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

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050

Iron and Steel Appendices

MARCH 2015

WSP | PARSONS BRINCKERHOFF

DNV·GL

APPENDIX A Methodology 1
1. Evidence Gathering 2
2. Literature Review 3
3. Criteria for Including Literature 4
4. Technical Literature Review 6
5. Social and Business Literature Review 9
6. Interviews 9
7. Evidence Gathering Workshop 15
8. Pathways 16
9. Pathways Development and Analysis 16
10. Pathways Modelling 19
11. Options 23
12. Pathway and Action Plan Workshop 24
13. Next Steps 24
APPENDIX B Full Social and Business Findings 27
1. SWOT Outcomes 27
2. Market Structure 29
3. Assessing Barriers and Enablers 30
4. Detailed Analysis of Enablers and Barriers 31
APPENDIX C Full Technology Options Register 67
1. Options Register 67
2. Incremental and Disruptive Options 75
APPENDIX D Additional Pathways Analysis 86
1. Option Deployment for Pathways under Different Scenarios 86
2. Sensitivity Analysis 92

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

APPENDIX A - METHODOLOGY

APPENDIX A METHODOLOGY

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

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

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

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

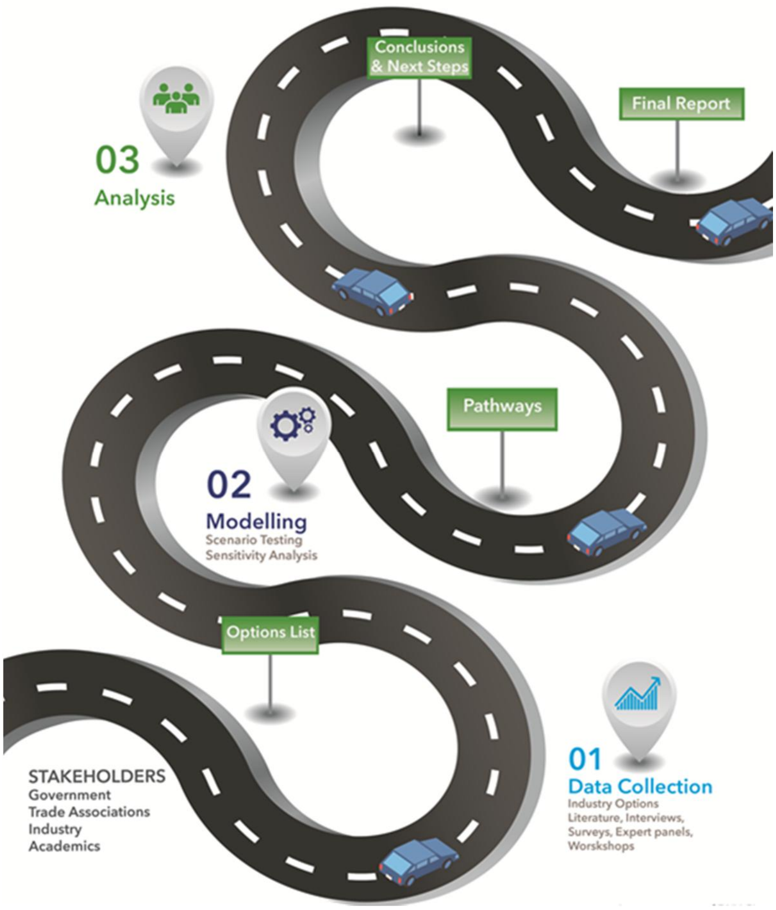

Figure 1: Roadmap Methodology

1. Evidence Gathering

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

- Decarbonisation options (i.e. technologies)
- 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 and information gathering workshops. By using three different sources of information, the evidence gathered could be triangulated to improve the overall research. Themes that were identified during the literature review could subsequently be used as a focus or a starting point during the interviews and workshops. The data from the literature could be subjected to sensitivity testing by comparing it with information from the interviews and the workshops. In a similar way, information gaps during the interviews and workshops could be populated using literature data.

The three sources of evidence were used to develop a consolidated list of barriers and enablers for decarbonisation, and a register of technical options for the iron and steel sector. This information was subsequently used to inform the development of a set of pathways to illustrate the decarbonisation potential of the iron and steel 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 90% of carbon emissions produced in the UK iron and steel sector and captured UK decision makers and technical specialists in the iron and steel sector. These interviews were conducted to provide greater depth and insight to the issues faced by companies.

The identification of relevant information and data was approached from a global and UK viewpoint. The global outlook examined dominating technologies and process types, global production and CO_2 emissions (in the EU-28) and the global outlook to 2050, including the implications for iron and steel 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 iron and steel producers and their key sites, dominant technologies and processes were also reviewed.

Options examined were relevant to various parts of the production process, i.e. coke making, sintering, BF (blast furnace), BOF (basic oxygen furnace), EAF (electric arc furnace), and secondary processes. Disruptive options such as rebuild or retrofit of integrated sites with advanced technologies, including HIsarna, Corex, Finex and CC (carbon capture) were also included.

2. Literature Review

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

The literature review covered over 130 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 including a wide range of documents both academic and grey literature. 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 section 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 or data collection
- Detailed literature analysis on technical points of note
- Identification of decarbonisation options and associated drivers or barriers
- Information on adoption rate, applicability, improvement potential, ease of implementation, capex, return on investment (ROI) and the saving potential for all options where available
- Construction of decarbonisation options list for short- (2015-2020), medium- (2020-2030) and long-term (2030-2050)
- Provision of information on strengths, weaknesses, opportunities, threats, enablers and barriers. This information was used in the information gathering workshop as a starting point for discussion. It provided evidence to support the development of a consolidated list of enablers and barriers for decarbonisation and, subsequently, to inform the list of the possible technological options and pathways that would lead to decarbonisation

	Details
Main focus **(all in the iron and steel sector)**	Energy efficiency improvements CO_2 and carbon reduction Heat recovery
Secondary focus	Drivers, barriers, policy Carbon capture (and storage/utilisation CCS/U) Disruptive technologies
Excluded	Supply chain Non-CO_2 emissions (e.g. CFCs) Technologies not applicable in UK iron and steel sector

Table 1: Scope of review

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

3. Criteria for Including Literature

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

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

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 130 papers, official publications and grey literature experts on iron and steel were collected using this search methodology. The quality, source and objectivity of each document was analysed by reading the abstract (where present), followed by a skim-read of the document.

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

- Category: is the content of the document focusing on technology, drivers or barriers or policy-related aspects
- Affiliation: what is the source of the document: academia, governance or is it sector-based
- Financial-technical evaluation criteria present (YES/NO)
- Overall quality of the document (+/++/+++)

- Relevance for the UK iron and steel sector (0/+/++/+++)
- Information on technological aspects (0/+/++/+++)
- Information on drivers and barriers: (0/+/++/+++)
- Information on policy/legislation: (0/+/++/+++)
- Document relevant for developing scenarios: (0/+/++/+++)

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

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

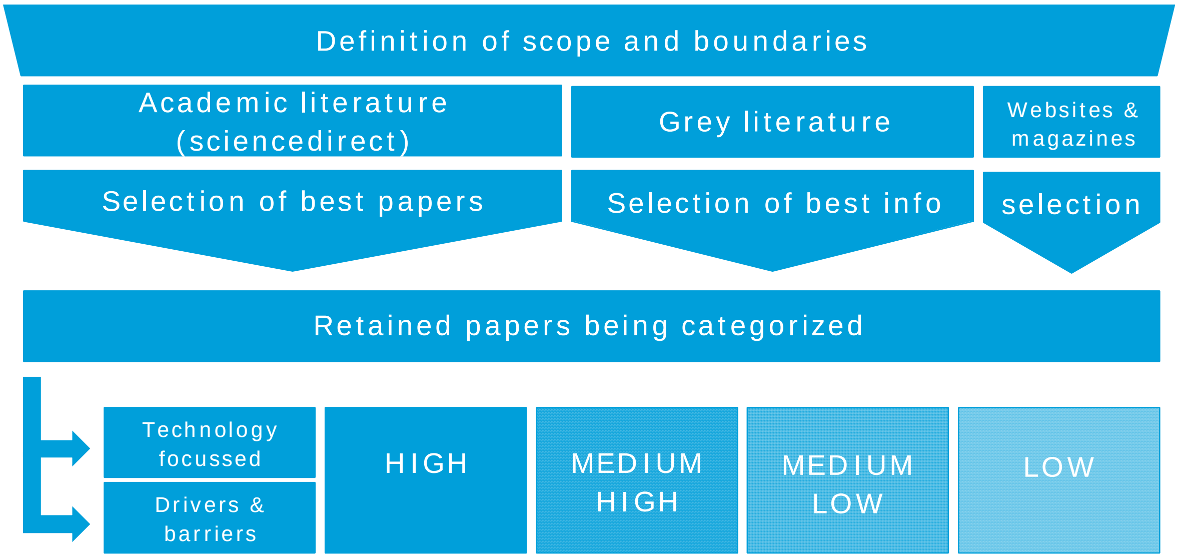

Figure 2: Diagram of the selecting and categorising process

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

Energy saving measures (if present) were listed from each document included in the review process and this list was used to construct a decarbonisation options list 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 or outlook and information or data on energy and carbon reduction 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 or data on energy and carbon reduction measures
4. Energy savings, where possible, were preferably extracted as a percentage, or as a specific energy saving per relevant unit
5. For financial savings, the amounts were kept in their original currency

4. Technical Literature Review

Identifying Literature

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

In parallel to the review process, a number of key academics were identified to participate and provide perspectives on current research and to provide additional input and feedback. This 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 iron and steel 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 or ENABLERS: What does research tell us about the drivers or enablers for organisations in the iron and steel sector to decarbonise their energy use? What are the perceived benefits for industrial organisations to decarbonise their heat use?

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

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

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

Information Found by the Consortium during Technical Literature Review

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

- "Iron"
- "Steel"
- "iron and steel"
- "iron and steel" AND "abatement"
- "iron and steel" AND "carbon capture / CCS"
- "iron and steel" AND "driver(s)/barrier(s)"

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

- “iron and steel” AND “economics”
- “iron and steel” AND “emissions”
- “iron and steel” AND “energy (savings)”
- “iron and steel” AND “energy case study”
- “iron and steel” AND “energy/energy consumption”
- “iron and steel” AND “low-carbon/decarbonisation/carbon”
- “iron and steel” AND “policy/politics”
- “iron and steel” AND “recycle/recycling/scrap”
- “iron and steel” AND “roadmap(s)”
- “iron and steel” AND “scenario(s)”
- “iron and steel” AND “UK”

Other documents in ScienceDirect were found by checking the references of the papers found by the above searches as well as searching for specific technologies.

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

Summary of strength of evidence on energy efficiency in iron and steel sector									
Division	Number of information sources reviewed					Strength of the evidence			
	Academic searches	Direct website searches	expert reviewer	grey literature	Total	HIGH	MEDIUM HIGH	MEDIUM LOW	LOW
General	7	7	5	0	19	9	6	2	1
Technologies	11	19	8	0	38	4	7	10	7
CO2 & CCS	7	9	3	0	19	1	3	11	4
Drivers/barriers	0	7	1	0	8	1	2	2	0
Social and business	7	9	3	13	32	9	3	3	8
Costs	3	10	2	0	15	7	2	3	2
Pathways	0	6	0	0	6	0	2	1	0

Figure 3: Overview of literature review

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

5. Social and Business Literature Review

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

- We reviewed over 54 documents to create a broad overview of the sector SWOT and identification of drivers and barriers to energy efficiency improvement and decarbonisation, and identification of main uncertainties in generic and business environment.
- Literature reviewed: included documents listed in the ITT (invitation to tender) as well as grey literature from Trade associations, companies, DECC and BIS. Specific search terms were used which were agreed with DECC to identify the key enablers and barriers.
- We used a systematic and structured approach to the literature review. The criteria for assessing the relevance of the literature were defined to determine whether they address the key principal questions. The literature identified was analysed using a quick assessment process to identify the most relevant information on SWOT, enablers and barriers to decarbonisation.
- Based on table of contents and a quick assessment we presented the results in a table as below. The analysis resulted in 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 3: Literature review assessment process

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

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

6. Interviews

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

Seven sites in the UK cover the majority (more than 90%) of the emissions of the sector, divided into three integrated steel plants and four EAF sites. It was agreed to undertake seven interviews with key players for the iron and steel sector. These included five iron and steel manufacturers, one member of UK Steel and one equipment manufacturer. We identified the proposed interviewees in liaison with UK Steel, DECC and BIS, and in accordance with the pre-defined criteria.

Seven face-to-face interviews were completed and the following companies were interviewed:

- Tata Steel - Group Director India and South-East Asia, EU, UK and the Netherlands (two integrated sites and one EAF site)
- Celsa - Head of Energy Purchasing for Celsa Group and EHS Manager for Cardiff site (one EAF site)
- Outokumpu - UK Environment Manager (one EAF site)
- Sheffield Forgemasters - Energy and Commercial Manager and Operations Director (one EAF site)
- SSI Steel - Technical Development Manager (one integrated site)
- Siemens - Technology Director Blast Furnace Technology Centre
- UK Steel - Head of UK Steel

Comments collated via UK Steel, the workshop and subsequent email correspondence was also used as part of the information gathering process.

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

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

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

Interview Protocol

Preparation

1. Interviewee identification

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

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

2. Interview preparation

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

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

3. Interview format

Introductions

Interviewer sets out the project context and interview agenda.

Goals

Interviewer introduces the goals of the project as follows:

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

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

    b. Develop an understanding of the decision-making processes

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

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

    a. As currently deployed by organisations

    b. As an option to be deployed in the future

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

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

Existing and future strategy for energy and carbon reduction

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

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

    a What are the main elements of the strategy?

