the current trends scenario.
4. Options were added to the BAU pathway or reduced or taken out of the Max Tech pathway until each intermediary pathway band was reached.
5. Technical constraints and interactions across the list of options were taken into account when selecting options and roll-out.
6. The roll-out was adjusted to account for the output of the social and business research as well as current investment cycles.
7. pathways were modelled under the current trends scenario, accounting for changes in production and the carbon emissions of the electricity grid.
8. The results were reviewed and modifications made to the deployment, applicability and reduction potential for any options that appeared to be giving an unexpected or unusual result.
9. Further changes to option choices were made as required through iterations of points 5-9.
10. Revised pathways under current trends were produced for presentation at the second workshop.
11. Feedback on pathways was used to make any further necessary adjustments to the pathways under current trends.
12. The final pathways developed under current trends were used as a basis for the development of pathways under challenging world and collaborative growth scenarios;
13. Deployment of each option under challenging world and collaborative growth was adjusted according to the constraints of each scenario, including the removal of options that would not be likely under challenging world and the deployment of additional options that would become feasible under collaborative growth; and
14. Roll-out for each option was adjusted within the technical and scenario constraints in order to reach each pathway band where possible (note that not all pathway bands are possible under some scenarios).

The options register is provided in Appendix C.

Deployment of Options

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

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

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

Option Interaction

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

- **One option excludes another:** This is taken into account by the user in the roll-out inputs in the Option Selector by ensuring that no exclusive options are rolled out to a conflicting level in the same time period.
- **One option depends upon another being adopted:** This is taken into account by the user in the roll-out section of the Option Selector by ensuring that if any option requires a precursor, then this precursor is rolled out to the appropriate level.
- **Options are independent and act in parallel:** The "Minimum Interaction" pathway curve assumes that all options are independent and their effect on energy or emissions are therefore incremental.
- **Options improve a common energy or emission stream and act in series:** The "Maximum Interaction" pathway curve assumes that the saving from each option reduces the remaining energy or emissions for downstream options to act upon.

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 of product or Mt CO_2/tonne of product), which should be taken into account when calculating emissions. However, a full bottom-up model would be needed, which was beyond the scope of this work.

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

The 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.

11. Pathways Modelling

Scenarios

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

For each pathway, the following three scenarios were tested: current trends, challenging world and collaborative growth. Scenario parameters are shown in Table 9 below.

Current Trends

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

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

Chemicals production was assumed to increase by 1% annually through to 2050 in response to moderate UK and global growth. Unilateral climate change policies in the UK/EU were assumed to place a constraint on the growth of the UK sector.

Challenging World

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

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

The chemicals industry was subject to lower global growth rates and weaker international trade, leading to a decline of 0.5% per year in UK production over the period. Lower levels of investment and innovation were also assumed as a result. Lower production levels lead to lower emissions, before any decarbonisation options are deployed.

Collaborative Growth

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

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

The UK chemicals industry sees growth at 2.5% per year, enabling higher levels of investment and innovation.

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

	Challenging world	Current trends	collaborative growth
World energy demand and supply outlook	Significant growth in demand with strong competition for resources. High dependence on imported fossil fuels	Balanced but demand growth dependent on supplies of fossil fuels from new fields.	Growing demands balanced by strong growth in supply of renewable energy, slowly declining importance of fossil fuels.
UK Economic outlook	Weaker Office of Budget Responsibility (OBR) growth assumption.	Current OBR growth assumption	High OBR growth assumptions
Carbon intensity of electricity	Weakest trend of electricity carbon intensity reduction 200g/kWh at 2030	Stronger trend of electricity carbon intensity reduction 100g/kWh at 2030	Rapid decline in electricity carbon intensity 50g/kWh at 2030
Price of electricity	Could be higher or lower	Central prices	Likely to be higher
Fossil Fuel	Higher and volatile fuel prices Updated energy production (UEP) high	UEP central	UEP central?
Carbon Prices	UEP low carbon price	UEP central carbon price	UEP high carbon prices
CCS availability	Technology develops slowly, only becoming established by 2040	Technology does not become established until 2030	Technology becomes proven and economic by 2020
Low carbon process technology	New technology viability delayed by 10 years	New technology economically viable as expected	New technology viability achieved early

Table 9: Summary of scenario context and specific assumptions applicable to the scenarios

The application of these scenarios to the UK chemicals sector provided the sector-specific trends shown in Table 10 below. These were used to inform the development of the pathways.

	Challenging world	Current trends	Collaborative growth
Chemical sector production growth p.a.	-0.5%	1%	2.5%
Opportunities for growth	• UK shale gas becomes available and provides a degree of feedstock security • Slow-down in unilateral climate change policies reduces competitiveness impacts	• UK shale gas becomes available and provides a degree of feedstock security • Bi-lateral trade agreements including Transatlantic Trade and Investment Partnership (TTIP) • Continued product innovations	• International agreement on climate change creates level playing field • UK shale gas becomes available and provides feedstock security • EU shale gas developed helping energy price competitiveness • World Trade Organisation agreement • High levels of product innovation
Challenges	• Increased protectionism and tariffs reduces demand for traded bulk chemicals and economic efficiency • High energy/resource prices • Slow-down in innovation	• Cost of unilateral climate change policies constrains growth	• Availability of resources
Changes in customer needs, products	• Emphasis on price	• Some demand for climate change solutions and products with carbon footprints	• Increased demand for climate change solutions and products with reduced carbon footprints
Changes in value chain	• Some onshoring of production to UK in response to protectionism • Current levels of clustering and collaboration	• Some onshoring and rebuilding of supply chains with growth sectors • Current levels of clustering and collaboration.	• Significant onshoring and rebuilding of supply chains • Increased levels of clustering and collaboration and recycling
Process, production technology	• Short payback measures implemented, plant lives extended where possible	• Short payback measures implemented, some plant replacement • Some development of alternative feedstocks – waste, biofuels, carbon capture and utilisation (CCU)	• Higher levels of investment • Good development of alternative feedstocks – waste, biofuels, CCU • Growth in biotechnology, Process Intensification and other innovative technologies.
Energy use / mix sector	• Continued use of gas for heat • Limited decarbonisation of power supply	• Mainly gas for heat, limited biomass and CCS • Significant decarbonisation of power supply	• Mainly gas for heat, more biomass and CCS • High decarbonisation of power supply

Table 10: Sector specific scenarios

12. Options

Options Processing

The options register was developed jointly by the technical and social and business research teams. This was achieved by obtaining the list of potential options from interviews, literature and the information gathering workshop. The technical team drafted the first list of options. However, each option had strengths, weaknesses, enablers, and barriers which needed to be taken into account to develop and refine the options register to feed into the model.

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

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

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

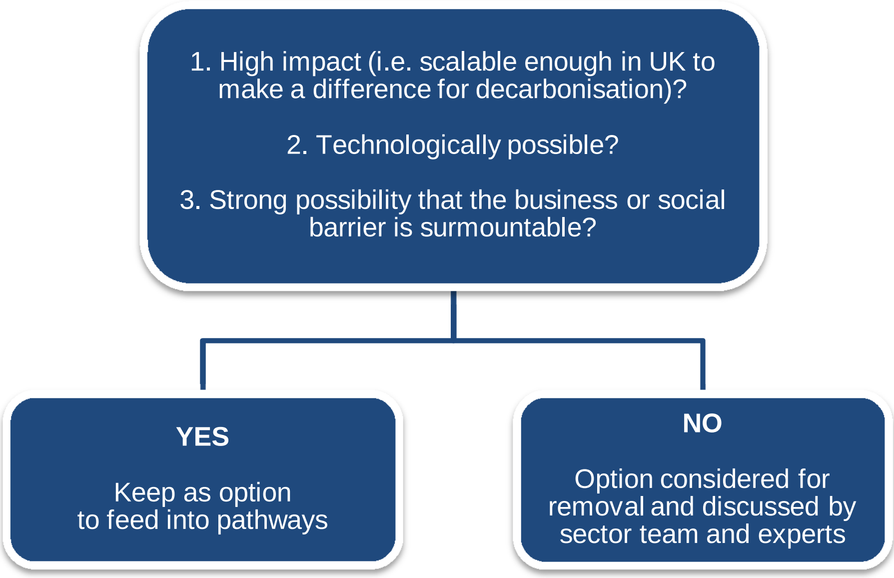

Figure 2: Social and business pathways impact tree

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 chemicals sector more generally.

