Technological Innovation Systems for Decarbonisation of Steel Production

– Implications for European Decision Makers

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Sammandrag

Den europeiska stålindustrin står för en betydande del av EUs CO_2-utsläpp, men har samtidigt begränsade möjligheter att minska utsläppen från befintliga produktionsmetoder. Det krävs därför nya, banbrytande processinnovationer för att åstadkomma verkligt stora utsläppsminskningar. Denna rapport ger en översiktlig beskrivning av den europeiska stålindustrin teknologiska innovationssystem, belyst genom ett nytt ramverk kallat "The 4W-framework". The 4W-framework bygger på fyra grundstenar; *where* (var äger innovation rum?), *who* (vem påverkar innovationskraften?), *why* (varför äger innovation rum?) och *what* (vad gör industrin i fråga om innovation?). I rapporten diskuteras även den europeiska stålindustrins förmåga att uppnå nollutsläpp med nuvarande produktionsmetoder, liksom vilka förbättringar som krävs för att uppnå de europeiska utsläppsmålen till 2050.

Syften med studien har varit att sammanställa ett antal nyckelrekommendationer till beslutsfattare som har möjlighet att påverka stålindustrins utveckling av banbrytande processinnovationer och därmed bidra till framtida utsläppsminskningar. Tio semistrukturerade intressentintervjuer och en benchmark-intervju genomfördes och resultatet kompletterades med en litteraturstudie samt en analys av officiella industridokument. Fyra huvudaktörer med särskilt inflytande över industrins innovationsförmåga kunde identifieras; stålproducenter, industriorganisationer, politiska beslutsfattare och akademiska aktörer. Det är främst till dessa aktörer som rekommendationerna riktas.

Den europeiska stålindustrins inställning till innovation för minskade koldioxidutsläpp beskrivs som pessimistisk och nuvarande incitament för att sträva mot nollutsläpp beskrivs som enbart finansiella - och svaga. Effektiv prissättning av utsläppsrätter, i kombination med innovativa affärsmodeller för stärkt europeisk konkurrenskraft gentemot andra regioner, kan därför förväntas spela en avgörande roll för att på sikt uppnå nollutsläpp inom den europeiska stålindustrin. Resultaten visar på ett starkt behov av förbättrad kommunikation och samarbete mellan industriaktörer och deras intressenter. I dagsläget finns begränsade möjligheter att förbättra nuvarande produktionsmetoder genom befintlig teknik och ULCOS-konsortiet sägs vara ett nyckelinitiativ för framtida utveckling av nya, banbrytande processinnovationer.

Vidare kan flera innovativa affärsmöjligheter och affärsmodeller identifieras genom studien. Bland dessa finns nya marknader för biprodukter, genom Carbon Capture and Usage, ökad efterfrågan hos slutkonsument på 'hållbart stål' samt ökad produktion av stål från skrot genom sekundärproduktion. Dessa affärsmöjligheter förväntas kräva ökat engagemang från slutkonsumenten, liksom större gemensamma kraftansträngningar av samtliga industriaktörer.

Nyckelord

Innovation, Koldioxidfri Stålproduktion, Hållbar Industriell Produktion, Banbrytande Processteknologier, Nollutsläpp, Technological Innovation System, Technology Readiness Level, Carbon Capture and Storage, Carbon Capture and Usage, The 4W-Framework, Cirkulär Ekonomi, Industriell Symbios.

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Abstract

The EU steel industry is a major contributor to human-induced CO_2 emissions and has limited possibilities to improve incumbent production methods further. The industry is therefore strongly dependent on new breakthrough decarbonisation technologies in order to further mitigate emissions. This report provides an overview of the EU steel industry's technological innovation system, through a new mapping method named the 4W-framework. The 4W-framework is built upon four main pillars; *where* innovation takes place, *who* the influencers of innovation are, *why* the industry innovates and *what* the industry does, in terms of innovation. The report also discusses the EU steel industry's ability to decarbonise through incumbent technologies, and which improvements are required in order to meet the current emission mitigation goals for year 2050.

The objective of the study has been to conclude some key implications for decision makers, who are in a position to affect the EU steel industry's innovation through breakthrough decarbonisation technologies. Ten semi-structured stakeholder interviews and one benchmark interview have been conducted, and the outcomes are complemented by a literature review and an analysis of official industry documents. Four key influencers of innovation are identified, and the key implications are mainly directed to these actors; steel producers, industry organisations, policy makers and academia.

The industry's attitude towards decarbonisation is described as pessimistic and current incentives are purely financial, and weak. Successful carbon pricing, in combination with innovative business models for elevated EU competitiveness, could therefore be expected to play an essential role in decarbonisation of the industry. The key findings of this study show a strong need for improved communication and collaboration between industry actors and their stakeholders. There are currently limited possibilities to improve incumbent production methods, and the ULCOS consortium is said to be a key initiative for development of breakthrough decarbonisation technologies.