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

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

    i) Please specify why:

    1. Constrained finance for funding for investments internally or externally

    2. Etc.

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

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

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

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

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

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

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

Stories (interviewees not self-identified as leaders)

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

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

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

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

Business Environment: value chain and capacity for innovation

Interviewer to ask the following questions:

1. What do you consider to be the main drivers for energy and carbon reduction in the sector?
    a. What are main characteristics of the main parts of the production process? Following the structure of the options register:
        i. Ask specific questions on any elements not covered in the desk research
        ii. Ask specific questions on the characteristics of the subsector (input, process, output, energy use, value chain, competitive forces)
    b. What do you perceive as the strengths and weaknesses of your value chain?
    c. What have been the main changes in the value chain over the last ten years?
    d. What innovations do you expect to see in the value chain in the coming 10/20/30 years?
    e. What are possible game changers for the value chain/ or sector?
2. Main innovators or early adopters in the sector:
    a. Who influences action (whom or what are they listening to? Why?
        i. Organisations and people within organisations (role or function)?
        ii. Within or outside the sector (other sectors, academics, non-government organisations, politicians, etc.)?
3. Questions on the dimensions of innovations[3] . These questions will be on a multiple choice list (answer categories strongly disagree, disagree, neither agree or not agree, agree, strongly agree[4]). After filling the list, ask for clarifications and examples that underpin answers in the following areas:
    a. Technical: networks with other companies, academics, knowledge of competitive and emerging technologies, participation in R&D, pilots, experiments
    b. Human capital: improvement projects, multi-disciplinary teams, training on innovation/change/improvement
    c. Organisation: horizontal communication lines, clear goals 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

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

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

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

Function of Interview 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 carbon reduction	20-30 minutes
Stories of energy or carbon reduction	30-45 minutes
Business environment and innovation power	15-20 minutes
Drivers and hurdles for sector change (to test survey or workshop questionnaire)	If time left

Table 4: General interview timeline

7. Evidence Gathering Workshop

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

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

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

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

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

8. Pathways

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

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

In addition, two purely technology-driven pathways were developed: a business as usual (BAU) pathway and a maximum technical (Max Tech) pathway. The BAU pathway consisted of the continued deployment of technologies that are presently being deployed across the sector. The Max Tech pathway included a technology or technology combination that would achieve the maximum CO_2 reduction possible within the sector, given constraints of deployment rates and interaction. The pathways have not been optimised to achieve a certain decarbonisation level.

A number of sensitivity tests were performed on the model to examine the impact of various parameters and option constraints on emissions reduction. The following sensitivities were identified for the iron and steel sector:

- Shift in production from BF-BOF to EAF
- Improvement in material efficiency in the sector
- No CC available
- No CC available and full availability of bio-charcoal for PCI
- Full CC available and full availability of bio-charcoal for PCI

9. Pathways Development and Analysis

Overview

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

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

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

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

Process

1. The gathered evidence (from literature review, sector team discussions, stakeholder feedback and judgement) was consolidated into a condensed list of options.
2. Timing and readiness of options was developed by the sector team and during the first workshop, based on evidence from literature, sector knowledge and technical expertise.
3. Options were classified as incremental and disruptive.

4. BAU and Max Tech options were chosen and rolled out to the maximum level and rate allowable under the current trends scenario.
5. Options were added to the BAU pathway or reduced or taken out of the Max Tech pathway until each intermediary pathway band was reached.
6. Technical constraints and interactions across the list of options were taken into account when selecting options and deployment.
7. The deployment was adjusted to account for the output of the social and business research as well as current investment cycles.
8. Pathways were modelled under the current trends scenario, accounting for changes in production and the carbon emissions of the electricity grid.
9. 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.
10. Further changes to option choices were made as required through iterations of points 5-9.
11. Revised pathways under current trends were produced for presentation at the second workshop.
12. Feedback on pathways was used to make any further necessary adjustments to the pathways under current trends.
13. The final pathways developed under current trends were used as a basis for the development of pathways under challenging world and collaborative growth scenarios.
14. 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.
15. Deployment for each option was adjusted within the technical and scenario constraints in order to reach each pathway band where possible. Note that not all pathway bands are possible under some scenarios.

The options are listed in appendix C.

Deployment of Options

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

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

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

Option Interaction

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

- **One option excludes another:** This is taken into account by the modeller in the deployment inputs in the Option Selector by ensuring that no exclusive options are rolled out to a conflicting level in the same time period. For example, near net shape casting and endless strip production are options that are mutually exclusive on casting lines. It can therefore be seen that as near net shape casting deploys to 75%, endless strip production reduces to 25% accordingly.
- **One option depends upon another being adopted:** This is taken into account by the modeller in the deployment section of the option selector by ensuring that if any option requires a precursor that this precursor is rolled out to the appropriate level.
- **Options are independent and act in parallel:** The ‘minimum interaction’ pathway curve assumes that all options are independent and their effect on energy or emissions are therefore incremental.
- **Options improve a common energy or emission stream and act in series:** The ‘maximum interaction’ pathway curve assumes that the saving from each option reduces the remaining energy or emissions for downstream options to act upon.

The pathways curves 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 steel or Mt CO_2/tonne steel, 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. It has been assumed that emissions change proportionally to production.

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.

10. Pathways Modelling

Scenarios

Modelling pathways starts with the development of scenarios. A scenario is a specific set of conditions external to the sector that would directly or indirectly affect the ability of the sector to decarbonise. An example of a condition in a scenario was the emission 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 5 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.

Iron and steel production was assumed to be static over the 2013-2050 period, with a shift away from UK production of commodity steel. It was assumed that the iron and steel business environment, the economic recession and the weak demand for steel may limit revenues and thereby hamper investment in decarbonisation. An uneven playing field and carbon leakage was assumed to influence the UK steel sector's lack of competitiveness on the global marketplace. Other governments were assumed to start taxing carbon.

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 iron and steel industry was subject to more intense competition, both for raw materials and sales, leading to a decline of 1.5% per year in UK production over the period. An uneven playing field and carbon leakage were an issue adding, to the UK iron and steel sector's lack of competitiveness on the global marketplace.

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 iron and steel industry sees growth at 1.5% per year, with a shift towards more advanced processes, increased reuse and recycling in general and growth in higher added value and lower carbon footprint products. The business environment was assumed to be positive with increased demand for UK steel and plants are working at the optimum capacity. A favourable global carbon price was assumed to be in place.

	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 emissions reduction, consistent targets for all countries
General technical innovation	Slow innovation and limited application	Modest innovation, incidental breakthroughs	Concerted efforts lead to broad range of early breakthroughs on Nano, bio, green and ICT technologies.
Attitude of end consumers to sustainability and energy efficiency	Consumer interest in green products only if price competitive. Limited interest in energy efficiency.	Limited consumer demand for green products, efficiency efforts limited to economically viable improvements	Consumer willing to pay extra for sustainable, low carbon products. Strong efforts to energy efficiency even where not cost effective.
Collaboration between sectors and organisations	Minimal joint effort, opportunistic, defensive	Only incidental, opportunistic, short term cooperation	Well supported shared and symbiotic relationships
Demographics (world outlook)	Declining slowly in the west Higher growth elsewhere	Declining slowly in the west Modest growth elsewhere	Stable in the west Slowing growth elsewhere

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

Table 5: Summary of scenario context and specific assumptions applicable to the scenarios

11. Options

Classification and Readiness of Options

The options were divided into two groups reflecting how intrusive the investment would be to the normal state of affairs.

- Incremental options
- Disruptive options

Incremental options are characterised by smaller incremental CO_2 savings to various parts of the production process (it should be noted that not all of the following options are available or practical for certain grades of steel requiring specific treatment), and include generic options as well as different technologies for coke making, sintering, BF, BOF, EAF, casting and secondary processes.

Disruptive options, in contrast, are breakthrough technologies such as rebuild or retrofit of integrated sites with advanced technologies, including HIsarna, Corex, Finex and CC.

Options Processing

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

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

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

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

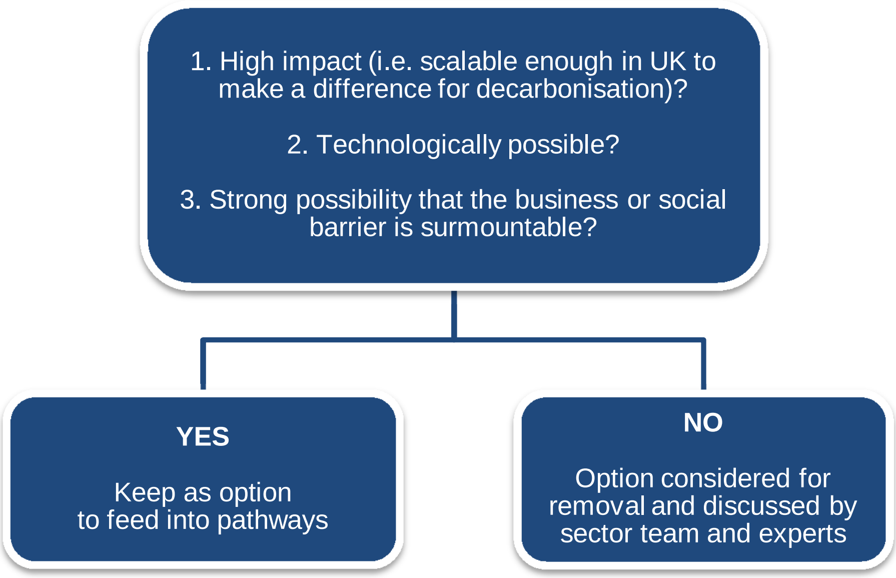

Figure 4: Social and business pathways impact tree

12. 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.

13. Next Steps

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

- Implementation of the pathways
- Decarbonisation and energy efficiency in the iron and steel sector more generally

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

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

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

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

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

APPENDIX B – FULL SOCIAL AND BUSINESS FINDINGS

APPENDIX B FULL SOCIAL AND BUSINESS FINDINGS

1. SWOT Outcomes

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

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
UK mature and stable market with strength in advanced steels and technologies	Excess manufacturing capacity in UK	Cost sharing through collaboration and lesson learning	Regulatory uncertainty and information asymmetries
UK steel companies have dedicated R&D departments	Highly price sensitive as globally traded	CC coupled with other technologies can reduce carbon emissions by 70%	Supply disruption/ resource scarcity
Comprehensive energy management systems in place	Step change improvements are limited	Increasing demand for steel for new technologies (renewable energies)	Scarcity of external financial capital
Top management willing to make climate change a priority	High CAPEX (perceived as high risk investment), slow capital turnover	Access growing markets and skilled labour globally	Volatile raw material prices due to highly consolidated supply chain
	Stakeholders demand quick payback (less than two years), but energy efficiency projects have	High energy or resource prices and increasing regulation drive energy efficiency improvements	
		Steel demand steady and increasing	

Table 6: SWOT Analysis

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

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

2. Market Structure

Subsector	Industry definition	UK market share of major companies	Key external drivers
Integrated (BF-BOF) sites	Integrated sites include BF-BOF as primary production route followed by secondary processes. BF-BOF accounts for most of the UK crude steel production (79% in 2012), and includes several primary processes such as coke production, sintering, blast furnaces, basic oxygen steelmaking and casting. Secondary processes involve those manufacturing processes executed after the steel first solidifies and up to and until the relevant steel products are ready for the end-user.	1. Tata Steel Europe – two integrated sites at Scunthorpe and Port Talbot, one EAF site at Rotherham (66%)[5] 2. SSI – one integrated site at Teesside (23%)	• Demand from motor vehicle manufacturing • Construction sector • Government capital expenditure • World price of iron ore • World price of coking coal
EAF sites	The secondary EAF production route accounts for the remainder of crude steel production in the UK. It includes primary processes such as scrap preparation, electric arc furnaces and casting, as well as secondary rolling processes.	1. Tata Steel Europe – two integrated sites at Scunthorpe and Port Talbot, one EAF site at Rotherham (66%) 2. Celsa Steel UK Ltd – one EAF site at Cardiff (8%) 3. Sheffield Forgemasters – one EAF site at Sheffield 4. Outokumpu – one EAF site at Sheffield	• Demand from motor vehicle manufacturing • Total value of construction • Government capital expenditure • Availability of scrap steel

Table 7: Market structure UK iron and steel sector

[5] The 66% market share accounts for the integrated and EAF sites together. SSI and Celsa Steel UK Ltd have 23% and 8% of the market share, and the remaining 3% is accounted by Sheffield Forgemasters and Outokumpu.

3. Assessing Barriers and Enablers

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 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 8 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 or causal mapping where possible.

Classification	Definition
High	High relevance for the UK iron and steel sector Good financial-economic decarbonisation data Recent information (after 2000) Provides a good example or story of decarbonisation Validated across all evidence gathering methods
Medium-high	Relevance for the UK iron and steel sector Financial-economic data not always complete or clear-cut and only generic decarbonisation data Provides a good example or 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 evidence gathering method
Low	Background information No or low applicability for the UK iron and steel sector Grey literature of limited value Old information Lack of relevance or only mentioned once

Table 8: Evidence classification definition

The following tables provide a summary of raw data collected relating to barriers and enablers. These are summarised in section 3.4.5 of the main report.