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

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

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

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

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – CHEMICALS

APPENDIX B – FULL SOCIAL AND BUSINESS FINDINGS

APPENDIX B FULL SOCIAL AND BUSINESS FINDINGS

1. SWOT Outcomes

The figure below highlights the key strengths, weaknesses, opportunities and threats in relation to industry investment into decarbonisation.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
Strong product innovation and R&D	Internal competition for resources	Cooperative research and innovation	Regulatory uncertainty
Recognised globally for its expertise R&D and in terms of high-value specialty products	There is a significant cost disadvantage to other regions	Advanced research and product development	Rising cost base of materials and fuel
Strong investment to date into energy reduction/efficiency	Fragmented supply chain	Supporting other sectors to grow and reduce greenhouse gas (GHG) emissions	Aging infrastructure and asset base
The sector contributes to a wide range of products across the economy	High energy consumption needs	Taking advantage of cost-effective abatement projects and technologies	Lower investment rates in the UK due to less attractive returns compared to other locations
Existing infrastructure is well-functioning and continuously integrated and optimized			

Table 11: SWOT analysis for chemicals sector

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. 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 12 below.

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

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

Classification	Definition
High	High relevance for the UK chemicals sector Good financial-economic decarbonisation data Recent information (after 2000) Provides a good example/story of decarbonisation Validated across all evidence gathering methods
Medium high	Relevance for the UK chemicals 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 or too general or too specific Relevant grey literature Old information but still relevant If only mentioned via one information gathering method
Low	Background information No or low applicability for the UK chemicals sector Grey literature of limited value Old information Lack of relevance and/or only mentioned once

Table 12: Evidence classification definition

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

3. Detailed analysis of enablers and barriers

Enablers

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
1	Financial	Financial incentives to adopt energy and decarbonisation technologies	2 Sources: The Chemistry Growth Strategy Group identified the need to "incentivise and increase update of existing energy efficiency measures…" and to "ensure the right framework and incentives for the adoption of energy efficient and low-carbon technologies to reduce emissions". McKinsey and Company identified the need to "allow markets to incentivise fast action by rewarding early movers that proactively reduce their CO_2e footprint".	Interviewee: One interview indicated that what is needed is "more incentives and less punishment" when discussing the update and adoption of more efficient technologies.	0.0% (0) – negative impact 5.9% (1) – no impact 5.9% (1) - no-to-low impact 23.5% (4) – low-to-medium impact 17.6% (3) – medium-to-high impact 47.1% (8) – very high impact 0.0% (0)I don't know	(4) Very High Impact: Workshop participants identified this as a key enabler to help companies develop their business case and achieve internal hurdle rates.	Workshop participants highlighted the need for incentives as a key enabler for the adoption of more efficient technology. This links to the enabler of recognising the key technologies and supporting these (see #16 below). Both interviewees and workshop participants highlighted the need for incentive schemes to be long-term commitments, as u-turns in policy (around incentive schemes) can be damaging, particularly when the business case for investment is marginal and is highly dependent upon factors such (fluctuating) energy prices.
2	Technology	A sector framework for investment in innovation / R&D	2 Sources: The Chemistry Growth Strategy Group identified the need to "stimulate R&D programmes and facilitate new technologies prior to commercialisation to focus	Interviewee: "We need to decide what the overall value position of the UK is going to be…if we understand how the parts of the industry	0.0% (0) – negative impact 11.8% (2)) – no impact 29.4% (5) -- no-to-low impact 23.5% (4) – low-to-	(3) Medium-High Impact: Workshop participants indicated that there is value in a sector framework and to focus innovation in where the	A common theme for R&D from across the literature, interviews and workshop, is that it needs to have clear direction. The UK must decide where it is to focus and how it can use

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
			on whole life cycle”. The European Chemistry Industry Council found that “R&D support for innovation should facilitate new breakthrough technologies in pre-competitive phases and should focus on innovative solutions across the borders of individual sectors”. The European Chemical Industry Council state that “industry will need to move beyond incremental energy efficiency towards more radical step changes” and that R&D is key to this.	can fit together, then collaborations can be based upon this” and “there is a need to convince and bring appropriate parties together”.	medium impact 29.4% (5) – medium-to-high impact 0.0% (0)– very high impact 5.9% (1) - I don't know	value chain is not delivering. The need for a ‘safe’ environment for investment was identified as a need – guided by a framework to provide direction to R&D efforts.	this to gain competitive advantage. The literature identifies the need to take a life cycle perspective, and workshop participants indicated the need to looks at the value chain. Either way, it means looking beyond specific companies and sub-sectors, and developing a holistic framework to guide activities.
3	Financial	Financial support for projects/ research	Not identified from literature – from interview.	Interviewee: “We do not have the resources to invest [in technology innovations] and need support in this area.	0.0% (0) – negative impact 17.6% (3) – no impact 23.5% (4) – no-to-low impact 35.3% (6) – low-to-medium impact 23.5% (4) – medium-to-high impact 0.0% (0) – very high impact 0.0% (0) - I don't know	(3) Medium-High Impact: Workshop participants felt that the importance of this enabler depended upon the organisation. Companies will prefer to use their own finance for smaller projects. Incentives to lower lending rates were identified as a means to enhance the enabler, in	The need for financial support will depend on the organisation. The majority of interview participants reported that finance was available internally. Further work would be required to understand the ability of smaller companies to finance improvements and any challenges that they face.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
						order to promote the business case.	
4	Market and Economy	Level playing field with competitor regions (e.g. EU, US, Middle East, Asia) in terms of policy / energy costs	3 Sources: The Chemistry Growth Strategy Group identified the need to "…create a regulatory climate and culture that strengthens international competitiveness and delivers growth while addressing social and environmental responsibilities". The European Climate Foundation identify that "well designed climate policies and competitiveness do not have to be contradictory, but can be complementary", and that smart strategies can both reduce emissions and stimulate Europe's industrial competitiveness. The European Chemistry Industry Council found that "industry wants a level playing field for the UK" as there is currently uncertainty around future carbon and energy prices.	Interviewee: "Investment partly depends on the price of carbon, and also on the balance of cost between regions" and "the conditions needs to be right [to invest in Europe], and the current competition issues need to be addressed". Interviewee: "The carbon price isn't as high as it should be, but in the UK carbon costs are higher than elsewhere. Three years ago the UK Government introduced a unilateral tax, and now after three years there has been a policy shift".	0.0% (0) – negative impact 17.6% (3) – no impact 5.9% (1) – no-to-low impact 5.9% (1) – low-to-medium impact 5.9% (1) – medium-to-high impact 64.7% (11) – very high impact 0.0% (0)I don't know	(4) Very High Impact: Workshop participants indicated that the attractiveness of the UK for investment is essential to fund energy efficient / low carbon. This can be achieved by extending support packages for energy intensive industry and work to drive down the costs associated with low carbon energy.	The need for a level playing field is seen to be a very important enabler across all information sources. It is a combination of factors that undermine global competitiveness, of which energy and policy costs are seen to be key contributors. The competitiveness of the UK is directly related to its attractiveness for inward investment, and therefore the ability to fund improvement projects.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
5	Technology	Greater information for the sector on key technologies and innovations	3 Sources: The European Chemical Industry Council found that there is a "lack of access to trusted and appropriate information" and that "Information is generic and not tailored…potential investors are not able to assess the benefits". Ricardo-AEA and Imperial College found that efficiency not always part of core business, and that "…staff do not know the options / technologies". Sorrell *et al* found that the "absence of credibility and trust in information on energy efficiency will mean that inefficient choices are made".	Not identified during interviews.	0.0% (0) – negative impact 11.8% (2) – no impact 29.4% (5) – no-to-low impact 35.3% (6) – low-to-medium impact 17.6% (3) – medium-to-high impact 5.9% (1) – very high impact 0.0% (0) I don't know	(1) Low Impact: Workshop participants did not identify this to be a significant enabler. Greater support for smaller companies / SMEs was identified as a potential need.	Numerous literature sources identified the lack of access to (credible) information as a barrier. This was not identified as a barrier (or the opposition as an enabler) during the interviews and workshop. This is not considered to be a significant enabler for larger companies, since these have dedicated technical or research departments.
6	People, Management and Organisation	Long-term co-operation and action by all stakeholders and across the value chain	1 Source: The European Chemistry Industry Council found that the industry will need to "continue to seek enhanced cooperation with other stakeholders along their value chain to foster development and greater uptake [of solutions]".	Interviewee: "We need to decide what the overall value position of the UK is going to be…if we understand how the parts of the industry can fit together, then collaborations can be based upon this" and "there is a need to	0.0% (0) – negative impact 23.5% (4) – no impact 23.5% (4) – no-to-low impact 23.5% (4) – low-to-high impact 23.5% (4) – medium-to-high impact 5.9% (1) – very high impact	(3) Medium Impact: Workshop participants indicated the need for a common understanding and clear framework (between Government, the value chain and customers) would be a basis for longer term action.	This was not identified as an enabler during the interviews and there is no clear opinion from the survey results. Workshop participants highlighted the challenge of this enabler in terms of the difficultly to encourage collaborate given