Several new business opportunities are identified through this study. Among them are new markets for by-products through Carbon Capture and Usage, increased end-user demand for 'sustainable steel', and increased production of steel from scrap through secondary steel production. These business opportunities can be expected to require increased end-user involvement as well as improved collaborative efforts.

Keywords

Innovation, Industrial Decarbonisation, Breakthrough Process Technologies, Technological Innovation System, Low-Carbon Steelmaking, Emission Mitigation, Technology Readiness Level, Carbon Capture and Storage, Carbon Capture and Usage, The 4W-Framework, Circular Economy, Industrial Symbiosis.

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Preface

Climate change is a severe and imminent threat to the environment and to humanity. As of today, many Europeans are aware of the substantial amount of greenhouse gas emissions generated by human activities: such as consumption, transportation or livestock production. Some consumers engage in emission-mitigating initiatives and show a willingness to change their buying pattern of consumer goods, in order to reduce their carbon footprint.

Yet, much less public concern is shown regarding emissions from the carbon-intensive industries, even though around 30% of global emissions can be allocated from industrial production and energy consumption[1]. Development of industrial processes is one of the key challenges ahead on the path towards a sustainable society. The EU steel industry has, to date, limited possibilities to improve incumbent production methods and is strongly dependent on new breakthrough decarbonisation technologies in order to further mitigate emissions. This is where the energy intensive industries need innovativeness, encouragement and public support, in order to achieve zero emissions within a foreseeable future.

In this study, I want to illustrate that innovation is not about complex theoretical methods that exist solely among specialists in a narrow field of expertise. Instead, innovation is all about people. Or, as one of the respondents put it:

> 'Innovation is nothing abstract, but in fact the result of people's wishes and ideas.'

In the conclusion of this study, the reader will find some key recommendations to decision makers who are in the position to influence the decarbonisation efforts of the EU steel industry. However, few societal reforms have occurred without the public engaging in the issues. Environmentally conscious citizens need to start engaging in decarbonisation of the sectors where it matters the most. Without the end user committing to form real incentives for carbon-intensive industries to mitigate emissions, for example by influencing decision makers or showing a willingness to pay for 'sustainable' commodities, little change can be anticipated.

As this study marks the end of my studies in the Master's programme in Industrial Engineering and Management, I am now leaving it in the hands of decision makers to carefully assess these recommendations, and to make sure that the suggested way forward is pursued in the EU steel industry. It is my sincere hope that I will be able to look back at this study in some years from now, to find that the final conclusions have become completely out-dated in a sustainable society where increased decarbonisation efforts are no longer needed.

Matilda Axelson

Brussels, March 2016

[1] IPCC (2014), pp. 749.

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During the research process, I have had the opportunity to surround myself with inspiring and highly experienced people, who have encouraged me throughout my research. Since I sincerely believe that shared confusion is a reliable source of innovative ideas, I have engaged in animated discussions with whoever has been willing to listen. I, thus, have several people to thank for answering my numerous questions during the past five months, and improving the outcome of my research:

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Tata Steel and ArcelorMittal, for giving me the enlightening possibility to test my theoretical research against day-to-day practice, by inviting me to visit the steel production plants of today and of tomorrow.

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Last but not least, all respondents, for contributing to the depth and credence of this study, and for their willingness to invest their time in making this study possible.

Table of Content

Terminology

Abbreviation		Explanation
Decarbonisation		Minimising greenhouse gas emissions (specifically CO_2 emissions) released into the atmosphere.
EU-28	European Union-28	The current 28 member states of the European Union.
EC	European Commission	Executive body of the European Union.
DG	Directorates-General	Departments under the European Commission.
Emission allowance		Tradable allowance to emit greenhouse gases (equivalent to one tonne of carbon dioxide) during a specific period of time.
EU ETS	The EU Emissions Trading System	The market on which EU emission allowances can be traded.
CEPI	Confederation of European Paper Industries	The EU Pulp- and Paper Industry Organisation.
EUROFER	The European Steel Association	The EU Iron- and Steel Industry Organisation.
Jernkontoret	The Swedish Steel Producers' Association	The Swedish Iron- and Steel Industry Organisation.
Estep	European Steel Technology Platform	Platform for the major stakeholders in the European steel industry.
Roadmap		Document describing an organisation's strategy for achieving a goal.
Vision		Document describing an organisation's aspiration of accomplishment.
TTP	The Two Team Project	CEPI's decarbonisation initiative.
Primary steel production		Production of steel from primary raw materials (coal and iron ore).
Secondary steel production		Production of steel from scrap.
BF-BOF	Blast Furnace-Basic Oxygen Furnace	A furnace for steelmaking.
EAF	Electrical Arc Furnace	A furnace for steelmaking.
DRI	Direct-Reduced Iron	A steelmaking technology.
TRL	Technology Readiness Level	Method of estimating technology maturity.
ULCOS	Ultra-Low Carbon dioxide Steelmaking	A consortium of EU companies and organisations on R&D of CO_2 emission reductions in steelmaking.
CCS	Carbon Capture and Storage	Capture and storage of CO_2 off-gases from industrial processes.
CCU	Carbon Capture and Usage	Capture and usage of CO_2 off-gases from industrial processes.