4. Detailed Analysis of Enablers and Barriers

Enablers

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
1	Market and economy	**Access to Growing Markets** As global demand is expected to increase, tapping into the global market can improve revenues and profits for UK steel sector.	**3 Literature Sources** IBIS Basic Steel Processing in the UK Sutton 2013 "Key drivers for future growth include: demand from motor vehicle manufacturing, total value of construction, government capital expenditure, world price of iron ore, and world price of coking coal." This industry is in long-term decline, but will find some respite over the next five years. The future looks much brighter for the Basic Steel Processing industry. As Britain continues on the path to economic recovery, greater investment in construction projects is expected to bolster demand for processed steel and bring sustained revenue growth to the industry. Over the five years through 2018-	**2 Interviews** Interviewee 1: "investments overseas take priority as this is where the growth is." Interviewee 2: "All new investments are linked to where they are experiencing growth."	**12 Votes**	Demand growth: China has driven global steel production at an unprecedented rate in the last decade. Whilst this has slowed recently, the IEA has projected strong growth to be resumed with crude steel demand increasing by 85% to 122% from 2006 to 2050. Key drivers for future growth include: demand from motor vehicle manufacturing, total value of construction, government capital expenditure, world price of iron ore, and world price of coking coal. The market research identified that the Iron & Steel market in the UK is on a decline, yet the Information Gathering Workshop and literature review found that one of the key enablers to decarbonisation is the fact that steel is a growth sector due to increasing global demand. This would suggest that there is a disconnect between the UK and the global market. This could move in two directions. – If the UK is unable to compete or tap into global steel demand, this could threaten its ability to decarbonise in relative terms. – If the UK is unable to compete, it may have to close down a production site which could lead to reduced absolute emissions. However, consolidation could create additional fear limiting companies' willingness to invest in other advanced technologies. The

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			19, industry revenue is forecast to grow at a compound annual rate of 1.7%, reaching £770.9 million at period close. In 2014-15 alone, revenue growth of 1.4% is expected. This growth is likely to be tempered by reduced demand from curtailed vehicle manufacturing output. Import competition will also intensify into the future, alongside rising steel prices, which are expected to force inefficient operators out of the industry." According to IBIS Iron and Steel Manufacturing in the UK Sutton 2013, the annual growth rate for UK Iron & Steel is projected to increase by 1.8% between 2014-2019" The World Bank GDP Growth (annual %) UK 2009 -2.8%, 2010: 1.7% 2011: 1.1% 2012 0.3% Real GDP Growth in			financial impacts of any policy measures implemented in the UK and the EU, on the sector should also be considered.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			2015 for Europe is 1.8%, North America 2.9%, and Asia Specific 4.0%. In 2018 real GDP Growth is expected to be 2.9% for North America, 2.3 % for Europe, and 3.6% in Asia Pacific.			
2	Regulation	**Increasing regulation** drives energy efficiency investment due to compliance.	**3 Literature Sources** McKinsey 2012 found that past climate change policies such as CCAs, CRCs, and solar FITs have led to organisational change, yet recently there has been a backlash of these policies as they have been changed or placed under review. "Companies who were penalised by the changes in policy are now hesitant to make investments for fear that the policy environment will change again, rendering the investment uneconomic." Ricardo AEA 2013 found that "CCAs and EUETS have already realised short term	**2 Interviews** One interviewee indicated that: 'compliance drives investment decisions. A key investment criterion is compliance (environment and health and safety, regulatory compliance. A second interviewee stated that: "For projects we want to invest in we look at financial criteria and other drivers including legislative, and regulation."	**7 Votes**	The literature review, specifically, McKinsey 2012, identified that in the past climate change policies such as CCAs , CRCs, and solar FITs have led to organisational change, yet recently there has been a backlash of these policies as they have been changed or placed under review. One company stated that its internal climate change policies and strategies which are aligned with governmental climate change policies do drive organisational change and influence investment decisions, but climate change policies and targets are weaker than what they could be if there was a stable regulatory framework in which companies could operate. Interviewees stated that Governmental policies have created an uneven playing field, which has led to perverse incentives, more investments in steel overseas rather than in the UK, and is adding to the decline of the UK steel market. Future climate change policies must be carefully crafted to help it innovate. Interviewees recommend that government place greater focus on the entire value chain and ensure there are a consistent regulatory framework and a joint vision between government and the sector on the

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			carbon reductions". UNEP 2013 found that increasing regulation was an enabler for companies to decarbonise. PWC 2014 found that a key By establishing a regulatory framework which drives innovation, for example by developing European standards that promote sustainable production of steel construction products;			way forward.
3	Market and economy	**Cost of carbon**	**4 Literature Sources** UK STEEL 2012 "Absorbing the cost of carbon under the EU ETS carbon legislation or passing it onto consumers represent a significant challenge to the steel industry. Ultra low-steel making will provide the sector with the opportunity to significantly reduce emissions from steel making; however this will not be line with the timeframe of proposed emissions	**4 Interviews** Interviewee 1: "What else reduces payback time? E.g. look at potential technologies that aren't around at the moment, as then these are a bit in the future when they do become available there will be a number of drivers, e.g. carbon pricing as technologies on worldwide basis e.g. if global carbon pricing in place will be a driver otherwise need subsidization in UK and EU"	**11 Votes**	All evidence gathering sources identified the cost of carbon as both a driver for decarbonisation as it creates a financial incentive to avoid costs, but at the same time participants in the workshop highlighted that the cost of carbon can become a barrier, if cost of carbon is too high, and therefore reduces funding available for decarbonisation projects.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			reductions in the current EU ETS. The steel sector will require significant investment to realise these technologies and the predicted cost of the Phase 3 of EU ETS will limit the sector's ability to invest in the project." Carbon Trust 2011 found that "The steel sector will increasingly be exposed to policies that seek to impose a cost of carbon on production emissions, through the development of new pricing mechanisms over time. As a result, producers of steel should continue to invest in the Research, Development, & Deployment of technologies that will decarbonise production over the long term, including top gas recycling, carbon capture & storage, bio-coke substitution, and alternative processes	Interviewee 2: "The third largest component in the cost structure is the energy taxes, levies, etc." Interviewee 3: "Often for a voluntary project like this, there was an environmental and strategic aspect, reducing carbon and reducing exposure to energy markets where prices are increasing." Interviewee 4: "In terms of energy and carbon control it is really a financial consideration for me. "		

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			such as electrolysis." Chukwumerije Okereke & Devin McDaniel 2012 found that: "The steel industry maybe particularly vulnerable to competitiveness impacts because a carbon price of h20/ton could amount to a 15% increase in production costs for a typical integrated steel mill, which is significant for an industry with relatively tight margins and high trade intensity." Johnson 2013 found that: "economic and uneconomic scenarios. Conditions for success: - incentives through e.g. energy efficiency programmes - full offset of distortive CO_2 costs until international level playing field is restored."			
4	Operational	**Sites located in clusters near a CCS viable location will be able to use CCS and gain a**	**2 Literature Sources** A joint report by UK STEEL and Tata Steel 2011 found that: "Historic, e.g.	**1 Interview** Interviewee 1: "We are lucky that we can connect to CCS if it were to happen. Our other	**11 Votes**	The information sources identified that those companies located in CCS viable sites will have a competitive advantage and will be more likely to be able to invest in CCS.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
		competitive advantage	geographic location of individual process units even within one manufacturing site." Centre for Low Carbon Innovation 2011 identified that: "Industrial geography: Dispersed geographic location characterises large integrated industries, such as Iron & Steel, with different parts of the process located in a dispersed manner which can lead to large inefficiencies, and prevent heat capture and transfer opportunities. Some industrial regions may benefit from a concentration of production (e.g. Aire valley), for plants located outside identified regional CCS clusters may be prevented from accessing CCS transportation and storage networks due to high pipeline connection costs."	plant is not good for CCS geographically."		
5	Market and economy	**Increased demand for certain materials**	**2 Literature Sources** BCG 2013 found that	**2 Interviews** Interviewee 1: Currently	**7 Votes**	Two Interviewees pointed out that steel is a core component of many renewable

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
		used in renewable energy, energy efficiency technologies such as steel leads to growing revenues to invest in decarbonisation.	a key "driver is the production of lighter cars, which would have the highest absolute CO_2 savings (p. 5)." A joint report by UK STEEL and Tata Steel 2011 found that "Light weighting of cars has the highest abatement opportunity, but technical barriers to doing so include design codes which place constraints on the design and performance of the product, Design stage there may be conflicting constraints such as performance trade-offs, Manufacturing and installation costs of light weight cars is higher, the handling of the product in the distribution stage of the supply chain can constraint eh products design, end user negative perfections of light weighting such as panels that flex and optimizing the end of life as may	there is lots of focus on the end of the supply chain. Companies and people using renewables receive lots of positive attention for their decarbonisation efforts, yet what is often ignored is the supply chain that enables these technologies to happen. It is depressing that steel companies are hampered for being polluters but are helping make reductions. A whole value chain approach is needed. A serious approach to Scope 3 emissions hot spots is needed. Interviewee 2: "Commercial opportunities- Wind turbines are steel intensive and offshore wind –take advantage of low carbon technologies. The opportunities vary by sector. Transport – automotive there is a very active agenda steel versus aluminium and fibre and copper as well. Yellow goods sustainability/low carbon not a big differentiating factor, earth moving equipment, caterpillar		energies that help reduce emissions. Key buying industries such as the construction, railway, motor vehicle, and residential buildings look to buy steel as it is durable and can help reduce the life-cycle emissions of buildings and vehicles. Increasing demand for steel will strengthen the steel sector's revenues and enable it to invest in advanced technologies.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			limit the possible reuse of the product. In addition to the technical barriers: carbon price policies may disincentives product light weighting steels as they tend to be more energy intensive in their manufacturing. (p.42,43)"	(JCB), all about durability. Products last longer."		
6	Financial and decision-making	**Environmental projects higher chance of obtaining internal funding/approval if linked to improving critical safety tasks**	-	**4 Interviews** Interviewee 1: "For such an investment decision to be made, you need to consider risks, DFCF, etc. Any investment with payback time lower than 12 months is very likely to be done. We also look at 3rd party funding availability (done by financing department) and forecast it with savings and cash flow on plant level. We also do an external analysis outside of the EU as well to assess competition, e.g. Turkey where price of electricity is much lower than the UK and hence total price of products is lower." Interviewee 2: "Energy efficiency projects will not be	-	The interviews highlighted that if the ROI is more than 12 months, investments are still likely to be successful if it helps the company to improve its market share, improve capacity, save costs, improve HSE performance, meet new regulation, or increase productivity a technology with longer pay back period can still be implemented.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				undertaken unless it is a side benefit to a critical safety task. Especially if it is a big spend. capex decisions are normally focused on the short term. If a project would pay back in several years, but it is not a critical safety capex, the capex will not be made.” Interviewee 3: “Energy efficiency projects will not be undertaken unless it is a side benefit to a critical safety task. Especially if it is a big spend. capex decisions are normally focused on the short term. If a project would pay back in several years, but it is not a critical safety capex, the capex will not be made.” Interviewee 4: “The most important is the financial justification. We only have a finite pot to put investments. The projects with the best financial return will get ahead of the queu. Investments made purely to improve CO_2 emissions, if it has no impact on productivity or		

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				health and safety, it will remain in the queu. As it has to have financial and other types of pay back.”		
7	Financial and decision-making	**Likelihood of investment increases if the project leads to direct large energy savings from new technology (For example, pulverised coal injection instead of steam coal).**	**3 Literature Sources** Ricardo AEA 2013: “Organisational driver: cost and threat of rising energy prices and willingness of top management to make climate change a priority.” Ernst& Young 2012: “Energy costs are still the primary driver of abatement efforts.” European Commission 2013: “Energy costs represent approximately 40% of operating costs in steelmaking. As in other Energy Intensive Industries (EII), energy costs are one of the main competitiveness drivers. P.4”	**4 Interviews** Interviewee 1: In general for all UK steel companies those cultural barriers not there, for decades they have been looking at new ways of saving energy that when technologies became available should adopt them but also need to factor in but less so for incremental investments. Interviewee 2: The third largest component in the cost structure is the energy taxes, levies, etc. Therefore, the company aims to reduce the use of electricity overall. Interviewee 3: “This costs less energy, and also less money. “ Interviewee 4: “Most of our capital investment in relation to climate change is focused on indirect energy and optimising current performance.”	**10 Votes**	The information sources gathered highlighted that as energy is expensive and increasing, those projects or investments that lead to substantial energy savings will likely be invested in over those that do not save energy. This is mainly because projects with direct large energy savings reduce costs.
8	Financial and decision-making	**If ROI is shorter than 12 months, project likely to receive**	**1 Literature Source** A joint report by UK STEEL and Tata	**7 Interviews** Interviewee 1: “Over 1 year ROI unlikely	**12 Votes**	All interviewees indicated that projects with a ROI of under 12 months were likely to be invested in. However, the majority of the

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
		funding	Steel 2011 Key barriers include: "As For Other sectors, e.g. required rates of return on investment, availability of capital (p.17)"	to be accepted by international board as have other companies overseas that may take priority." Interviewee 2: "Any investment with payback time lower than 12 months is very likely to be done." Interviewee 3: "capex decisions are normally focused on the short term. If a project would pay back in several years, but it is not a critical safety capex, the capex will not be made." Interviewee 4: "capex, pay back of 3 years why don't you invest? Main issue is the availability of capital not the length of the pay back. Amount of money you can invest and have is limited by the capital you have to invest." Interviewee 5: "All of the projects are meant to reduce costs and impact on environment (CO_2 and energy). The hard payback period and cash flow is what is preventing		advanced technologies proposed have longer paybacks. Interviewees indicated that projects with ROI longer than 12 months or over 2 years could still be successful if they had environmental, productivity, compliance, safety, and/or energy benefits. Projects or investments that support a key strategic pillar are also more likely to be invested in.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				them from being implemented." Interviewee 6: "There is no such thing as s constructed cut off. There is no cut off for ROI. But what we have to recognise as project proposers is that if you want your project proved over others you have to have very good reasons and back it up. We have in the past made investments about larger projects with longer ROI that becomes a more strategic decision." Interviewee 7: "Target 18 months (ROI). It will depend. It is not a hard fast rule you have to follow but 18 months is a good target. In the marketplace it veers closer to 1 year rather than 18 months."		