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
				convince and bring appropriate parties together".	0.0% (0) - I don't know		competition issues.
7	Legislation and Policy	A stable and predictable policy framework	1 Source: The European Chemistry Industry Council indicates that a "stable and predictable policy framework" is required in order to create "increased certainty for business". Note: this is related to the 'level playing field' enabler above and there is some overlap.	Interviewee: "An enabler is more certainty on what future legislation looks like. This is for investment decisions. So in terms of the EU ETS, carbon prices and so on". Interviewee: When discussing the renewable heat incentive for CHP, "The economics [of projects] can be finely balanced, and changes in policy can have significant impacts. Regulatory changes can leave you high and dry". Interviewee: "Certainty around the future policy landscape is needed – in the past there have been reversals and changes in direction. We need stability".	0.0% (0) – negative impact 11.8% (2) – no impact 5.9% (1) – no impact 5.9% (1) – low-to-medium impact 58.8% (10) – medium-to-high impact 17.6% (3) – very high impact 0.0% (0) - I don't know	Score not recorded.	The need for stability and certainty was identified by the majority of interviewees and workshop participants. This was identified from two perspectives – firstly the need for policy reversals to be avoided, and secondly the uncertainty of future policy and the associated costs. From the survey the majority of respondents scored this enabler as having a medium-high impact or high impact.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
8	People, Management and Organisation	Willingness of top management to make climate change a priority	1 Source: Sorrell *et al* identified that "energy management tends to have low status and may be viewed as peripheral issue by top management", and so there is a need for commitment from the top.	Not identified during interviews.	0.0% (0) – negative impact 0.0% (0) – no impact 17.6% (3) – no-to-low impact 5.9% (1) – low-to-medium impact 35.3% (6) – medium-to-high impact 41.2% (7) – very high impact 0.0% (0) I don't know	(1) Low Impact: Workshop participants indicated that decisions are customer and product led, and climate change is not a principal priority.	This was not identified as an enabler during the interviews, but all interviewees highlighted that energy is of vital importance to their business and is high profile. Workshop participants also indicated that decisions are made based on production and not led by concerns for climate change.
9	People, Management and Organisation	Environmental Management System to drive performance improvement	1 Source: The Centre for Sustainable Energy (CSE) and the Environmental Change Institute, University of Oxford found that "the evidence suggests that adoption of certificated Environmental Management System can lead to modest improvements in the environmental performance of an organisation, especially where improvements result from	Not identified during interviews.	0.0% (0) – negative impact 5.9% (1)- no impact 35.3% (6) – no-to-low impact 29.4% (5) – low-to-medium impact 29.4% (5) – medium-to-high impact 0.0% (0)- very high impact 0.0% (0) I don't know	(3) Medium-High Impact: Workshop participants indicated that ISO 50001 is a more important enabler. This gives the framework and requires commitment to maintain certification.	The presence of an EMS was not considered to be a significant enabler. However, workshop participants indicated that ISO 50001 requirements to have targets and demonstrate improvement helps to raise the profile within companies and promotes marginal improvement projects.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
			no or low cost measures".				
10	People, Management and Organisation	A strong, evidence-based business case for energy and decarbonisation measures that capture all benefits and cost	1 Source: The Carbon Trust identifies that business cases for investments "will need to be robust. Savings must be deliverable and all financial savings and costs captured".	Interviewee: "Payback on projects is the main consideration. Projects must meet the relevant financial criteria…" Interviewee: "An installation needs to be able to demonstrate profitability. A profitable industry will be invested in". Interviewee: "An important enabler is the de-risking of projects. Government can provide long term commitments for projects from 5 to 20 years. This will help overcome marginal or uncertain investment decisions".	0.0% (0) – negative impact 5.9% (1) – no impact 11.8% (2) – no-to-low impact 35.3% (6) – low-to-medium impact 35.3% (6) – medium-to-high impact 11.8% (2) – very high impact 0.0% (0) - I don't know	(4) Very High Impact: Workshop participants indicated that an evidence-based business case requires data, and good data helps to identify quick wins. The ability to demonstrate an attractive payback period was identified as being the top enabler. It was noted that energy efficiency 'wins' over decarbonisation. It was mentioned that Government needs to realise that legislation (and costs) impact on the business case, and therefore investment decisions.	Across all interviewees and workshop participants this was identified as a top enabler. Without a strong business case an improvement project will not pass through decision-making hierarchies. The need for certainty was highlighted as an issue, particularly for larger investments with payback over 5 years. The uncertainty over policy and energy costs can undermine business cases, particular when in completion internally with other regions where returns are more certain and secure (e.g. Asia).
11	People, Management and Organisation	Proximity of the energy manager to the CEO	1 Source: The Centre for Sustainable Energy (CSE) and the Environmental Change Institute, University of Oxford found that "the	Not identified during interviews.	0.0% (0) – negative impact 23.5% (4) – no impact 23.5% (4) – no-to-low impact 23.5% (4) – low-to-	(2) Medium Impact: Workshop participants indicated that the link is an important one, but it depends on the competence of the	See #9 above.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
			closer in the hierarchy the individual with energy management responsibilities is to the CEO, the more likely the organisation is to have energy management activity.		medium impact 17.6% (3)- medium-to-high impact 5.9% (1) – very high impact 5.9% (1) - I don't know	energy manager. It was suggested that a "certified energy manager" title would improve credibility.	
12	Financial	Increasing energy prices incentivises the need to reduce energy consumption	1 Source: The Centre for Sustainable Energy (CSE) and the Environmental Change Institute, University of Oxford found that	Not identified during interviews.	17.6% (3) – negative impact 0.0% (0) – no impact 17.6% (3) – no-to-low impact 11.8% (2) – low-to-medium impact 17.6% (3) – medium-to-high impact 35.3% (6) – very high impact 0.0% (0) - I don't know	Workshop participants did not see this as an enabler.	From the evidence this is not recognised to be an enabler, with the exception of the survey results. A number of interviewees highlighted that energy is core business, and that there is always an incentive to manage it. But the predominant scenario is one of uncertainty, and the management of this uncertainty.
13	People, Management and Organisation	External pressures (from NGOs, media, local community but NOT customers - see below	Identified from interviews and not literature.	Interviewee: "Are operations are scrutinised by a range of external parties, who question our performance…"	0.0% (0) – negative impact 35.3% (6) – no impact 41.2% (7) – no-to-low impact 17.6% (3) – low-to-medium impact 5.9% (1) – medium-to-high impact 0.0% (0) – very high impact 0.0% (0) -I don't know	(1) Low Impact: Workshop participants did not consider this to be an important enabler. A pull from end users was identified to be more significant.	This was identified as being of lower importance as an enabler.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
14	Market and economy	Customer demands for low(er) carbon products	Identified from interviews and not from literature	Interviewee: "Customer demands for low carbon products will have an influence over the longer term". Interviewee: "If our customers are investing and expanding then this enables us to do the same".	0.0% (0) – negative impact 11.8% (2) – no impact 11.8% (2) – no-to-low impact 29.4% (5) – low-to-medium impact 17.6% (3) – medium-to-high impact 29.4% (5) – very high impact 0.0% (0) -I don't know	(2) Medium Impact: Workshop participants identify that this is a strong enabler for lowering the carbon footprint of end users (e.g. energy efficiency products) but of limited effect on lowering the carbon footprint of production.	This enabler was identified by two interviewees and workshop participants rated it as a medium impact enabler, but this tended to be relevant in the medium-long term.
15	Legislation and Policy	Recognising what key technologies are and developing strategy around these	Note: identified from interviews and not from literature. The Chemistry Growth Strategy Group identified the need to "identify which technologies and innovations are likely to help reduce emissions and optimise heat across sector".	Interviewee: "We need to decide what the overall value position of the UK is going to be…if we understand how the parts of the industry can fit together, then collaborations can be based upon this" and "there is a need to convince and bring appropriate parties together". Interviewee: "We need to recognise which technologies should be implemented. Policy statements that give direction on this	Not included in survey as identified during interviews conducted after survey issue.	(4) Very High Impact: This was recognised as a very important enabler – requiring a partnership of Government, academics and industry. This will help to ensure an early uptake of new processes / products if there is adequate focus on development and commercialisation.	This enabler was identified by a number of interviewees, who felt that there is a need for greater focus and direction in term of the key technologies for decarbonisation. The risk of not defining the key technologies is wasted resource in the development of aspects that will not have the required level of impact (i.e. disruptive impact).