Table 9: Raw data – enablers for the UK iron and steel sector

Barriers

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
1	Market and economy	**Global competition** from lower cost producers from the emerging markets.	**3 Literature Sources** According to IBIS Basic Steel Processing in the UK Sutton 2013, "structural risk is forecast to be at a VERY HIGH level over the outlook period. The industry, which faces subdued demand growth, is in decline. In addition, import competition is intense, particularly at the lower-value added end of the product range. Revenue volatility is very high, due to both fluctuations in the price of steel inputs and shifts in demand. Industry exports are expected to contribute 60.3% of industry revenue in 2013-14. This shows an extremely high level of export dependence for industry players, with over two-thirds of revenue generated from shipping products overseas. However, this percentage has	**2 Interviews** One interview found that: "we also do an external analysis outside of the EU as well to assess competition, e.g. Turkey where price of electricity is much lower than the UK and hence total price of products is lower." A second interviewee stated that: "there are so many social issues, fierce competition from around the world".	**19 votes**	The three evidence sources identified that due to the price sensitivity of steel, the economic crises, and inability to pass on increasing costs onto consumers, UK exports have declined by 15.3% since 2009. However, this decline has led to a leaner steel sector, increasing its competitiveness and the forecast of 2.1% increase in exports from 2018-2019 indicates that this barrier is likely to be overcome over the next years. However, to succeed, UK based steel manufacturers must set their own price point, and protect themselves against the sensitivities of the world steel price. This barrier is linked to internal competition with overseas affiliates for available funds for capex investments as multinational companies invest in overseas operations given increased demand in those markets. This barrier is also exacerbated by the un-level playing field caused by carbon regulation in the UK and EU.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			actually fallen over the past five years, with exports contributing 75.6% in 2008-09. During this period, economies worldwide have struggled financially and this has left firms reluctant to import when costs can be spared by sourcing domestically. Many others have been forced to curtail budgets in the face of economic hardship to the detriment of export demand. This is demonstrated by export revenue falling at a compound annual rate of 7.5% over the five years through 2013-14. Exports as a monetary total have themselves decreased at a compound annual rate of 2.0% over the five years through 2013-14. This is despite the pound depreciating during the recession, which resulted in exports being comparatively cheaper for overseas			

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			markets. The level of imports is expected to grow at a compound annual rate of 1.6% over the five years through 2018-19. Over this period, the amount of domestic demand captured by foreign competition is expected to remain unchanged at 48.0%. By comparison, exports are expected to grow at a compound annual rate of 2.1% over the five years through 2018- 19. The downturn that ravaged the domestic steel production industry made it leaner and more efficient. This enabled it to better compete internationally. The value of the Iron & Steel export market is forecast to reach £5.6 billion at the close of 2018-19.Industry revenue is expected to increase at a compound annual rate of 1.8% over the next five years, faster than economic growth and not typical of a			

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			declining industry." JRC 2013 found that "the barriers that can prevent the industry from achieving these improvements include global competition, widespread fluctuation in energy prices, and uncertainties about future energy prices." UK STEEL 2012 identified that "the UK manufactures a wide range of specialised, high quality steel products. However, the large bulk of our output, as with other developed nations, is of qualities available from non-EU competitors. Steel is a globally produced and traded product and the global market is highly price sensitive. The principal sources of import competition are Russia, Ukraine, China, Turkey, Republic of Korea, Serbia, Switzerland, Thailand, Brazil and Belarus [96] none of which have			

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			internalised costs of carbon. It would therefore be impossible to pass on the costs of carbon to our EU customers, who could very simply switch to imported sources."			
2	Financial and decision-making	**Shareholders demand quick payback (2 years)**	**2 Literature Sources** According to McKinsey 2012, "In the commercial and industrial sectors, stakeholders demand a rapid payback period of ~2 years while many EE investments have a longer payback period. While capital constraints may be a barrier for SMEs or underperforming companies, large commercial and industrial organisations can secure necessary financing to make an EE investment if attractive." According to UK STEEL Tata Steel (for BIS/DECC Energy Intensive Industries Strategy Board) 2011 "As For Other sectors,	**7 Interviews** Interviewee 1: "Investing in burners was a no brainer payback was 3 to 6 months." Interviewee 2: For an investment with a three or four year payback, the project sponsor will have to come up with additional reasons to improve the payback period. There must be a strong business case. Interviewee 3: "Any investment with payback time lower than 12 months is very likely to be done." Interviewee 4: ROI 18 months is target of clients but market veers closer to 1 year rather than 18 months. Interviewee 5: "The cost saving from reduced	**12 Votes**	The literature review found that companies are less likely to finance investments in decarbonisation if the payback period is greater than two years. This was reinforced by all interviews conducted, which identified that the longer the payback period the more additional benefits a project must have in order to gain funding. Shareholder demand for a quick payback is likely a consequence of the economic recession, and the high competition for funding. The interviews suggested that longer pay back periods can be overcome through alternative financing arrangements, such as off balance sheet investments: Third parties take on projects (upfront financial risk) or investment from the Green investment bank. However, interviewees noted that the application processes for obtaining investments should be made less bureaucratic and simple.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			e.g. required rates of return on investment, availability of capital (p.17)."	natural gas import and pay back was about 3 years. 3 years is on the high end of pay back accepted." Interviewee 6: Over 1 year ROI unlikely to be accepted by international board as have other companies overseas that may take priority. Interviewee 7: capex decisions are normally focused on the short term. If a project would pay back in several years, but it is not a critical safety capex, the capex will not be made. There are several exceptions to this, when commitments to expenditures were already made before 2006 or 2007, before the financial crisis broke out.		
3	Financial and decision-making	**Availability of capital/ competition for funds**	**2 Literature Sources** According to a joint report between UK STEEL and Tata Steel (for BIS/DECC Energy Intensive Industries Strategy Board) 2011 "As For Other sectors, e.g. required rates of return on investment,	**3 Interviews** Interviewee 1: "It is moreover difficult to get external finance for investments." Interviewee 2: "capex, pay back of 3 years why don't you invest? Main issue is the availability of capital not the length of the pay back. Amount of	**15 Votes**	The interviews identified the largest competition for financing was from operations outside of the UK and from other large investment projects funded internally. Proposed mechanisms for overcoming these barriers in the interviews and workshop included: attractive energy taxes and levies can reduce costs and free up capital for decarbonisation. Flexible covenants with banks can overcome other financial hurdles Steel companies can target global investors that are not affected

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			availability of capital (p.17)." Centre for Low Carbon Innovation 2011 found that "Availability of capital: A large proportion of UK companies operating in the energy intensive sector are subsidiaries of global organisations. They compete internally for capital investment. Higher costs make it more difficult to justify internal group investment in the UK. The Green Investment Bank was, however, seen as potential source of capital for energy efficiency projects. Lack of financial support for R&D: Some respondents commented on the difficulty of accessing government support to promote industry R&D."	money you can invest and have is limited by the capital you have to invest. Interviewee 3: "We are low gear in terms of finance. Our finance is asset based. It puts limitations on capital availability. It has benefits on the rates at which capital is available. But it puts limitations on our ability to invest in larger projects. I think it means that the majority of investments we make must come from revenue rather than additional borrowing. If we are looking at larger projects, this must be arranged within our existing financing arrangements."		by the crisis to obtain funding. Longer pay back periods can be overcome through alternative financing arrangements, such as off balance sheet investments: Third parties take on projects (upfront financial risk).
4	Market and economy	**Slow rate of capital stock turnover**	**2 Literature Sources** According to IBIS Iron & Steel Manufacturing in the UK Sutton 2013, "the Iron &	**2 Interviews** Interviewee 1:"Whether we start working more in the UK would be based on the cycle. We have got	**8 Votes**	Start-up costs are particularly high in the industry, predominantly because of the high level of large-scale machinery necessary to manufacture Iron & Steel. In the production process large machinery is

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			Steel Manufacturing industry exhibits a high level of barriers to entry, with new entrants facing high start-up costs, strict environmental regulations and competition from established brands. Start-up costs are particularly high in the industry, predominantly because of the high level of large-scale machinery necessary to manufacture Iron & Steel. In the production process large machinery is required, such as blast furnaces and rolling and forging mills, to complete most stages of the process. Producers will also require large facilities that can accommodate this bulky machinery. This initial cost can be prohibitive for prospective entrants, especially given the tightening credit conditions and lack of investment in the economy. The Iron &	to be bringing in something during a blast furnace shut down.” Interviewee 2: “But investment cycles e.g. blast furnaces operate in 10 years so opportunities rare but most carbon intensive routes. Two blast furnaces have been either relined and restarted or are brand new. ”		required, such as blast furnaces and rolling and forging mills, to complete most stages of the process. Producers will also require large facilities that can accommodate this bulky machinery. This initial cost can be prohibitive for prospective entrants, especially given the tightening credit conditions and lack of investment in the economy. This was reinforced in the workshop and interviews that the timing of advanced technology deployment will have to be aligned with the lifecycle of each plant.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			Steel Manufacturing industry is characterised by a high level of capital intensity. For every £1.00 spent on capital, £2.47 is spent on labour. The nature of metal manufacturing is inherently capital intensive and requires investment in expensive equipment such as large furnaces, shredders, rolling mills, strip casters and other heavy machinery. The industry is also dominated by a handful of large firms that have focussed on automating their production processes to ensure maximum efficiency, thus reducing labour dependence." Rootzéna and Johnssona 2013 "A large share of the existing capital stock/assets will need to undergo major refurbishment or replacement over the coming decades. The			

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			assumed average technical lifetime of key process equipment in the primary steel production is set to 50 years.”			
5	Market and economy	**Increasing electricity and gas prices**	9 Literature Sources A higher electricity Brunke and Blesl (2014) price was highlighted in the literature review as a key barrier specifically for electric arc furnaces. However, through a sensitivity analysis, Brunke and Blesl (2014) found that Energy-related production costs of the BF/BOF route increased on average by 6–13% between 2013 and 2035. (Meaning driver for EAF to invest in reducing energy consumption through innovation is to compensate for higher electricity prices). David Kennedy, Ewa Kmietowicz for CCC 2013 found that “current electricity prices for industrial	**4 Interviews** The interviews identified that the cost of operating in the UK is higher due to higher electricity costs which hinders investment decisions. Interview 1: “For voluntary energy efficiency projects, there was an environmental and strategic aspect, reducing carbon and reducing exposure to energy markets where prices are increasing.” Interview 2: “To pay for all these schemes, electricity prices (unabated costs) are going up, which is hurting steel industry. “ Interview 3: “Electricity is the second highest component in the cost structure therefore is of paramount importance. “ Interview 4: “Energy prices- no single market	**12 Votes** During the workshop EIT stated: ‘A number of representatives identified the high and rising costs of energy and energy taxes in the UK, as well as rising commodity prices, as a barrier to investment. Parent companies see relatively poor returns on investment in the UK compared with other countries. The representatives consulted referenced the TUC/EIUG report (2010) on the cumulative impacts of climate change policy on the energy intensive industries, with both electricity and gas costs expected to rise by up to 22% by 2020’ The Centre for Low Carbon Futures (2011) .	Increasing electricity and gas prices in the UK can be seen as both a barrier and an enabler. Higher electricity prices can increase costs and competitiveness in comparison to global competition that operate in countries with lower electricity prices. However, higher energy costs also incentivize companies to invest in energy efficient technologies and therefore decarbonise. Uncertainty about future energy prices also acts as a barrier to investment. The UK government, specifically the HM Treasury in its 2014 Budget has indicated that UK energy prices are as far as 50% higher as those in France and that the government intends to secure affordable energy.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			users in the UK are high relative to those in the rest of the EU and internationally, largely reflecting higher base prices (wholesale plus network costs), with greater low-carbon price adding £12/MWh. enablers: Lower medium to long-term electricity prices. Between 2020-2030 is the (next investment cycle), Key drivers are the costs of CfDs (contract of difference), carbon price, and higher system costs due to intermittency. Flues, F. et al 2005 found that "higher energy prices tend to raise energy efficiency (or tend to reduce specific energy consumption) in the steel sector. This tie between energy-price/-efficiency is due to economic agents' reaction to the price signal: they raise their efforts to diminish the	for energy prices. Energy prices are higher than in Holland, In Holland higher than in other countries. You can argue this could help you in terms of energy efficiency schemes, but you are actually taking money away from the company because you are taking away profitability."		

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			averse price-effect on their profits by lowering the use of the now more costly input." Eurofer 2013 found that "US shale gas and increasing pressure to export scrap and increasing electricity and gas prices will threaten electric arc furnaces (EAF) competitiveness. (p.35)" JRC 2013 found that "the barriers that can prevent the industry from achieving these improvements include global competition, widespread fluctuation in energy prices, and uncertainties about future energy prices." Capros et al. 2013 found that the price of electricity pre-tax by sector is increasing until 2020, before stabilising. http://ec.europa.eu/energy/observatory/tren			

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			ds_2030/doc/trends_to_2050_update_2013.pdf Eurostat Structural Business Statistics (SBS) database According to the European Commission 2014, "In 2012, electricity costs in production costs were 5% for Blast Furnaces, and 12-15% for Electric Arc Furnaces." http://ec.europa.eu/energy/doc/2030/20140122_swd_prices.pdf According to the HM Treasury Budget for 2014 Article 1.105 specifically recognizes that the UK energy prices are as far as 50% higher as those in France and that the government intends to secure affordable energy.			
6	Value chain	**Steel customers primarily make decisions on costs, not on carbon**	**1 Literature Source** Prof. Sarita Srivastav conducted a case study on Tata's	**4 Interviews** Interviewee 1: "Our company provides interim products to construction	-	Interviewees indicated that decarbonisation would become a strategic issue if more customers demanded low carbon steel products through purchasing requirements,

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
		emissions	sustainability strategy and business ethics and found that "The benefits of taking responsibility for sustainability include an enhanced reputation which, in turn, leads to greater customer loyalty. The benefits can also be seen in terms of efficiency, with businesses using fewer raw materials, less power and more recycling. Both of these have an impact on profits and shareholder confidence."	designers. Customers so far haven't requested low-carbon products but ask for responsible sourcing and traceability. Our company is trying to promote themselves as greener steel provider." Interviewee 2: "If there is an appetite for that in our customer base or general public that would become a strategic issue. At the moment most of our customers are struggling as well. They would rather see lower prices and increased efficiency. At the moment most of our customers are struggling as well. They would rather see lower prices and increased efficiency. Demand from customers, information demand for CO_2 emissions as part of purchasing decisions. We are seeing increasing elements and criteria that our customers are using as part of their purchasing decisions including environmental and health and safety criteria. If CO_2 was a key criterion this would drive change internally."		but all interviews so far confirmed that customers are currently not requesting this type of information. This differs from more consuming facing sectors where customers may request this information. The literature review indicated that investing in sustainability and energy efficiency, steel companies such as Tata, can enhance their customer loyalty. Thus, even if customers are not demanding lower carbon steel,

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				Interviewee 3: “Customers do not choose products because it is more energy efficient purely customers are mostly cost driven.” Interviewee 4: “Customers are not asking for low carbon steel.”		
7	Regulation	**Regulatory uncertainty**	**2 Literature Sources** Ernst & Young 2012 “It is, however, important to note that cost is not the only carbon-related driver. The full set of considerations can be categorized as follows: Regulatory clarity and uncertainty…” McKinsey 2012: “Complex and changing policy landscape is a challenge. Several existing policies (e.g., CRC, CCAs, Solar FiTs) have changed significantly or are currently under review. Companies who were penalised by the changes in	**2 Interviews** Interviewee 1: “If we look at CCS, what we are trying to do is develop the project. Government/regulatory uncertainty, technological uncertainty, and having to identify ingenious ways of funding the project. Regulatory environment and uncertainty is a key barrier. Risks and benefits will constantly change. The end dates of schemes aren’t really clear. CCS, CCL, compensation schemes for energy costs there are no guarantees of the life of the scheme. “ Interviewee 2: “Regulatory environment and uncertainty is a key barrier. Risks and	**10 Votes**	The inconsistencies in policies and constant changing of policies creates uncertainty and leads to companies withholding investment decisions as they are unsure if future investments will be sound if policies are changed again.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			policy are now hesitant to make investments for fear that the policy environment will change again, rendering the investment uneconomic. Many new policies have been introduced in the last 2 years and there is a lack of clarity on what the landscape will look like going forward. Given the complex policy landscape, not all companies are aware of the existing EE incentives"	benefits will constantly change. The end dates of schemes aren't really clear. CCS, CCL, compensation schemes for energy costs there are no guarantees of the life of the scheme. "		
8	Financial and decision-making	**Increasing Cost of Carbon and uneven playing field (financial barrier)**	**7 Literature Sources** Wooders and ISSD 2012 found that "competitiveness and leakage concerns must be taken into account in decision-making for decarbonising steel." TUC 2012 identified that "avoiding carbon leakage (the loss of jobs, investment and carbon controls to countries with weaker (or no) climate	**3 Interviews** Interviewee 1: "The third largest component in the cost structure is the energy taxes, levies, etc. Therefore, our company aims to reduce the use of electricity overall." Interviewee 2: "UK electricity prices (including CO_2 allowances) are more expensive than Germany or France. Cost of operating in the UK therefore hinders investment to some	**8 Votes**	All evidence gathering sources confirmed that another key barrier is the existence of carbon leakage and an unfair playing field in the UK and EU where companies must pay for carbon in comparison to global competitors who do not have to factor in this additional cost. Interviewees suggested that a global carbon pricing model would even the playing field and incentivise decarbonisation if the price was high enough.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			change policies. Wider economic challenges: But the EIIs are currently under enormous pressure as a result of both the general economic climate and UK and European environmental and energy policies. There is significant evidence that, unless immediate steps are taken, these policies will have a corrosive effect on the viability of individual businesses and entire industry sectors within the UK. As witness to these concerns, the closure of the UK's last remaining aluminium smelter in the north-east and the announced closure of a steel plant in north Kent are just two current examples of industries under intense pressure." Ernst & Young 2012 found that "Energy costs are still the primary driver of abatement efforts. '-Regulation has	extent." Interviewee 3: "We have been hit by a number of issues. We can't fire on a new boiler plant due to EU ETS limits. We are doubling our emissions, because of the policy. The gas coke oven of our new plant doesn't meet EU ETS levels, but this doubles our emissions. This is the UK implementation of the EU ETS policy. EU ETS is a significant cost to us."		