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
				are really important when going to the Board. Interviewee: When discussing limitations to evolve current processes, "there is a need to look realistically to wards 2050. Any moves from current process will require massive investment".			
16	Market and Economy	Cheaper gas (e.g. through investment in shale gas)	Identified from interviews and not from literature.	Interviewee: "Cheaper gas through shale gas would be a huge enabler" as the lower cost allows investment elsewhere.	Not included in survey as identified during interviews conducted after survey issue.	(3) Medium-High Impact: Workshop participants identified that decreased volatility of gas prices and the increase security of supply would result in the UK being more attractive for investment. This investment enables investment in energy saving and low carbon technology.	This enabler relates to the ability to invest in improvements if more capital is available due to lower energy costs. But this is not considered to apply to those companies with access to internal finance for improvement projects. The link between expenditure on energy and budgets for investment projects is not so clear in these cases.
17	Operational	Infrastructure will need replacing at some point	Identified from interviews and not from literature.	Interviewee: "Over time infrastructure will need replacing, and so some marginal gains will occur. The business case will be	Not included in survey as identified during interviews conducted after survey issue.	(4) Very High Impact: Workshop participants indicated that this is a very important impact, but investment is based on a number of variables. Short-term	This enabler was identified by one interviewees, who highlighted the need to periodically replace and improve assets provided opportunities for marginal gains.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshop	Analysis and Interpretation
				there we will look to always install something 'better' than before in terms of emissions".		benefits and improved performance are attractive benefits that support the business case.	Workshop participants rated this as having a very high impact, given that the business case is strengthened by an operational need for upgrades.

Barriers

Number	Category	Barriers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis
1	Financial	Energy subsides deter investment in efficient technologies	The International Energy Agency found that "energy subsidies that act as barriers to deploying more energy-efficient technologies".	Not identified in interviews	5.9% (1)- negative impact 23.5% (4) – no impact 23.5% (4) – no-to-low impact 5.9% (1) – low-to-medium impact 17.6% (3) – medium-to-high impact 11.8% (2) – very high impact 11.8% (2) - I don't know	(2) Low Impact: Workshop participants did not see this is an issue in the UK. They identified that better subsidies elsewhere may incentivise update in other countries / regions.	From the evidence, this does not appear to be perceived as a significant barrier.
2	Financial	Access to capital / funding	The Centre for Low Carbon Futures found that "many companies are subsidiaries of global organisations and compete internally for investment. Higher costs can make it difficult to justify investment in UK". The Chemistry Growth Strategy Group identified that there is "inadequate signposting to	Interviewee: "It can be difficult to get senior management to understand [the policy setting in the UK]…it is difficult for them to assess risk and the UK appears a lot more complex to other regions we are competing with for capex". Interviewee: "Investment decisions are going against the UK, as our business will	0.0% (0) – negative impact 17.6% (3) – no impact 11.8% (2) – no-to-low impact 17.6% (3) – low-to-medium impact 35.3% (6) – medium-to-high impact 17.6% (3) – very high impact 0.0% (0) - I don't know)	(3) Medium-High Impact: Workshop participants indicated that the importance of this barrier depended on profitability. Minor projects with returns within two years would more likely receive funding due to certainty of returns and lower risk. Participants also indicated this access depends	The barrier of access to capital can exist in two forms – firstly, directly in terms of a lack of funding. This was identified as being more of an issue for smaller companies. Most interviewees did not identify capital as an issue. The barrier also persists indirectly, when finance is available but it is not possible to demonstrate a strong enough business case in order to obtain funding or where the where the level of risk is considered too high to warrant investment.

Number	Category	Barriers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis
			Government and private sector funding initiatives".	choose to invest in other counties with more certainty and financial returns".		on the level of internal competition for financing, and company specific return on investment targets.	
3	Market and Economy	Energy prices and policy costs	The Centre for Low Carbon Futures found that the price of energy is "a barrier to investment. Parent companies see a poor return on investment in the UK compared to elsewhere". The International Energy Agency found that a key barrier to investment is the "uncertainty of future energy costs".	Interviewee: "There is a barrier related to Government and changing legislative positions, creating uncertainty…". Interviewee: "The cost of manufacturing is high and energy costs are a real worry. It is difficult to justify spending more elsewhere".	11.8% (2) – negative impact 5.9% (1) – no impact 5.9% (1) – no-to-low impact 35.3% (6) –low-to-medium impact 17.6% (3) – medium-to-high impact 23.5% (4) – very high impact 0.0% (0) - I don't know	(4) Very High Impact: Workshop participants identified energy prices as the major cost to their business and directly impacts the bottom line. Issues were identified in terms of inconsistency within policy and policy costs.	High energy prices and policy costs were identified as one of the top barriers. Workshop participants did not consider the high energy costs were an enabler and stimulate investment in energy reduction / efficiency. Rather it is seen as a cost of business that impacts upon: the ability to compete globally; and the attractiveness of investment in the UK.
4	Technology	High cost of research, demonstration for new technologies	Ricardo-AEA and Imperial College identified the "high cost of research, development and demonstration of new technologies".	Interviewee: "We do not have the resources to invest [in technology innovations] and need support in this area.	0.0% (0) – negative impact 0.0% (0) – no impact 23.5% (4) – no-to-low impact 23.5% (4) – low-	(3) Medium-High Impact: Workshop participants indicated that the barrier is not necessarily the	The survey results indicated this to be a significant barrier. Workshop participants considered that the issue was not cost, but that the focus for R&D is upon aspects other than decarbonisation (e.g. product

Number	Category	Barriers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis
					to-medium impact 35.3% (6) – medium-to-high impact 17.6% (3) – very high impact 0.0% (0) -I don't know	cost, but that R&D efforts are not focused on decarbonisation but on product development, reliability etc. There is a need to take decarbonisation into account when doing R&D. Participants also reported that it is difficult to move from R&D into commercialisation.	development).
5	Technology	Commercialisation of new and unproven technologies	The International Energy Agency found that the "commercial scale up of new and unproven technologies" is an issue for future deployment. The Chemistry Growth Strategy Growth found that "much greater research is urgently required on the potential for	Not identified in interviews.	0.0% (0) – negative impact 0.0% (0) – no impact 11.8% (2) – no-to-low impact 35.3% (6) – low-to-medium impact 35.3% (6) – medium-to-high impact 17.6% (3) – very high impact 0.0% (0) - I don't know	(4) Very High Impact: Workshop participants reported that this is a very significant barrier for small technology developers (due to access to skills and finance etc.), but less so for large commodity producers. It was reported that commodity	This issue was not raised by workshop participants, but potentially because a number of companies have a dedicated research function who would be more aware of the issues and challenges. Workshop participants did not consider this to be an issue for larger companies, but more for smaller technology developers.