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			encouraged many companies to put in place carbon management strategies -Improved carbon disclosure has helped to increase awareness and transparency of climate change issues. -Cap-and-trade programs have had little positive financial impact on corporates, but this will change. -Climate change represents an important opportunity for business, as well as a risk." PWC 2014 "Enabler: By working to establish a level playing field at international level, for example by using trade policy to ensure that European steel producers have access to third country markets" UK STEEL 2012 found that "absorbing the cost of carbon under the EU ETS			

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			carbon legislation or passing it onto consumers represent a significant challenge to the steel industry." Centre for Low Carbon Innovation 2011: Price of energy: A number of representatives identified the high and rising costs of energy and energy taxes in the UK, as well as rising commodity prices, as a barrier to investment. Johnson 2013 found that: "economic and uneconomic scenarios. Conditions for success: - access to scrap and energy at competitive prices - incentives through e.g. energy efficiency programmes - full offset of distortive CO_2 costs until international level playing field is restored."			
9	Regulation	**Energy taxes and levies (financial barrier)**	**1 Literature Source** McKinsey 2012 found that: "Companies will need to adapt and be	**5 Interviews** Interviewee 1: "EU-ETS is not fit for purpose for any other sector, but power	-	Interviewees indicated that government is not helping the situation through increased energy taxes, levies and increasing carbon price which is another additional cost

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			competitive on a range of factors not just labour and tax. Government needs to take down regulatory barriers to trade and enable and support R&D (p.10).	because as it tightens and companies buy more allowances it is only depriving them of cash. This makes it more difficult to invest." Interviewee 2: "UK electricity prices (including CO_2 allowances) are more expensive than Germany or France. Cost of operating in the UK therefore hinders investment to some extent." Interviewee 3: "Government run energy efficiency schemes, take away profits." Interviewee 4: "Climate change policies have had an impact on organisational change, but a negative one. Taken focus away from how to decarbonise or solve the problem to how to avoid cost." Interviewee 5: "This is the UK implementation of the EU ETS policy. EU ETS is a significant cost to us. The allowance and benchmark levels were		making it more difficult for them to invest in decarbonisation in the UK. The economic recession and several years of lower demand have also led to reduce revenues. Attractive energy taxes and levies can reduce costs and free up capital for decarbonisation.

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
				set at unachievable levels so we are running a deficit. One of the factors that is not helping us invest. In terms of setting taxes against investment. Rather than us having caps on CCS. The thought is CCS will reduce CO_2 costs. But while the projects being implemented there is a development cost, but there are still the EU ETS costs. If the tax and environmental liabilities during the demonstration project."		
10	Financial and decision-making	**Decarbonisation and reducing carbon emissions is not seen as a strategic issue**	**1 Literature Source** EEDO 2012 found that: "the lack of salience of energy efficiency increases the impact of hassle costs and behavioural barriers. Energy efficiency changes may involve significant hassle costs for those carrying out the investment, which increases the costs of the investment. For example, disruption caused by building works or disruption to production lines. Energy efficiency	**3 interviews** Interviewee 1: "Decarbonisation is not a business goal. Decarbonisation is not the first priority amongst equals to the CEO. At the moment, the steel sector is struggling with profitability, getting into the black out of the red. Once this improves, then there will be time to look at energy efficiency, and other initiatives linked to sustainability such as biodiversity, looking at general upkeep, appearance of the site etc. It very much depends on the prevailing	Discussion held, but topic was not voted on.	The interviews and literature review confirmed decarbonisation is often seen as a cost saving initiative, a technical engineering issue, and is not regarded as a strategic issue or a core part of a company's business strategy. Reviewing the sustainability and annual reports of the key steel companies highlighted that decarbonisation is a key part of Iron & Steel companies sustainability strategies, but is often not reflected in their overall business strategies. All of the companies interviewed and participants of the workshop indicated that they had sustainability strategies in place where energy efficiency and decarbonisation were key pillars of this strategy. However, the interviews and discussions at the Information Gathering Workshop indicated that some investments have been stalled due to the recession and the weak

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis and Interpretation
			improvements may not be seen as strategic for a company."	conditions. I don't see when those times come back that we would be able to use CO_2 emissions as our marketing point. If there is an appetite for that in our customer base or general public that would become a strategic issue. At the moment most of our customers are struggling as well. They would rather see lower prices and increased efficiency." Interviewee 2: "Climate change policies have had an impact on organisational change, but a negative one. Taken focus away from how to decarbonise or solve the problem to how to avoid cost." Interviewee 3: "Carbon/energy efficiency competes with everything else in the business. It is not the driver of the business; it is one option for saving money."		economy, creating a tumultuous business environment for large capex investments such as new low carbon technologies. All three information sources highlighted that there is strong buy-in across the sector for decarbonisation. Due to the small number of big players in the UK, innovation and R&D is a non-compete zone. The UK is especially strong in innovation and R&D which the sector is leveraging by tackling decarbonisation together. Decarbonisation is seen as a technical issue and not a strategic issue. Interviewees also indicated a joint collaborative way forward coupled with a clear vision of the future would help to ensure that decarbonisation moves from a technical issue and incremental improvements through kit replacement to a key strategic priority for the sector. They all stated that this can only be achieved if revenues increase so companies have funds to invest.

Table 10: Raw data – barriers for the UK iron and steel sector

APPENDIX C – FULL TECHNOLOGY OPTIONS REGISTER

INCLUDING DESCRIPTIONS

APPENDIX C FULL TECHNOLOGY OPTIONS REGISTER

1. Options Register

Technology options identified in the tables below come from sources listed in the references in section 6 of the main iron and steel sector report.

All Plant							
Option	**Technology Readiness Level[6]**	**Adoption rate**	**Practical Applicability**	**Capex (per applicable site)[7]**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Heat recovery and re-use: conventional options	8-9	50%	88%	£1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	1% (C)	Estimate from industry experience, based on half the heat saving (~2% value from Tata Steel comments received, 2014)
Improved automation and process control	9	20%	63%	£750,000	Directly from literature and review by sector team. (US EPA, 2012; Berkley National Lab, 2010)	1% (C)	Estimate from industry experience, based on similar magnitude as heat saving (~1% value from Tata Steel comments received, 2014)

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

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

All Plant							
Option	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex (per applicable site)[7]	Capex Data Source	CO_2 (C) or Electricity (E) Reduction	Reduction Data Source
Installing VSDs on electrical motors (pumps and fans)	9	50%	100%	£4,270,000	Directly from literature and review by sector team. (US EPA, 2012; Berkley National Lab, 2010)	(E)	Electricity energy savings based on literature: Coking plant 0.006-0.008GJ/tonne coke; BOF 0.003GJ/tonne crude steel; hot strip mill 0.3 GJ/tonne product; re-heating furnace 0.33 GJ/tonne product; EAF 0.06GJ/tonne steel (US EPA, 2012)
Reducing yield losses	8-9	40%	100%	£500,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	3% (C)	Estimated from industry experience (2014)
Compressed air system optimisation	9	34%	100%	£750,000	Adapted for this project based on the following references and review by stakeholders at workshops (Berkeley National Lab, 2010)	3% (E)	Estimated from industry experience at ~3% electrical saving for BF-BOF & ~0.5% for EAF
Use of premium efficiency electrical motors	9	13%	100%	£4,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members at workshops	10% (E)	General literature trend is 1-10% electrical savings compared to standard motors

All Plant							
Option	**Technology Readiness Level**[6]	**Adoption rate**	**Practical Applicability**	**Capex (per applicable site)**[7]	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Steam or power production system upgrades	8-9	32%	86%	£50,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members at workshops	7% (C)	Estimated value from workshop feedback
Heat recovery and re-use: innovative options	5-7	0%	88%	£1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	1% (C)	Estimated based on heat recovery and re-use conventional option and Tata data
Improved site or sector integration	8-9	10%	50%	£400,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	15% (C)	High level estimate based on workshop feedback

Table 11: All plant full technology options register

Integrated (BF-BOF) sites							
Option	**Technology Readiness Level**	**Adoption rate**	**Practical Applicability**	**Capex (per applicable site)**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Coke Making							

Fuel substitution: coking plant	8-9	0%	50%	£750,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	10% (C)	Estimated value from workshop feedback (2-10% savings range)
Coke dry quenching	8-9	0%	50%	£46,500,000	Adapted for this project based on the following references and review by stakeholders at workshops (Pardo et al., 2012; Berkley National Lab, 2010; EC 2013; NEDO, 2008)	5% (C)	Estimated value from workshop feedback and literature (IIP, 2014)
Sintering							
Waste heat recovery: sintering	8-9	7%	100%	£5,000,000	Adapted for this project based on the following references and review by stakeholders at workshops (Pardo et al., 2012; US EPA, 2012; Berkley National Lab, 2010; IIP, 2014; NEDO, 2008)	25% (C)	Estimated value same magnitude as typical fuel saving achieved, based on Industry experience (2014) and literature (IIP, 2014)
Blast Furnace							
Pulverised coal injection (PCI)	8-9	85%	100%	£45,000,000	Directly from literature and review by sector team (Feliciano-Bruzual, 2014; Berkley National Lab, 2010)	5% (C)	Value based estimated equivalent to fuel savings derived from literature (IIP, 2014)
Pulverised coal injection with	5-7	0%	85%	-	Not part of cost evaluation	29% (C)	Directly from literature (Feliciano-Bruzual, 2014;

use of biomass (bio-PCI)							DECC, 2014) Literature value scaled from 29% to 25.5% according to assumed bio-charcoal carbon intensity at 0.025kgCO_2/kWh
Basic Oxygen Furnace							
BOF heat and gas recovery	8-9	29%	100%	£35,000,000	Directly from literature and review by sector team (Pardo et al., 2012; US EPA, 2012; Berkley National Lab, 2010)	5% (C)	Value same magnitude as fuel savings estimate, based on literature values (IIP, 2014; NEDO 2008; US EPA 2012)
Blast Furnace and Basic Oxygen Furnace							
Retrofit solution without CC	8-9	0%	100%	£100,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	20% (C)	Value based on workshop feedback (20-30% range without biomass), literature value for TGR (15%), and Tata Steel feedback during social and business research (20%), 2014
Stove flue gas recycling without CC	8-9[8]	0%	100%	£13,500,000	Adapted for this project based on the following references and review by stakeholders at workshops (Pardo et al., 2012)	8% (C)	Value based on workshop feedback estimate for stove flue gas recycling with CCS, and downscaled if no CCS
Stove flue gas recycling with CC	6[7]	0%	100%	£17,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	27% (C)	Value based on Linde, Communications with A. Cameron (2014)

[8] Element Energy, 2014 (note: for oxy-combustion capture; post-combustion TRL 7)

Retrofit solution[9] with CC[10]	6	0%	100%	£130,000,000	Value based on literature (DECC, 2013)	50% (C)	Value based on workshop feedback (60-80% range given) and literature value (50% for TGR with CCS)
Advanced technologies without CC and rebuild	6	0%	100%	£700,000,000	Provided by trade association and their members with review by sector team and PB/DNV GL	25% (C)	Value based on workshop feedback (20-40% range given), Tata Steel feedback from social and business research (25%), 2014, and from literature HIsarna without CCS up to 20%, Corex 20%, Finex 4%
Advanced technologies with CC and rebuild	5	0%	100%	£1,360,000,000	Provided by trade association and their members with review by sector team and PB/DNV GL.	80% (C)	Value based on workshop feedback (60-90% range given), literature (Draft report CCS and CCU potential in UK DECC) HIsarna with CCS up to 80%, Tata Steel feedback from social and business research (80%), 2014
Advanced electrolysis techniques	4	0%	-	Not part of any pathway		80% (C) (switch to Elec)	Based on workshop feedback, noting saving is dependent on electricity grid carbon intensity

Table 12: Integrated (BF-BOF) site full technology options register

[9] Post combustion capture including power plant
[10] All costs are for CO2 capture alone, including CO2 purification and compression. Costs associated with transport and storage/utilisation are excluded

Electric Arc Furnace							
Option	**Technology Readiness Level**	**Adoption rate**	**Practical Applicability**	**Capex (per applicable site)**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Scrap densification or shredding	8-9	35%	70%	£1,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members at workshops	5% (E)	Estimate based on Industry experience, ~5% magnitude confirmed in Tata Steel comments received, 2014
Ultra high power transformers	8-9	33%	75%	£1,750,000	Directly from literature and review by sector team (EPA, 2012)	5% (E)	Estimate based on Industry experience, ~5% magnitude confirmed in Tata Steel comments received, 2014
Improved process control: EAF	8-9	48%	100%	£1,500,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members at workshops	(E)	Value used based on literature at 30kWh/t steel (US EPA, 2012)