Number	Category	Barriers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis
			commercialisation of CCS".			producers will tend to make more incremental changes to established plants, rather than introduce new technologies.	
6	People, Management and Organisation	Lack of knowledge of technologies / options	The European Chemical Industry Council found that there is a "lack of access to trusted and appropriate information" and that "Information is generic and not tailored…potential investors are not able to assess the benefits". Ricardo-AEA and Imperial College found that efficiency not always part of core business, and that "…staff do not know the options / technologies". Sorrell *et al* found that the "absence of credibility and trust in information on	Interviewee: "We have access to the technology, we know what they are, but they only offer marginal gains or no gains at all…"	0.0% (0) – negative impact 17.6% (3) – no impact 17.6% (3) – no-to-low impact 35.3% (6) – low-to-medium impact 17.6% (3) – medium-to-high impact 11.8% (2) – very high impact 0.0% (0) - I don't know	(4) Very High Impact: Workshop participants indicated that R&D is production led, and there is a need to take decarbonisation into account in R&D efforts. Others felt that there is good access to information, through the groups of the CIA for example.	It is not clear whether this presents a barrier. It was not identified as significant by interviewees or from the workshop. It is considered likely that the main issue is the lack of availability of resource to work on decarbonisation projects (see #14 below).

Number	Category	Barriers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis
			energy efficiency will mean that inefficient choices are made".				
7	Technology	Limitations of existing technologies	The Centre for Low Carbon Futures found that "…much has already been done to improve process efficiency" and that there are limitations to further improvement. The European Chemistry Industry Council found that "many companies have good energy management systems in place and already keep good track of the onsite energy generation and distribution systems, limiting the potential to further improve".	Interviewee: "We have access to the technology, we know what they are, but they only offer marginal gains or no gains at all…"	0.0% (0) – negative impact 23.5% (4) – no impact 0.0% (0) – no-to-low impact 41.2% (7) – low-to-medium impact 29.4% (5) – medium-to-high impact 5.9% (1) – very high impact 0.0% (0) - I don't know	(1) Low Impact: Workshop participants felt that current practice is quite far from the limits of existing technologies (in terms of potential improvements), and there is still lots of low hanging fruit available.	There were contrasting views on this barrier – for example one interviewee indicating that technologies only offers marginal or no gains, whilst others feel that there are still considerable improvements to be made. The evidence gathering indicates that this barrier is likely to be a company-specific issue and related to the level of investment made to date. There may still exist significant potential to optimise existing technology.
8	Legislation and Policy	Uncertainty over regulation of new technologies	The European Chemistry Industry Council identified that "regulatory uncertainty around	Interviewee: "CCS is an area that could be a strategic opportunity, but policy cost and	0.0% (0) – negative impact 5.9% (1) – no impact 11.8% (2) – no-to-	(3) Medium-High Impact: Workshop participants indicated that	This issue was raised largely in term of CCS where the regulatory requirements will be stringent, and at present are not sufficiently developed to allow companies to understand the

Number	Category	Barriers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis
			new innovative technologies" represent a barrier to investment.	regulatory uncertainty are all barriers to investment".	low impact 35.3% (6) – low-to-medium impact 23.5% (4) – medium-to-high impact 23.5% (4) – very high impact 0.0% (0) - I don't know	there are perceived risks from regulation but also in terms of uncertainty in outcomes. It was reported that there would be limited investment with regulatory uncertainty, particular in terms of new technologies.	potential costs and risks.
9	Operational	Inefficiency and loss of revenue for shutting down plants for upgrades	Ricardo-AEA and Imperial College identified one of the most important barriers (for all sectors) to be the "high value placed on operational continuity".	Interviewee: "There is a need to maximise production and keep the plant running. You do not want to take if offline for upgrades as this affected profitability." Interviewee: "Taking plant offline for upgrades is complex and costly."	0.0% (0) – negative impact 17.6% (3) – no impact 17.6% (3) – no-to-low impact 11.8% (2) – low-to-medium impact 41.2% (7) – medium-to-high impact 11.8% (2) – very high impact 0.0% (0) - I don't know	(1) Low Impact: Workshop participants indicated that this is not a barrier, due to periodic shut down periods. It was considered to be 'unusual' if this presented a barrier.	The need to shut down plant for upgrade is a barrier for some companies. This is dependent on the ability to bypass equipment and maintain some level of production. The workshop group did not feel that this was a barrier, as shut downs are common practice and provide periodic access for improvement works.
10	Market and Economy	Low and unstable carbon price	The International Energy Agency found that "high investment costs are not cost effective without higher carbon		5.9% (1) – negative impact 11.8% (2) – no impact 23.5% (4) – no-to-low impact 29.4% (5) – low-	(3) Medium-High Impact: Workshop participants reported that it is difficult to invest in projects due to	This barrier is identified as being similar to other barriers that result in uncertainty. Uncertainty in carbon price was identified by workshop participants as resulting in problems to prepare a robust business case – since future costs are uncertain.

Number	Category	Barriers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis
			price". Ricardo-AEA and Imperial College found that the "lack of a stable policy regime" was a barrier to investment, alongside a low carbon price.		to-medium impact 17.6% (3) – medium-to-high impact 11.8% (2) – very high impact 0.0% (0 - I don't know	[potential] changes in carbon price [which will undermine the business case].	
11	Financial	Unattractive payback periods and stringent ROI	Sorrell *et al* found that the "…use of very stringent payback periods" of less than two years were an example of an "organisational failure" for energy efficiency.	Interviewee: "Payback on projects is the main consideration. Projects must meet the relevant financial criteria…" Interviewee: "Achieving a good payback period is key…" Interviewee: "Payback terms are typically two to three years Interviewee discussing a project that was not taken forward: " We did quite a lot of work on it, but it didn't make it as the payback was slower [than other projects].	5.9% (1) – negative impact 11.8% (2) – no impact 23.5% (4) no-to-low impact 29.4% (5) – low-to-medium impact 17.6% (3) – medium-to-high impact 11.8% (2) – very high impact 0.0% (0) - I don't know	(3) Medium-High Impact: Workshop participants indicated that the importance of this barrier depended on profitability. Minor projects with returns within two years would more likely receive funding due to certainty of returns and lower risk. Participants also indicated this access depends on the level of internal competition for financing, and company specific return on investment targets.	Payback periods and ROI were identified as key barriers from the interviews, survey and workshop. It was not identified widely within the literature. This barrier is closely related to the level of internal competition of funding, particularly within global companies with operations worldwide. These companies have a range of investment opportunities, and business case and payback periods are critical to securing investment. Interviewees and workshop participants highlighted the relative unattractiveness of investing in the UK versus locations in Asia for example – where the business case and returns are stronger and more predictable.