Table 13: Electric arc furnace full technology options register

Secondary Processes							
Option	**Technology Readiness Level**	**Adoption rate**	**Practical Applicability**	**Capex (per applicable site)**	**Capex Data Source**	**CO_2 (C) or Electricity (E) Reduction**	**Reduction Data Source**
Hot charging	9	3%	80%	£26,300,000	Directly from literature and reviewed by sector team (US EPA, 2012)	3% (C)	Estimated value from industry experience (2014) & literature (US EPA, 2012)

Improved planning and throughput optimisation: secondary processes	9	12%	100%	£350,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	5% (C)	Estimated value from industry experience (2014)
Re-heating furnace optimization	9	19%	100%	£1,500,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	(fuel only)	Value used based on 5-10% fuel savings range given in literature range (IIP, 2014)
Near net shape casting	8-9	10%	20%	£150,000,000	Directly from literature and review by sector team (US EPA, 2012; IIP, 2014)	58% (C)	Value used based on range of literature (IIP, 2014; US EPA, 2012;; EC, 2013)
Endless strip production	8-9	0%	20%	£30,000,000	Expert judgement (PB/DNV GL consortium) with review from trade association and their members	40% (C)	Value used based on workshop feedback (40-60% savings range) and literature range (40-60% specific energy consumption in traditional mill (IIP, 2014)
Heat recovery from cooling water	9	0%	100%	£1,500,000	Directly from literature and review by sector team (US EPA, 2012)	<1% (C)	Value used based on literature (IIP, 2014; US EPA, 2012)
Regenerative or recuperative burners: secondary processes	9	54%	100%	£4,270,000	Directly from literature and review by sector team (US EPA, 2012)	(fuel only)	Value based on (up to) 30% fuel saving from literature (IIP, 2014)

Table 14: Secondary processes full technology options register

2. Incremental and Disruptive Options

As mentioned in appendix A, options were classified into incremental and disruptive options. The disruptive options were regrouped from a technology specific categorisation to a more generic grouping during the workshop. This is because participants felt unable to identify specific technologies that are expected to play a significant role in different pathways. The regrouping was subsequently discussed in the sector team and adopted for the remainder of the project.

The incremental options were grouped into generic options, coke making, sintering, blast furnace, basic oxygen furnace, electric arc furnace, casting, and secondary processes.

Descriptions of these disruptive and incremental options are provided in the tables below.

Disruptive Options

The disruptive options are listed in Table 15.

Option	Description
Advanced technologies with CC and rebuild	For example HIsarna with CC, Corex, Finex: descriptions of these technologies are provided in the main report
Advanced technologies without CC and rebuild	For example HIsarna with CC, Corex, Finex: descriptions of these technologies are provided in the main report
Advanced electrolysis techniques	Replacement of thermal processes to reduce iron ore with electrolysis based processes
Retrofit solution with CC	TGR with CC, on-site power plant with CC, coke and sintering lines and other processes with CC
Retrofit solution without CC	TGR without CC, biomass or charcoal use
Improved site or sector integration	Ecopond, industry park or complex, heat integration, BF slag use in cement, waste gas integration

Table 15: Disruptive options

Generic Options

The generic options are listed in Table 16.

Option	Description
Improved automation and process control	Applicable to all parts or sites, i.e. coke making, sintering, BF, BOF, EAF; optimised automation and process control leads to higher production, lower consumption, less downtime, etc.; includes energy management
Heat recovery and re-use: conventional options	Internal use (for example on-site power generation, steam generation or pre-heating of raw material) External use (for example integration in local district heating network or export to other industries)
Heat recovery and re-use: innovative options	Organic rankine cycle (using organic working fluid, producing electricity from waste heat); kalina cycle (thermodynamic process for converting thermal energy into usable mechanical power); thermophotovoltaic (TPV) conversion (direct conversion of radiation heat to electricity)
Installing VSDs on electrical motors (pumps and fans)	Variable speed drives (VSDs) allow the desired set point for the flow rate to be realized by changing the rotation speed of the motor, rather than by means of a control valve

Improved planning	Optimised planning leads to higher productivity, less waiting time, reduced heat losses, etc.
Compressed air system optimisation	Measures can include compressed air pressure reduction, leak detection and remediation, avoiding unnecessary use, optimising dew point setting, improved compressor control, etc.
Steam or power production system optimisation	Various measures can be considered, for example blow down optimisation, feed water quality optimisation (avoid scaling), improved boiler cleaning procedures, oxygen tuning, flue gas heat recovery, feed water pre-heating, VSDs on feed water pumps, condensate return optimisation, improved insulation, optimising control of multiple boilers, etc.
Use of premium efficiency electrical motors	When replacing large electrical motors with high duty factor, premium efficiency motors make economic sense
Reducing yield losses	Avoiding off-spec products and reducing yield losses can considerable reduce energy consumption
Biomass based steam generation	Partial or total replacement of fossil fuels to produce steam will lead to considerable CO_2 emissions reduction
Energy management	
Lighting optimisation	
Right sizing of equipment	For example pumps (for example coke quenching pumps)
Substitution for low carbon fuels	
Reduction of distribution losses	

Table 16: Generic options

Coke Making

The coke making options are listed in Table 17.

Option	Description
Coke dry quenching	Coke is cooled by inert gas instead of by spraying water, allowing recovery of thermal energy in the quenching gas; steam or electricity can be produced; also improves coke quality and allows lower coke consumption in BF
Coal moisture control	Reduction moisture of coke making feed from 8%-10% to 6% by means of low-pressure steam or sensible heat from coke oven gas, which results in a reduction in carbonisation heat demand and improves productivity and coke quality
Fuel substitution	Use of waste plastics or equivalent in coke oven
Further use of coke oven gas	Coke oven gas recovery potential: 6 - 8 GJ / tonne coke produced Example of use: supplementary fuel in BF
Coal stamp charging	Compacting coal outside the coke oven, this is then pushed into the oven; 30-35% increase of bulk density of the charge, resulting in 10-12% increase of productivity of the oven; conserves coking coal, increases coke plant yield, and may improve heat recovery; allows use of lower grade coal

Automation and process control system	Improved process control by a state-of-the-art automation system
Heat recovery coke ovens	
Use of petroleum coke instead of coke	Alternative material to act as carbon source, produced by the oil refining sector; could potentially eliminate requirement for coke making

Table 17: Coke making options

Sintering

Sintering options are listed in Table 18.

Option	Description
Selective waste gas recycling (EPOSINT)	Environmentally process optimised sintering: selective recycling from wind boxes with burn-through at or near the bottom of the bed; reduction of off-gas volume, increased productivity, reduction of emissions Alternatives include: sectional gas recirculation and low emissions and energy optimised sintering process
Improved ignition oven efficiency with multi-slit burners or curtain flame ignition system	Regulation of the inner pressure of the ignition oven and multi-slit burners (uniform ignition and rapid heating); lower energy consumption leads to emissions reduction Alternative: curtain flame ignition system
Waste fuel use	Use of waste oils (and other wastes with caloric content) as fuel, substituting coke breeze.
Emissions optimised sintering (EOS)	Housing of entire sinter strand and the recirculation of collected waste gases to the entire surface; 40-50% recycling rate of waste gas
Waste heat recovery	Heat recovery from sinter machine exhaust and sinter cooler off-air to produce steam in recovery boilers, used as process steam or to produce electricity; sinter machine exhaust can be recirculated to the sinter machine after or without a recovery boiler; sinter cooler off-air can be recirculated to the sinter machine or used for combustion air pre-heating in the ignition hood or pre-heating sinter mix or district heating
Woodchar in sinter making	Substitution of ca. 20% of coke breeze is technically feasible; process improvements (increased productivity by 8%) and reduction of acid gas levels
Pelletised BF dust	Pelletisation improves combustion characteristics of BF dust and allows higher substitution rate of coke breeze
Automation and process control system	Improved process control by a state-of-the-art automation system
Improved charging system	Improved sinter permeability and efficiency through improved charging system that maintains constant particle size; reduced material return due to poor sintering
Leakage reduction	Reduced air leakage reduces the fan power consumption
Energy management	

Table 18: Sintering options

Blast Furnace

The blast furnace options are listed in Table 19.

Option	Description
Automation and BF process control system	Improved process control by a state-of-the-art automation system
Use of high-quality ore	Use of high-quality ore (high metal and low gauge content) increases productivity and energy efficiency
Top pressure recovery turbine (TPRT)	Gas leaving the furnace at 2-3 bar (and 200°C) is used to drive a turbine to produce electricity; gas exiting TPRT can still be used as fuel in other processes (ca. 3 MJ/Nm³); depending on dust removal, wet and dry systems are discerned; dry systems allow higher power production (up to 30%) than wet systems and are economically more favourable (capex of dry systems is 70% of the capex of wet systems)
Pulverised coal injection (PCI)	Injection of coal granules constitutes a supplemental carbon source, supporting the iron reduction and reducing the coke need; in turn, energy use and emissions are reduced; substitution level is limited and depends on many factors; max level is ca. 0.27 tonne coal / tonne hot metal; use of oxy-coal allows further increase and reduces coke quantities accordingly
Improved BF gas recovery	BF gas has significant energy content (2.7-4.0 MJ/Nm³) and can be used as fuel for the generation of electricity; often the gas is enriched by coke oven gas or natural gas prior to use; depending on the BF, part of the BF gas is lost when charging; techniques for recovering this gas are available
Bell-less top (BLT) charging	Screening of input materials (coke and sinter) before charging improves the distribution and, in turn, the coking rate and productivity
Natural gas or oil injection	Similar to PCI, use of natural gas or (heavy fuel) oil reduces the coke demand; emissions reductions depend on the type of oil and gas Oxy-oil technology allows oil injection rates up to 0.13 tonne oil / tonne hot metal, with 15 kg coke saving / tonne hot metal as a result With natural gas, hydrogen is used as reducing agent, which leads to less CO_2, reduces heat demand, and increases productivity Typical injection rates: 0.04-0.11 tonne natural gas / tonne hot metal (max 0.155 tonne / tonne) Natural gas can also replace PCI, usually at 200-500 Nm³ natural gas / tonne injected coal
Fuel substitution	Use of processed charcoal with enhanced mechanical stability or waste plastic or bio-charcoal or equivalent.
Increased BF top pressure	Annular wet scrubber is used for BF off-gas cleaning, which allows top pressure to be controlled accurately and consistently Increased top pressure improves BF operation and productivity and saves energy through lower gas velocity and increased retention time
Injection of coke oven gas	Use of coke oven gas as reductant in BF yields a reduction in coke and other reductant consumption; maximum level of coke oven gas injection at tuyère level: 0.1 tonne / tonne holt metal

	and rates of 47 kg / tonne hot metal have been done
Plastic waste injection	Plastic waste injection reduces the demand for coke; as plastics also contain hydrogen, similar benefits as for natural gas injection hold; theoretical limit is 70 kg waste plastics / tonne hot metal (67 kg/tonne is practiced).
Charging of carbon composite agglomerates (CCB)	CCB can improve energy efficiency of a BF; it extends the variety of raw materials and promotes resource recycling (CCB = mixture fine iron ore and fine carbonaceous materials with some binding agent in most cases)
Slag heat recovery	0.25-0.30 tonne liquid slag (1450°C) / tonne hot metal is produced; different heat recovery systems are investigated; technical difficulties have so far prevented commercial success
Hot stove heat recuperation	Improved hot stove efficiency by recovering flue gas heat (250°C) and using this to pre-heat the combustion fuel or air; other heat sources can be used, for example sinter cooling off-air Alternatively, recovered heat from hot stoves can be used for pre-heating BF air, combustion air pre-heating for boilers, etc.
Increased hot blast temperature (> 1000°C)	Different techniques are available to increase hot blast temperature
Substitution of coal by biomass in PCI	Part of ULCOS and other projects; substitution of PCI by charcoal would allow 40% of the carbon input to the BF to be CO_2 neutral
Use of charcoal	Replacement of coke with charcoal leads to significant CO_2 emissions reduction
Stove flue gas recycling	Switch BF stove operations from air-fuel to oxy-fuel combustion with flame temperature moderation by flue gas recycling; this results in waste heat recovery and CO_2 concentration
Improved hot stoves process control	Automated operation helps to maintain optimal conditions, resulting in energy consumption reduction of the stoves, increasing reliability and extending lifetime Improved combustion in the stove may yield another 0.04 GJ energy saving / tonne hot metal.

Table 19: Blast furnace options

Basic Oxygen Furnace

The basic oxygen furnace options are listed in Table 20.

Option	Description
BOF heat and gas recovery	BOF gas holds 0.84 GJ energy / tonne steel with a heating value of 8.8 MJ/Nm³. Heat recovery processes are classified as combustion and non-combustion. Combustion: CO is combusted when leaving the furnace and the resulting hot gas is used in a heat recovery boiler. Non-combustion: sensible heat of CO rich BOF gas is recovered in a waste heat boiler prior to gas cleaning and storage and later used as fuel by mixing with other by-product gases (COG or BF gas). Allows 70% recovery of latent and sensible heat. CO can also be recovered and exported as feedstock to the chemicals sector, e.g. for isocyanate production. Some steel plants already doing this.
Improved ladle pre-heating	Ladle pre-heating requires about 0.02 GJ energy / tonne steel. The process can be improved by for example using an efficient burner, proper scheduling, monitoring temperatures, installing hoods to reduce radiating losses, and using recuperative and oxyfuel burners.
Alu-bronze alloy for BOF walls,	Use of alu-bronze alloys extends life of critical components. Use

hood and roof	has been demonstrated in a BOF, showing benefits: energy savings, reduced maintenance and lifecycle costs, no slag build-up problems, minimized shut-downs and subsequent reheating, increased lifetime.
Improved process monitoring and control	Increased process control of BOF leads to increased productivity and energy and cost savings. Examples: exhaust gas analysis systems (MultiGas Analyser), contour sensing system (laser contouring system), simultaneous determination of steel and slag composition (In-Situ Real-Time Measurement of Melt Constituents) and oxygen management system.
Recycling of BOF steelmaking slag	Integrated system of technologies for recovering Fe-value from BOF slag.
BOF bottom stirring (combined blowing)	Introduction of small amount of inert gas from the BOF bottom to provide mild stirring and promote equilibrium. This improves BOF yield and product quality, reduces O_2 and flux consumption, and increases vessel life.