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – CHEMICALS

APPENDIX C – FULL TECHNOLOGY OPTIONS REGISTER

APPENDIX C FULL TECHNOLOGY OPTIONS REGISTER

Option name	Sub-sector/ product	Description	Technology Readiness Levels[6]	Adoption (%)	Applicability (%)	CO2 savings (%)	Fossil fuel savings (%)	Biomass fuel savings (%)	Fossil feedstock savings (%)	Biomass feedstock savings (%)	Electricity savings (%)	CO_2 / energy data source	sector capex (£ million)[7]	Capex data source
01 Biomass as fuel	All	Biomass fuels are used in place of fossil fuels, e.g. directly combusted in boilers to raise steam, converted into syngas via gasification, or converted into methane via anaerobic digestion.	9 for direct combustion, 5-7 for gasification[8]	0%	50%	85%	100%	-100%	0%	0%	0%	CO_2 savings reflect biomass emission factor of 20g/kWh as agreed with DECC	1000	Derived from AEA 2011, DECC 2013
02 Waste as fuel	All	Replace fossil fuels with waste-derived fuels, e.g. municipal waste.	6-9	0%	25%	100%	100%	0%	0%	0%	0%	Based on assumption that waste counts as zero carbon	500	Professional judgment based on similarities to biomass fuel systems

[6] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL.
[7] Capital costs for chemicals are expressed as a total cost for the sector. While cost data on some options was available on per site basis, data for others was expressed differently e.g. cost/tonne of production capacity, cost/tonne of emissions. These could more readily be converted into a sector cost than a per site cost. In addition, the sector is diverse with a very wide range of site sizes, process types, plant age and condition, investment requirements etc. (particularly in the case of the energy efficiency options) could potentially make a per site value misleading for some options. The total sector cost has been therefore been considered the clearest way to express the investment cost for the different options.
[8] http://www.nrel.gov/docs/fy11osti/50441.pdf

Option name	Sub-sector/ product	Description	Technology Readiness Levels[6]	Adoption (%)	Applicability (%)	CO2 savings (%)	Fossil fuel savings (%)	Biomass fuel savings (%)	Fossil feedstock savings (%)	Biomass feedstock savings (%)	Electricity savings (%)	CO_2 / energy data source	sector capex (£ million)[7]	Capex data source
04 Decarbo-nised methane as fuel	All	Replace natural gas with methane derived from low carbon source e.g. anaerobic digestion or hydrogen generated using renewable electricity combined with captured CO_2.	9 for anaerobic digestion, 5-6 for hydrogen	0%	100%	100%	0%	0%	0%	0%	0%	Professional judgment, assuming all energy used is renewable	4500	Derived from Arcadis
05 Biomass as feedstock	All	Use feedstocks derived from biomass (e.g. syngas from gasification, ethanol from fermentation) to replace fossil fuel derived feedstocks such as natural gas or naptha.	5-7[9]	0%	100%	26%	-250%	0%	100%	-100%	-250%	Derived from IEA-ICCA and BREW. CO2 savings also reflect biomass emission factor of 30g/kWh as agreed with DECC	10000	Derived from Hannula, 2013, IEA 2008 and Fan, 2013
07 Hydrogen by electrolysis – ammonia production	All	Make ammonia using hydrogen from water electrolysis with renewable electricity instead of hydrogen from fossil syngas	6[10]	0%	100%	100%	100%	0%	100%	0%	-2000%	Energy use derived from CEFIC/Ecofys and IEA-ICCA. Emissions reduction from professional judgment that all energy used will be renewable		

[9] SPIRE, https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/sites/default/files/report/SPIRE%20PPP%20-%20Sustainable%20Process%20Industries%20through%20Resource%20and%20Energy%20Efficiency,%20A.SPIRE_.pdf

[10] Derived from IEA/ICCA/DECHEMA

Option name	Sub-sector/ product	Description	Technology Readiness Levels[6]	Adoption (%)	Applicability (%)	CO2 savings (%)	Fossil fuel savings (%)	Biomass fuel savings (%)	Fossil feedstock savings (%)	Biomass feedstock savings (%)	Electricity savings (%)	CO_2 / energy data source	sector capex (£ million)[7]	Capex data source
08 Hydrogen by electrolysis – hydrogen production	All	Produce hydrogen from water electrolysis with renewable electricity instead of hydrogen from fossil syngas	6[11]	0%	100%	100%	100%	0%	100%	0%	-2000%	Energy use derived from CEFIC/Ecofys and IEA-ICCA. Emissions reduction from professional judgment that all energy used will be renewable		
09 Recycled plastics - syngas	All	Recycle plastics to syngas to provide feedstock for processes such as ammonia (direct use of syngas) or olefins (via methanol)	4-6	0%	100%	10%	-250%	0%	100%	-100%	-250%	Derived from IEA-ICCA and professional judgment based on similarities in process requirements to biomass feedstock processes		
10 Combined Heat and Power (CHP)	All	Further deployment of CHP to replace separate heat and electricity supply, noting that there is already significant deployment in the sector.	9	30%	50%	8%	8%	0%	0%	0%	8%	From Parsons Brinckerhoff professional experience		

[11] Derived from IEA/ICCA/DECHEMA

Option name	Sub-sector/ product	Description	Technology Readiness Levels[6]	Adoption (%)	Applicability (%)	CO2 savings (%)	Fossil fuel savings (%)	Biomass fuel savings (%)	Fossil feedstock savings (%)	Biomass feedstock savings (%)	Electricity savings (%)	CO_2 / energy data source	sector capex (£ million)[7]	Capex data source
11 Integrate gas turbines with cracking furnace	Olefins	Integration of gas turbines with cracking heaters to generate additional electricity or drive compressors etc. (a form of CHP)	6-7	0%	100%	10%	10%	0%	0%	0%	10%	Derived from IEA 2008 plus interview		
12 Carbon Capture and Storage (CCS) - combustion (incl. biomass	All	Capture of CO_2 from combustion gases, and subsequent geological storage.	6[12]	0%	60%	80%	-10%	0%	0%	0%	-10%	Derived from Parsons B professional experience and Parsons Brinckerhoff /GCCSI	2500	Derived from Element Energy 2014 (2)
13 CCS - process – ammonia production	Ammonia	Deploy CCS on process emissions from the steam methane reforming process currently used to make ammonia (i.e. on high purity CO_2 stream)	6-7	0%	100%	90%	-10%	0%	0%	0%	-10%	Derived from Ricardo-AEA, UKCCS, Parsons Brinckerhoff professional experience	100	Derived from Element Energy 2014

[12] Element Energy, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/311482/Element_Energy_DECC_BIS_Industrial_CCS_and_CCU_final_report_14052014.pdf

Option name	Sub-sector/ product	Description	Technology Readiness Levels[6]	Adoption (%)	Applicability (%)	CO2 savings (%)	Fossil fuel savings (%)	Biomass fuel savings (%)	Fossil feedstock savings (%)	Biomass feedstock savings (%)	Electricity savings (%)	CO_2 / energy data source	sector capex (£ million)[7]	Capex data source
14 CCS - process – hydrogen production	Hydrogen	Deploy CCS on process emissions from steam methane reforming process (i.e. on high purity CO_2 stream) currently used to make hydrogen	6-7	0%	100%	90%	-10%	0%	0%	0%	-10%	Derived from Ricardo-AEA, UKCCS, Parsons Brinckerhoff professional experience	33	Derived from Element Energy 2014
15 CCU	All	Use of captured carbon as a feedstock. Many processes use carbon-based feedstocks and the CO2 could, with suitable further processing, be used as a substitute.	3-5[13]	0%	100%	77%	-70%	0%	100%	0%	-70%	Derived from IEA-ICCA and DUKES data		
16 Improved insulation	All	Further reduce energy consumption by improving insulation to reduce heat losses.	9	0%	100%	1%	1%	0%	0%	0%	0%	Derived from Ecofys 2012 and workshop 1 feedback	84	Derived from SPICE3, US DoE, industry feedback

[13] Element Energy, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/311482/Element_Energy_DECC_BIS_Industrial_CCS_and_CCU_final_report_14052014.pdf

Option name	Sub-sector/ product	Description	Technology Readiness Levels[6]	Adoption (%)	Applicability (%)	CO2 savings (%)	Fossil fuel savings (%)	Biomass fuel savings (%)	Fossil feedstock savings (%)	Biomass feedstock savings (%)	Electricity savings (%)	CO_2 / energy data source	sector capex (£ million)[7]	Capex data source
17 Improved waste heat recovery	All	Recover heat currently wasted e.g. through condensate recovery, pre-heating input with low grade heat from used cooling streams etc.	8-9	0%	100%	2%	2%	0%	0%	0%	0%	Derived from Ricardo-AEA and workshop 1 feedback	140	Derived from Element Energy 2014, US DoE, LCICG heat summary, industry feedback
18 Improved process control	All	Further improve the control and operation of processes and unit operations to reduce energy consumption per unit of production output.	9	0%	100%	1%	1%	0%	0%	0%	1%	Derived from IEA-ICCA, CEFIC/Ecofys and workshop 1 feedback	34	Derived from SPICE3, industry feedback
19 More efficient equipment	All	Further deployment of more efficient equipment such as motors, drives, compressors, chillers etc.	8-9	0%	100%	4%	4%	0%	0%	0%	4%	Derived from CEFIC/Ecofys, CIA feedback, workshop 1 feedback	440	Derived from SNIFFER, SPICE3, industry feedback
20 Improved steam system efficiency	All	Improvements to boiler efficiency and distribution systems	9	0%	100%	4%	4%	0%	0%	0%	0%	Derived from CEFIC/Ecofys and workshop 1 feedback	44	Derived from SPICE3, SNIFFER, CLCF, Carbon Trust

Option name	Sub-sector/ product	Description	Technology Readiness Levels[6]	Adoption (%)	Applicability (%)	CO2 savings (%)	Fossil fuel savings (%)	Biomass fuel savings (%)	Fossil feedstock savings (%)	Biomass feedstock savings (%)	Electricity savings (%)	CO_2 / energy data source	sector capex (£ million)[7]	Capex data source
21 Membrane technology	All	Deploy membrane technologies to replace more energy intensive separation technologies such as distillation	3-5	0%	10%	8%	8%	0%	0%	0%	8%	Derived from Ricardo-AEA, IEA 2008, workshop 1 feedback		
22 Process Intensification	All	Deploy process intensification techniques (miniaturisation, synergies between process steps etc.) to optimise energy use	3-5	0%	20%	8%	8%	0%	0%	0%	8%	Derived from Ricardo-AEA		
23 High temperature cracking	Olefins	Use higher temperature furnaces in cracking process	6-8	0%	100%	2%	2%	0%	0%	0%	0%	Derived from IEA 2008		
24 Catalytic cracking	Olefins	Deploy catalytic cracking to replace the current steam cracking process	5-7	0%	100%	15%	15%	0%	0%	0%	0%	Derived from CEFIC/Ecofys, IEA-ICCA		
25 Retrofit ODC for chlorine production	Chlorine	Retrofit Oxygen Depolarised Cathode (ODC) to membrane cells	7[14]	0%	25%	23%	23%	0%	0%	0%	23%	Derived from CEFIC/Ecofys and interview		

[14] Derived from CEFIC/Ecofys

Option name	Sub-sector/ product	Description	Technology Readiness Levels[6]	Adoption (%)	Applicability (%)	CO2 savings (%)	Fossil fuel savings (%)	Biomass fuel savings (%)	Fossil feedstock savings (%)	Biomass feedstock savings (%)	Electricity savings (%)	CO_2 / energy data source	sector capex (£ million)[7]	Capex data source
26 Bioprocessing	All	Use of biological production pathways (e.g. fermentation, biocatalysts)	1-6 (wide range of possible processes)	0%	10%	10%	0%	0%	0%	0%	0%	Derived from Ricardo-AEA and professional judgment		
27 Methanol-to-olefins	Olefins	Make olefins from natural gas via methanol, replacing the current process of steam cracking of naptha or ethane	7-8[15]	0%	100%	10%	-300%	0%	0%	0%	-300%	Derived from CEFIC/Ecofys, IEA-ICCA		
28 High temperature steam electrolysis	Ammonia	Nuclear high temperature steam electrolysis (US Department of Energy development project)	3-4[16]	0%	100%	100%	100%	0%	100%	0%	-1700%	From CEFIC/Ecofys		
29 Solid state synthesis	Ammonia	Solid state ammonia synthesis using electricity	3-5[17]	0%	100%	100%	100%	0%	100%	0%	-1800%	From CEFIC/Ecofys		
30 Clustering	All	Connect industrial sites close to each other to allow efficient use of energy and materials	9	25%	50%	25%	25%	0%	0%	0%	25%	Derived from LOCIMAP and professional judgment		

[15] Derived from IEA-ICC-DECHEMA
[16] Derived from CEFIC/Ecofys
[17] Derived from CEFIC/Ecofys

Other Notes:

- % savings are compared to current processes.
- Negative savings means more energy or feedstock is required than with current processes
- Rows 3 and 6 are not shown as these refer to options no longer included in the model, however the original numbering has been maintained for consistency.
- All costs are for CO_2 capture alone, including CO_2 purification and compression. Costs associated with transport and storage/utilisation are excluded.

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – IRON AND STEEL

APPENDIX D – ADDITIONAL PATHWAYS ANALYSIS

APPENDIX D ADDITIONAL PATHWAYS ANALYSIS

1. Option deployment for pathways under different scenarios

Challenging World

Pathway: BAU Scenario: Challenging World (CW)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	15%	15%	15%	15%	15%	15%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	10%	10%	10%	10%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	0%	5%	10%	10%	10%	10%	10%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
16 Improved insulation	Energy Efficiency	0%	100%	0%	5%	10%	15%	20%	25%	25%	25%	25%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	5%	10%	15%	15%	15%	15%	15%	15%
18 Improved process control	Energy Efficiency	0%	100%	0%	5%	10%	25%	50%	60%	80%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	10%	10%	20%	40%	60%	80%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	5%	10%	15%	20%	25%	25%	25%	25%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	0%	0%	5%	5%	5%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	0%	0%	0%	5%	5%	5%	5%

Figure 3: BAU pathway, challenging world scenario

Pathway: 40 - 60%   Scenario: Challenging World (CW)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	25%	25%	25%	25%	25%	25%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	10%	10%	10%	10%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	0%	5%	5%	5%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	30%	30%	30%	5%	5%	5%	5%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
16 Improved insulation	Energy Efficiency	0%	100%	0%	0%	10%	15%	20%	25%	25%	25%	25%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	0%	10%	15%	20%	25%	25%	25%	25%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	20%	50%	75%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	20%	30%	40%	60%	80%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	0%	10%	15%	20%	25%	25%	25%	25%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	0%	5%	10%	10%	10%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	0%	5%	10%	10%	10%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	0%	0%	10%	20%	25%	25%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	0%	0%	5%	10%	10%	15%	15%

Figure 4: 40-60% pathway, challenging world scenario

Pathway: Max Tech Scenario: Challenging World (CW)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	25%	50%	50%	50%	50%	50%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	10%	10%	10%	10%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	50%	100%	100%	75%	50%	25%	0%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	0%	0%	25%	25%	25%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	33%	33%	33%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	33%	33%	33%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
16 Improved insulation	Energy Efficiency	0%	100%	0%	5%	25%	50%	100%	100%	100%	100%	100%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	5%	25%	50%	75%	100%	100%	100%	100%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	50%	100%	100%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	50%	75%	100%	100%	100%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	5%	25%	50%	100%	100%	100%	100%	100%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	0%	0%	0%	100%	100%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	5%	10%	20%	25%	30%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	0%	0%	100%	100%	100%	100%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	0%	0%	25%	50%	75%	100%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	5%	5%	10%	10%	15%	15%	20%

Figure 5: Max Tech pathway, challenging world scenario

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

OPTION	Category	ADOP.	APP.	DEPLOYMENT								
				2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	10%	10%	10%	10%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	5%	5%	10%	10%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	100%	100%	100%	100%	100%	100%	100%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	0%	0%	33%	33%	33%	33%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	0%	0%	50%	50%	50%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	33%	33%	33%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	33%	33%	33%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
16 Improved insulation	Energy Efficiency	0%	100%	0%	5%	50%	100%	100%	100%	100%	100%	100%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	5%	25%	50%	75%	100%	100%	100%	100%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	50%	100%	100%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	50%	75%	100%	100%	100%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	5%	25%	50%	75%	100%	100%	100%	100%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	0%	0%	100%	100%	100%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	5%	10%	20%	25%	30%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	0%	0%	100%	100%	100%	100%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	0%	0%	25%	50%	75%	100%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	5%	5%	10%	10%	15%	15%	15%