Table 20: Basic oxygen furnace options

Electric Arc Furnace

The electric arc furnace options are listed in Table 21.

Option	Description
Bottom stirring or stirring gas injection	Injection of inert gas in EAF bottom to increase heat transfer. Also an increased liquid yield has been noted.
Charge or scrap pre-heating	Use of waste heat to pre-heat scrap, performed in charging baskets, in charging shaft (shaft furnace), or in dedicated scrap conveying system allowing continuous charging (shaft furnace or tunnel furnace). Shaft furnace: post combustion energy is used to pre-heat scrap. Partial / total scrap amount pre-heating, depending on system. Saving depends on scrap and degree of post-combustion. Significant reduction in tap-to-tap time. Reduction in electrode consumption, improved yield, increased productivity, and decreased flue gas dust emissions are noted. Note increased dioxin production and related energy requirements for extra treatment. Tunnel Furnace (CONSTEEL process): continuous pre-heating while transporting charge to EAF. 33% productivity increase and 40% electrode consumption reduction has been noted.
Foamy slag practices	Reduction of radiation heat loss by covering arc and melt surface with foamy slag (obtained by injecting granular coal and O_2 or by lancing O_2 only). Increase in productivity through reduction of tap-to-tap times.
Improved process control	Improved process control reduces electricity consumption, improves productivity, reduces cost, and increased equipment life time. Modern controls use a variety of sensors and integrate real-time monitoring of process variables. Neural networks and fuzzy logic systems have been developed.
Flue gas monitoring and control	Use of chemical energy (combustion of CO to CO_2) in the furnace is enhanced by monitoring the furnace exhaust gas (flow rate and composition) via optical sensors and adjusting post-combustion (for example adjustment of O_2 injection). Benefits: reduced consumption of electricity, natural gas, electrode material;

	increased productivity; reduced refractory wear.
Waste heat recovery for EAF	Technology to recover EAF waste heat as saturated steam or hot water. Particularly high potential for EAF using primarily DRI. Steam can be used directly or can be superheated to enhance power generation efficiency. Approx. 130 kWh energy / tonne steel can be recovered.
Airtight EAF process	Typical air ingress: 150 tonne EAF with heat duration 1 hour: 30,000 Nm^3 at ambient temperature. This results in significant thermal losses, which can largely be avoided by airtight operation.
Co-melt	DC EAF with typically four slanted side electrodes (provided by VAI). Advantages: high productivity (tap-to-tap times < 45 min), reduced total energy consumption, reduced electrode consumption, complete off gas collection, reduced off gas volume, reduced maintenance cost.
Contiarc furnace	Continuously fed furnace with charge pre-heating by rising process gas in counter-current flow. Considerable reduction of waste gas volume, thereby reducing energy consumption for flue gas cleaning. Note increased dioxin production and related energy requirements for extra treatment.
Twin-shell DC arc furnace	Two EAF vessels with common arc and power supply. Increased productivity by reduced tap-to-tap tome and reduced energy consumption through reduced heat losses.
Engineered refractories	Specially engineered refractories reduce ladle leakages and the formation of slag in transfer operations.
Eccentric bottom tapping	Slag-free tapping, leading to shorter tap-to-tap times, reduced refractory and electrode consumption, and improved ladle life.
Ultra high power (UHP) transformers	Transformer losses can be as high as 7% of electrical input (depending on size and age of transformer). Converting furnace operation to UHP increased productivity and reduces energy losses. Installing new transformers or paralleling existing transformers needed.
DC arc furnace	Single electrode with the bottom of the vessel serving as anode. Energy savings, higher melting efficiency, and extended hearth life have been noted. Power consumption: 1.8 - 2.2 GJ / tonne steel. Electrode consumption: 1 - 2 kg / tonne steel (half of conventional furnaces).
ECOARC	New generation shaft-type EAF for continuous charging. Substantially reduced electricity consumption and lower emissions.
Scrap densification or shredding	Density of scrap in the basket is improved (scrap shredding), therefore improving efficiency of each heat.
Switch to dry vacuum pumps	Replace steam ejectors or liquid ring pumps for dry vacuum pumps.
Oxy-fuel burners or lancing	Oxy-fuel burners allow partial substitution of electricity with O_2 and fuel. These burners reduce energy demand, increase furnace capacity, reduce electrode material consumption, can increase temperature homogeneity, and help removal of specific elements from the bath. Stationary wall-mounted burners and combined lance-burners are common.

Table 21: Electric arc furnace options

Casting

The casting options are listed in Table 22.

Option	Description
Continuous casting	Liquid steel flows from the ladle into the tundish and then a water-cooled mould. Solidification starts in the mould and continues through the caster.
Efficient ladle pre-heating	The caster ladle is typically pre-heated by gas burners with an estimated consumption of 0.02 GJ per tonne steel. Various techniques are available to increase efficiency, for example reduction heat losses, improved temperature controls, improved planning, and use of regenerative and oxy-fuel burners
Near net shape casting	Casting to form and dimensions close to finished product reduces processing and reheating needs. Thin Slab Casting (TSC) and Strip Casting (SC) are two main continuous process types of near net shape casting. TSC: cast directly to slabs of 30 - 60 mm thickness instead of 120 - 300 mm SC: - Castrip® process: direct casting of thin strip from liquid steel (0.8 - 2.0 mm) - SC: direct casting of strip around 3 mm thickness using two water-cooled casting rolls
Endless strip production	New development of thin slag casting and direct rolling. Significant savings compared to conventional rolling operations are possible, even more if cold rolling and annealing can be suppressed (for thin plates). In addition, a reduction of consumables and an improved yield is noted.
Direct rolling (integrated casting and rolling)	Casted slab is rolled directly in the hot strip mill, avoiding intermediate handling and energy costs.
Process re-engineering	Emission reductions from for example producing ingots that require less processing in the order of 25% have been claimed.
Heat recovery from cooling water	Low temperature cooling water can be used to produce low pressure steam by means of an absorption heat pump, or it can feed into a district heating network.
Efficient tundish heating	Installation of recuperative burners increases the efficiency of combustion-heated tundishes (typically 20%). Heating by electrical induction could provide 98% efficiency but power generation losses are higher.
Un-heated tundish	Use of cold tundish has been demonstrated with several benefits: reduction of natural gas consumption, increase in lifetime of tundish lids, improvement working conditions. No influence on product quality was observed. Efficient and controlled tundish drying is required.
Continuous temperature monitoring and control	Better control of tapping temperature avoids need for subsequent temperature adjustments. Novel fibre-optical temperature measuring technique has been demonstrated.
On-line laser ultrasonic measurement system	Inspection technique combining fibre optics and laser ultrasonics, allowing contactless inspection of high-temperature material during manufacturing. Real-time wall thickness and temperature profiles are produced. Signature profiles allow immediate identification of causes of defects and rapid remediation.
Accelerated cooling	
Sequencing of casts for specialty	

sequences	
Heat recovery from hot slabs other than direct rolling	
MGGate for continuous caster	Improved active flow control by means of an electromagnetic system has been demonstrated. The technology allows independent control over casting rate.

Table 22: Casting options

Secondary Processes

The secondary processes options are listed in Table 23.

Option	Description
Hot charging	Charging slabs at high temperatures in the reheating furnaces yields energy savings. In addition, it improves material quality, reduces material losses, and enhances productivity.
Regenerative burners or recuperative burners	Regenerative burners are equipped with heat reservoirs to recover the waste heat of the furnace gas to heat-up the combustion air. Recuperative burners use gas or gas heat exchangers in or on the stack of the furnace to recover the furnace waste heat by the preheating combustion air. Numerous designs exist.
Improved insulation	Upgrading conventional insulation to ceramic low-thermal-mass insulation significantly reduces heat losses through the furnace walls.
Flameless burners or dilute oxygen combustion	Combustion under diluted O_2 conditions using internal flue gas recirculation. Both air (flameless air-fuel burner) as commercial O_2 (oxyfuel burner) are used as oxidant. Flameless oxyfuel gives high efficiency, reduced fuel consumption, low NOx, and better thermal uniformity.
Walking beam furnace	A walking beam furnace with proper combustion control (compared to for example pusher type furnaces) is considered state-of-the-art in terms of reheating furnaces.
Heat recovery from cooling water	Rolled steel is cooled by water spraying, producing waste heat at approximately 80°C. Low pressure steam (1.7 - 3.5 bar, 130°C) can be produced by means of an absorption heat pump.
Improved planning and throughput optimisation	Reduces the need to 'keep warm' and thereby reduces heat loss, and ensures better utilisation of rolling mill capacity. Similarly, avoiding furnace overloading will lead to reduced energy consumption per unit.
Process control in hot strip mill	Improved hot strip mill process control leads to reduced rejects and indirectly to energy savings and improved productivity. Primary air is O_2 level control and hence combustion optimisation of the furnace.
Proper reheating temperature	If product characteristics allow, the reheating temperature can be reduced.
O_2 level control and VSDs on combustion fans	Proper O_2 control by means of VSD equipped combustion fans leads to energy savings, even with varying furnace loads.
Avoid furnace overloading	Overloaded furnaces lead to excessive fuel consumption. Note that maximizing hearth coverage improves efficiency.
Premium efficiency motors for rolling mill drives	Replacing normal efficiency AC drives with premium efficiency ones will save energy.

Installing lubrication systems	A proper lubrication system avoids specific transport related problems (vibrations, roll wear, banding, etc).
Cold rolling - annealing line loss reduction	Implementing heat recovery methods on the annealing furnace (for example regenerative or recuperative burners, improved insulation) and improved process management, VSDs, etc on the annealing line, will yield energy savings.
Cold rolling - automated monitoring and targeting system	Automated monitoring and targeting at a cold strip mill allows power demand and effluent reduction.
Cold rolling - reduced steam use in acid pickling line	Steam use can be reduced by a system of lids and floating balls on top of the pickling bath.
Cold rolling - continuous annealing furnace	A continuous annealing furnace is an integrated version of the conventional batch processes in one line, allowing significant energy savings and increased productivity.
Pulse firing in reheating furnaces	
Pressure control for furnace	Proper pressure control allows reduced gas or fuel and electricity consumption.

Table 24: Secondary processes options

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

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
Short Term												
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	25%	50%	50%	75%	75%	75%	75%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	25%	50%	50%	75%	75%	75%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	25%	50%	75%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	25%	50%	50%	75%	75%	75%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	25%	50%	50%	75%	75%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	85%	100%	0%	25%	25%	25%	25%	25%	25%	25%	25%
08 Reducing yield losses	total	40%	100%	0%	25%	25%	50%	50%	75%	75%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	25%	50%	50%	75%	75%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	25%	50%	50%	75%	75%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	25%	50%	50%	75%	75%	75%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	0%	0%	25%	25%	25%	50%	50%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	25%	50%	50%	75%	75%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	25%	50%	50%	75%	75%	75%	100%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	0%	25%	50%	50%	50%	75%	75%	100%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	25%	50%	50%	75%	50%	50%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	0%	25%	50%	50%	75%	75%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	25%	25%	50%	50%	50%	50%	50%
19 UHP Transformers	EAF	33%	75%	0%	25%	25%	50%	50%	75%	75%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	25%	25%	50%	50%	75%	75%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22 Improved Process Control - EAF	EAF	48%	100%	0%	0%	0%	0%	25%	60%	50%	75%	75%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 5: BAU pathway, challenging world scenario

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT								
				2014	2015	2020	2025	2030	2035	2040	2045	2050
Short Term												
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	25%	50%	50%	75%	75%	50%	50%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	25%	50%	75%	75%	100%	100%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	25%	50%	100%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	25%	50%	75%	75%	100%	100%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	25%	50%	100%	100%	100%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	85%	100%	0%	25%	25%	25%	25%	25%	25%	25%	25%
08 Reducing yield losses	total	40%	100%	0%	25%	25%	50%	50%	75%	100%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	25%	50%	50%	75%	100%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	25%	50%	50%	75%	100%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	25%	50%	50%	75%	100%	100%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	0%	0%	25%	50%	50%	75%	75%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	25%	50%	50%	100%	100%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	25%	50%	50%	100%	100%	75%	75%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	0%	25%	50%	50%	100%	100%	75%	75%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	25%	50%	50%	50%	25%	25%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	0%	25%	50%	75%	75%	100%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	25%	25%	50%	50%	75%	75%	100%
19 UHP Transformers	EAF	33%	75%	0%	25%	25%	50%	50%	75%	75%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	25%	25%	50%	50%	75%	100%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	0%	0%	25%	25%	25%	50%	50%
22 Improved Process Control - EAF	EAF	48%	100%	0%	0%	0%	0%	25%	25%	50%	75%	100%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	0%	0%	25%	25%	25%	25%	25%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	25%	25%	25%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	0%	0%	0%	25%	25%	25%	25%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	25%	25%	25%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	0%	0%	25%	25%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	25%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 6: Max Tech pathway, challenging world scenario

Collaborative Growth

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT								
				2014	2015	2020	2025	2030	2035	2040	2045	2050
Short Term												
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	50%	75%	75%	75%	50%	50%	50%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	50%	75%	75%	100%	100%	100%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	50%	75%	100%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	50%	75%	75%	100%	100%	100%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	85%	100%	0%	25%	25%	25%	25%	25%	25%	25%	25%
08 Reducing yield losses	total	40%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	50%	100%	100%	100%	100%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	0%	0%	25%	25%	50%	50%	75%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	50%	75%	100%	100%	75%	75%	50%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	0%	25%	50%	75%	100%	75%	75%	50%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	25%	50%	75%	50%	50%	25%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	0%	25%	50%	75%	100%	100%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	25%	50%	75%	75%	100%	100%	100%
19 UHP Transformers	EAF	33%	75%	0%	25%	75%	100%	100%	100%	100%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	50%	50%	75%	75%	100%	100%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	0%	0%	25%	25%	50%	50%	50%
22 Improved Process Control - EAF	EAF	48%	100%	0%	25%	50%	50%	75%	75%	100%	100%	100%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	0%	0%	25%	50%	50%	50%	25%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	25%	25%	25%	25%	25%	0%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	25%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	25%	25%	50%	50%	50%	50%	50%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	25%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	25%	25%	50%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	0%	25%	25%	50%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 7: BAU pathway, collaborative growth scenario

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT								
				2014	2015	2020	2025	2030	2035	2040	2045	2050
Short Term												
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	50%	50%	50%	25%	25%	25%	25%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	50%	75%	75%	100%	100%	100%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	50%	75%	100%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	50%	75%	75%	100%	100%	100%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	85%	100%	0%	25%	25%	25%	25%	25%	25%	25%	25%
08 Reducing yield losses	total	40%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	50%	100%	100%	100%	100%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	25%	25%	50%	50%	75%	75%	75%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	50%	75%	100%	75%	75%	75%	50%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	25%	50%	75%	100%	75%	75%	75%	50%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	50%	50%	50%	25%	25%	25%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	50%	75%	100%	100%	100%	100%	100%
19 UHP Transformers	EAF	33%	75%	0%	25%	75%	100%	100%	100%	100%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	25%	50%	50%	75%	75%	75%	75%
22 Improved Process Control - EAF	EAF	48%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	25%	25%	0%	0%	0%	0%	0%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	25%	0%	0%	0%	0%	0%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	0%	25%	25%	25%	25%	25%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	25%	25%	25%	25%	0%	0%	0%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	25%	25%	50%	50%	50%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	25%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	25%	50%	50%	50%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	25%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 8: 20-40% CO_2 reduction pathway, collaborative growth scenario

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT								
Short Term				2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	50%	50%	25%	25%	25%	25%	25%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	50%	75%	75%	100%	100%	100%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	50%	75%	100%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	50%	75%	75%	100%	100%	100%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	85%	100%	0%	25%	25%	25%	25%	25%	25%	25%	25%
08 Reducing yield losses	total	40%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	50%	100%	100%	100%	100%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	25%	25%	50%	50%	75%	75%	75%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	50%	75%	100%	100%	75%	50%	25%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	25%	50%	75%	100%	100%	75%	50%	25%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	50%	50%	50%	25%	25%	25%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	50%	75%	100%	100%	100%	100%	100%
19 UHP Transformers	EAF	33%	75%	0%	25%	75%	100%	100%	100%	100%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	25%	50%	75%	75%	75%	75%	75%
22 Improved Process Control - EAF	EAF	48%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	25%	25%	0%	0%	0%	0%	0%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	25%	0%	0%	0%	0%	0%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	0%	25%	25%	25%	25%	25%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	25%	25%	25%	25%	0%	0%	0%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	25%	50%	50%	50%	25%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	0%	25%	50%	75%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	25%	50%	75%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 9: 40-60% CO_2 reduction pathway, collaborative growth scenario

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT								
				2014	2015	2020	2025	2030	2035	2040	2045	2050
Short Term												
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	50%	50%	25%	25%	25%	25%	25%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	50%	75%	75%	100%	100%	100%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	50%	75%	100%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	50%	75%	75%	100%	100%	100%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	85%	100%	0%	25%	25%	25%	25%	25%	25%	25%	25%
08 Reducing yield losses	total	40%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	50%	100%	100%	100%	100%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	25%	25%	50%	50%	75%	75%	75%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	50%	75%	100%	75%	50%	25%	0%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	25%	50%	75%	100%	75%	50%	25%	0%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	50%	50%	50%	25%	25%	25%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	50%	100%	100%	100%	100%	100%	100%
19 UHP Transformers	EAF	33%	75%	0%	25%	75%	100%	100%	100%	100%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	25%	50%	75%	75%	75%	75%	75%
22 Improved Process Control - EAF	EAF	48%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	25%	25%	25%	25%	25%	0%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	0%	0%	25%	25%	0%	0%	0%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	25%	50%	50%	25%	0%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	25%	50%	75%	100%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	25%	50%	75%	100%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 10: Max Tech pathway, collaborative growth scenario

2. Sensitivity Analysis

Material Ffficiency

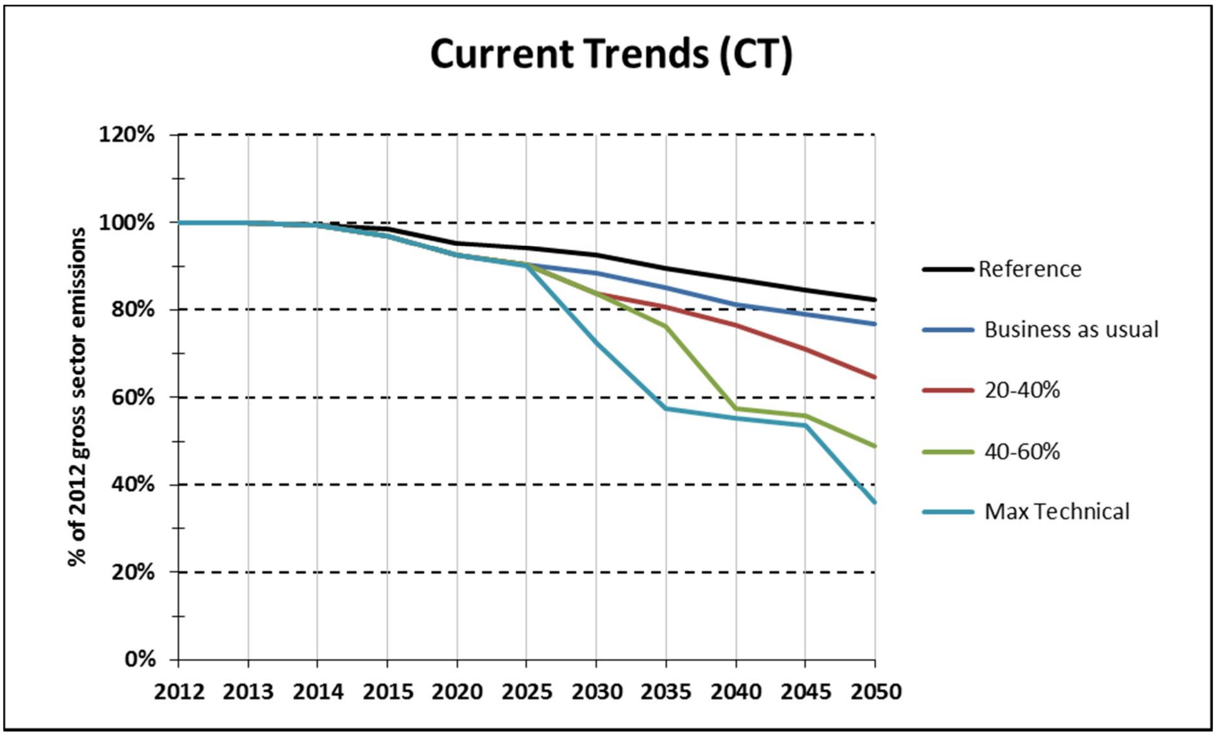

Figure 11: Sensitivity analysis material efficiency, current trends scenario

No Carbon Capture

Figure 12: Sensitivity analysis no CC, current trends scenario

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT								
				2014	2015	2020	2025	2030	2035	2040	2045	2050
Short Term												
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	50%	75%	75%	75%	50%	50%	50%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	50%	75%	100%	100%	100%	100%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	50%	75%	100%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	0%	85%	0%	25%	25%	25%	25%	25%	25%	25%	25%
08 Reducing yield losses	total	40%	100%	0%	25%	50%	75%	75%	100%	100%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	50%	100%	100%	100%	100%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	0%	0%	25%	25%	50%	50%	75%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	50%	75%	100%	75%	75%	75%	50%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	0%	25%	50%	100%	75%	75%	75%	50%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	25%	50%	75%	50%	50%	25%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	0%	25%	50%	75%	100%	100%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	25%	50%	75%	75%	100%	100%	100%
19 UHP Transformers	EAF	33%	75%	0%	25%	75%	100%	100%	100%	100%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	25%	50%	50%	75%	75%	100%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	0%	25%	25%	25%	50%	50%	50%
22 Improved Process Control - EAF	EAF	48%	100%	0%	0%	0%	25%	25%	50%	75%	100%	100%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	0%	0%	25%	25%	50%	50%	50%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	25%	25%	50%	50%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	25%	25%	25%	50%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 13: Deployment table for sensitivity analysis no CC, current trends scenario

Biomass without Carbon Capture

Figure 14: Sensitivity biomass without CC, current trends scenario

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT								
Short Term				2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	50%	75%	75%	75%	50%	50%	50%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	50%	75%	100%	100%	100%	100%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	50%	75%	100%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	0%	85%	0%	25%	25%	50%	75%	100%	100%	100%	100%
08 Reducing yield losses	total	40%	100%	0%	25%	50%	75%	75%	100%	100%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	50%	100%	100%	100%	100%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	0%	0%	25%	25%	50%	50%	75%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	50%	75%	100%	75%	75%	75%	50%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	0%	25%	50%	100%	75%	75%	75%	50%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	25%	50%	75%	50%	50%	25%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	0%	25%	50%	75%	100%	100%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	25%	50%	75%	75%	100%	100%	100%
19 UHP Transformers	EAF	33%	75%	0%	25%	75%	100%	100%	100%	100%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	25%	50%	50%	75%	75%	100%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	0%	25%	25%	25%	50%	50%	50%
22 Improved Process Control - EAF	EAF	48%	100%	0%	0%	0%	25%	25%	50%	75%	100%	100%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	0%	0%	25%	25%	50%	50%	50%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	25%	25%	50%	50%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	25%	25%	25%	50%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	25%	25%	25%	50%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 15: Deployment table for sensitivity analysis biomass without CC, current trends scenario

Biomass with Carbon Capture

The linked image cannot be displayed. The file may have been moved, renamed, or deleted. Verify that the link points to the correct file and location.

Figure 16: Sensitivity analysis biomass with CC, current trends scenario

OPTION	PROCESS	ADOPT.	APP.	DEPLOYMENT								
				2014	2015	2020	2025	2030	2035	2040	2045	2050
Short Term												
01 Heat Recovery & Re-use - Conventional Options	total	50%	88%	0%	25%	50%	75%	75%	75%	50%	50%	50%
02 Improved Automation & Process Control	total	20%	63%	0%	25%	50%	75%	100%	100%	100%	100%	100%
03 Hot Charging	Secondary	3%	80%	0%	25%	50%	75%	100%	100%	100%	100%	100%
04 Fuel Substitution - coking plant	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
05 Improved Planning & Throughput Optimisation - sec p	Secondary	12%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
06 Installing VSDs on Electrical Motors (Pumps & Fans)	total	50%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
07 Pulverised Coal Injection (PCI)	BF	0%	85%	0%	25%	25%	50%	75%	100%	100%	100%	100%
08 Reducing yield losses	total	40%	100%	0%	25%	50%	75%	75%	100%	100%	100%	100%
09 Scrap Densification / Shredding	EAF	35%	70%	0%	25%	50%	100%	100%	100%	100%	100%	100%
10 Compressed Air System Optimization	total	34%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
11 Re-heating Furnace Optimization	Secondary	19%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
Short-Medium Term												
12 Near Net Shape Casting	Secondary	10%	20%	0%	0%	0%	25%	25%	50%	50%	75%	75%
13 Use of premium efficiency electrical motors	total	13%	100%	0%	25%	50%	75%	100%	100%	100%	100%	100%
14 Waste Heat Recovery - sintering	Sintering	7%	100%	0%	25%	50%	75%	100%	75%	75%	75%	50%
15 BOF Heat & Gas Recovery	BOF	29%	100%	0%	0%	25%	50%	100%	75%	75%	75%	50%
16 Endless Strip Production (ESP)	Secondary	0%	20%	0%	25%	25%	50%	75%	50%	50%	25%	25%
17 Heat Recovery from Cooling Water	Secondary	0%	100%	0%	0%	25%	50%	75%	100%	100%	100%	100%
18 Steam / Power Production System Upgrades	total	32%	86%	0%	25%	25%	50%	75%	75%	100%	100%	100%
19 UHP Transformers	EAF	33%	75%	0%	25%	75%	100%	100%	100%	100%	100%	100%
20 Regenerative / recuperative burners - sec processes	Secondary	54%	100%	0%	25%	25%	50%	50%	75%	75%	100%	100%
Medium Term												
21 Heat Recovery & Re-use - Innovative Options	total	0%	88%	0%	0%	0%	25%	25%	25%	50%	50%	50%
22 Improved Process Control - EAF	EAF	48%	100%	0%	0%	0%	25%	25%	50%	75%	100%	100%
23 Retrofit Solution without CCS	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24 Stove Flue Gas Recycling (w/o CCS)	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25 Stove Flue Gas Recycling (w/ CCS)	Integrated	0%	100%	0%	0%	0%	0%	25%	25%	25%	25%	25%
26 Increased EAF production share	EAF	Sensitivity test		0%	0%	0%	0%	0%	0%	0%	0%	0%
Medium-Long Term												
27 Coke Dry Quenching (CDQ)	Coking	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
28 Retrofit Solution with CCS	Integrated	0%	100%	0%	0%	0%	0%	25%	25%	25%	25%	50%
29 Advanced Technologies without CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30 Improved site / sector integration	total	10%	50%	0%	0%	0%	0%	0%	25%	25%	25%	50%
31 Advanced Technologies with CCS & Rebuild	Integrated	0%	100%	0%	0%	0%	25%	25%	25%	50%
32 Advanced Electrolysis Techniques	Integrated	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 17: Deployment table for sensitivity analysis biomass with CC, current trends scenario

WSP and Parsons Brinckerhoff have combined and are now one of the world's leading engineering professional services consulting firms.

Together we provide services to transform the built environment and restore the natural environment, and our expertise ranges from environmental remediation to urban planning, from engineering iconic buildings to designing sustainable transport networks, and from developing the energy sources of the future to enabling new ways of extracting essential resources.

We have approximately 32,000 employees, including engineers, technicians, scientists, architects, planners, surveyors, program and construction management professionals, and various environmental experts.

We are based in more than 500 offices across 39 countries worldwide.

www.wspgroup.com; www.pbworld.com.

DNV GL

Driven by its purpose of safeguarding life, property and the environment, DNV GL enables organisations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil & gas, and energy industries. We also provide certification services to customers across a wide range of industries.

Combining leading technical and operational expertise, risk methodology and in-depth industry knowledge, we empower our customers' decisions and actions with trust and confidence. We continuously invest in research and collaborative innovation to provide customers and society with operational and technological foresight.

With our origins stretching back to 1864, our reach today is global. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping customers make the world safer, smarter and greener.

www.dnvgl.com

WSP | PARSONS BRINCKERHOFF

DNV·GL