Figure 6: Max Tech (no biomass), challenging world scenario

Collaborative Growth

Pathway: BAU Scenario: Collaborative Growth (CG)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	25%	25%	25%	25%	25%	25%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	10%	10%	10%	10%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	5%	10%	15%	15%	15%	15%	15%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	33%	33%	33%	33%	33%	33%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	33%	33%	33%	33%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	33%	33%	33%	33%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	0%	5%	5%	5%
16 Improved insulation	Energy Efficiency	0%	100%	0%	0%	10%	20%	30%	40%	50%	60%	70%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	0%	10%	20%	30%	40%	50%	50%	50%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	50%	75%	100%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	25%	50%	75%	100%	100%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	0%	10%	50%	75%	100%	100%	100%	100%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	0%	10%	20%	20%	20%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	0%	10%	20%	30%	40%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	33%	33%	33%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	0%	0%	100%	100%	100%	100%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	0%	5%	10%	25%	25%	25%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	5%	15%	20%	25%	30%	30%	30%

Figure 7: BAU pathway, collaborative growth scenario

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

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	25%	30%	35%	40%	40%	40%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	10%	10%	10%	10%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	0%	5%	5%	10%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	30%	30%	30%	5%	5%	5%	5%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	33%	66%	66%	66%	66%	66%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	0%	0%	25%	25%	25%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	33%	33%	33%	33%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	33%	33%	33%	33%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	5%	10%	10%	10%
16 Improved insulation	Energy Efficiency	0%	100%	0%	0%	15%	30%	40%	50%	60%	80%	100%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	0%	10%	20%	40%	60%	80%	80%	80%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	75%	100%	100%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	50%	75%	100%	100%	100%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	0%	20%	75%	100%	100%	100%	100%	100%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	10%	20%	30%	40%	50%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	10%	20%	30%	40%	50%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	33%	66%	100%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	0%	0%	100%	100%	100%	100%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	0%	10%	20%	30%	40%	50%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	5%	15%	25%	35%	45%	55%	65%

Figure 8: 40-60% pathway, collaborative growth scenario

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

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	25%	40%	50%	50%	50%	50%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	5%	5%	0%	0%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	0%	5%	5%	10%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	65%	65%	50%	25%	15%	5%	5%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	40%	75%	75%	75%	75%	75%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	0%	25%	50%	50%	50%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	0%	25%	50%	50%	50%	50%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	0%	25%	50%	50%	50%	50%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	5%	10%	10%	15%
16 Improved insulation	Energy Efficiency	0%	100%	0%	0%	50%	60%	75%	75%	80%	80%	100%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	0%	10%	50%	60%	75%	80%	80%	80%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	75%	100%	100%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	50%	75%	100%	100%	100%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	0%	20%	75%	100%	100%	100%	100%	100%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	10%	25%	50%	60%	75%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	10%	20%	30%	40%	50%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	33%	66%	75%	100%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	0%	0%	100%	100%	100%	100%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	0%	20%	40%	50%	60%	75%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	5%	15%	25%	35%	45%	55%	65%

Figure 9: 60-80% pathway, collaborative growth scenario

Pathway: 60 - 80%   Scenario: Collaborative Growth (CG)

OPTION	Category	ADOP.	APP.	DEPLOYMENT								
				2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	25%	40%	50%	75%	75%	75%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	5%	5%	0%	0%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	0%	5%	5%	10%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	40%	40%	40%	40%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	65%	65%	50%	25%	15%	5%	5%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	40%	75%	75%	75%	75%	75%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	0%	25%	50%	50%	50%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	0%	25%	50%	50%	50%	50%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	0%	25%	50%	50%	50%	50%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	0%	5%	10%	15%	20%
16 Improved insulation	Energy Efficiency	0%	100%	0%	0%	50%	60%	75%	75%	80%	80%	100%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	0%	10%	50%	60%	75%	80%	80%	80%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	75%	100%	100%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	50%	75%	100%	100%	100%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	0%	20%	75%	100%	100%	100%	100%	100%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	10%	25%	50%	60%	75%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	10%	20%	30%	40%	50%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	33%	66%	75%	100%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	0%	0%	100%	100%	100%	100%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	0%	20%	40%	50%	60%	75%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	5%	15%	25%	35%	45%	55%	65%

Figure 10: Max Tech pathway, collaborative growth scenario

Pathway: Max Tech   Scenario: Collaborative Growth (CG)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	25%	50%	75%	100%	100%	100%	100%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	0%	0%	0%	0%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	5%	5%	10%	10%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	80%	80%	80%	80%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	100%	100%	75%	50%	25%	0%	0%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	50%	100%	100%	100%	100%	100%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	50%	100%	100%	100%	100%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	50%	100%	100%	100%	100%	100%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	50%	100%	100%	100%	100%	100%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	5%	10%	15%	20%	25%
16 Improved insulation	Energy Efficiency	0%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	100%	100%	100%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	100%	100%	100%	100%	100%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	0%	50%	100%	100%	100%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	10%	25%	30%	40%	50%	60%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	33%	100%	100%	100%	100%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	100%	100%	100%	100%	100%	100%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	25%	50%	75%	100%	100%	100%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	5%	15%	25%	35%	45%	50%	50%

Figure 11: Max Tech pathway, collaborative growth scenario

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

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Biomass as fuel	Fuel Substitution	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
02 Waste as fuel	Fuel Substitution	0%	25%	0%	5%	5%	10%	10%	10%	10%	10%	10%
03 Low carbon electricity	Fuel Substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
04 Decarbonised methane as fuel	Fuel Substitution	0%	100%	0%	0%	0%	0%	0%	5%	5%	10%	10%
05 Biomass as feedstock	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Hydrogen by electrolysis - Ammonia	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	5%	10%	10%
08 Hydrogen by electrolysis - Hydrogen	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	5%	10%	10%
09 Recycled plastics - syngas	Feedstock Switch	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 CHP	CHP	30%	50%	0%	0%	100%	100%	100%	100%	100%	100%	100%
11 Integrate gas turbines with cracking furnace	CHP	0%	100%	0%	0%	0%	50%	100%	100%	100%	100%	100%
12 CCS - combustion (incl. biomass)	Carbon Capture	0%	60%	0%	0%	0%	0%	50%	100%	100%	100%	100%
13 CCS - process - Ammonia	Carbon Capture	0%	100%	0%	0%	0%	50%	100%	100%	100%	100%	100%
14 CCS - process - Hydrogen	Carbon Capture	0%	100%	0%	0%	0%	50%	100%	100%	100%	100%	100%
15 CCU	Carbon Capture	0%	100%	0%	0%	0%	0%	5%	10%	15%	20%	25%
16 Improved insulation	Energy Efficiency	0%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
17 Improved waste heat recovery	Energy Efficiency	0%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
18 Improved process control	Energy Efficiency	0%	100%	0%	10%	100%	100%	100%	100%	100%	100%	100%
19 More efficient equipment	Energy Efficiency	0%	100%	0%	10%	100%	100%	100%	100%	100%	100%	100%
20 Improved steam system efficiency	Energy Efficiency	0%	100%	0%	0%	100%	100%	100%	100%	100%	100%	100%
21 Membrane technology	New Process Technologies	0%	10%	0%	0%	0%	0%	0%	50%	100%	100%	100%
22 Process Intensification	New Process Technologies	0%	20%	0%	0%	0%	0%	25%	30%	40%	50%	60%
23 High temperature cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Catalytic cracking	New Process Technologies	0%	100%	0%	0%	0%	0%	33%	100%	100%	100%	100%
25 Retrofit ODC for chlorine production	New Process Technologies	0%	25%	0%	0%	0%	100%	100%	100%	100%	100%	100%
26 Bioprocessing	New Chemical Pathways	0%	10%	0%	0%	0%	25%	50%	75%	100%	100%	100%
27 Methanol-to-olefins	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 High temperature steam electrolysis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Solid state synthesis	New Chemical Pathways	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Clustering	Clustering	25%	50%	0%	0%	5%	15%	25%	35%	45%	50%	50%

Figure 12: Max Tech (no biomass) pathway, collaborative growth scenario

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