1. Introduction

In this chapter, the challenge of decarbonisation is put into context and used to formulate the scope of the study. The chapter also includes a disposition of the report.

1.1. Context

The context of this study is presented in the following sections.

1.1.1. Climate change and EU emission goals

CO_2 is the greenhouse gas to the largest extent emitted into the atmosphere due to human activities and one of the main contributors to climate change. Large quantities of CO_2 are released into the atmosphere as a result of industrial processes, and a significant increase has occurred since the industrial revolution.[2] Today, CO_2 emissions are one of the main threats to the environment, and one of the key challenges to tackle in order to mitigate human-induced global warming. Steel production is currently responsible for 6.7% of worldwide CO_2-emission.[3] In comparison, production of 1.0 tonne crude steel generates approximately 1.8 tonne CO_2 emissions.[4]

The EU-28 is the world's third largest contributor to CO_2 emissions (3.4 gigatonne year 2014), after China (10.5 gigatonne year 2014) and USA (5.3 gigatonne year 2014).[5] In 2010, the European Commission launched the *Low-carbon Roadmap* for moving the EU towards a competitive low-carbon economy until 2050. The roadmap suggests that the EU should cut domestic CO_2 emissions by 80%-95% until 2050, below the levels of 1990.[6] All industrial sectors would need to contribute in order to achieve this goal, and especially energy intensive industries such as the EU iron- and steel industry.

1.1.2. Decarbonisation of the EU steel industry

As of yet, only limited research has been conducted on innovation within the energy-intensive industries.[7] Several extensive reports on decarbonisation are available, fewer on the contribution from innovation to the matter. Meanwhile, the iron- and steel industry[8] is a large volume contributor to the carbon dioxide emissions, and major challenges lies ahead in order to reach the goal of reducing EU CO_2-emission levels by 80-95% until 2050 (compared to the levels of 1990).[9] To the steel industry, decarbonisation will be a key issue to handle during the upcoming decades. The EU steel industry has already demonstrated high capabilities in *product innovations*, such as speciality steels and applications. Decarbonisation, however, requires not only product innovation and specialisations but also fundamental *process innovations*. Examples of breakthrough decarbonisation technologies are technical mitigation options, such as Carbon Capture Storage (CCS), biofuels and or fuels derived from electricity (such as hydrogen or other power-to-gas fuels).

[2] EDGAR (2016).
[3] World Steel Association (2015a), pp. 20.
[4] World Steel Association (2014).
[5] EDGAR (2016).
[6] CLIMATE ACTION (2016).
[7] Åhman, M. et al. (2013), pp. 1.
[8] The iron and steel industry will hereafter be referred to as 'the steel industry'.
[9] Åhman, M. & Nilsson, L. J., (2015), pp. 92.

1.2. Scope and objectives of study

The objectives, research questions and delimitations of this study are presented in the following sections.

1.2.1. Overall objective of study

The overall objective of this study is to describe the current innovation system of the EU steel industry, and explore how it may need to develop for the purpose of improving innovation for breakthrough low-carbon process technologies. This study is aiming to outline the key innovation system implications for decarbonisation of the industry, and to identify some key success factors for development of innovation initiatives fostering decarbonisation. The implications will conclude potential instant actions or reforms, in order to improve innovation efforts and to perform change in the longer perspective (until year 2050).

The main recipients of the analysis are decision makers within the EU steel industry, who are in a position to affect the innovation strategy of their firm or organisation. The study will also be relevant to other stakeholders, whose decisions have a direct or indirect effect on the innovation capability of EU steel industry.

1.2.1.1. Secondary objective

The study's secondary objective is to scientifically contribute in the field of innovation systems and low-carbon transition studies, fields where decarbonisation in the steel sector is so far relatively unexplored. Furthermore, the public awareness of the issue is low, and this study is aiming to shed light on a topic that is usually falling outside the spotlight.

1.2.1.2. Meeting the objective

In order to meet the objectives, the industry's current interests and incentives to decarbonise have been identified and analysed, as well as the drivers and obstacles to innovation, and how these could be influenced in order to improve CO_2 emissions mitigation.

For these purposes, this study builds on four main components:

- Map the current innovative system and the innovative environment within the EU steel industry from three perspectives; macro environment, micro environment and an internal perspective.
- Map the current relations between the industry and its stakeholders, mainly regarding supporting activities on innovative decarbonisation initiatives.
- Analyse the industry actors' incentives to (and interests in) transition to decarbonisation with the aim of identifying a possible value gap, as well as concluding what actions need to be improved or developed in the innovation system.
- Conclude a list of implications for executive decision makers on how to further support and foster innovation through breakthrough decarbonisation technologies in the industry.

1.2.2. Research questions

The research is guided by the following four research questions:

Research Question 1 **– WHERE does innovation take place?**

1. **In what environment are the key actors operating?**
    a. What does the external environment look like?
    b. Could the innovation system be improved in order to facilitate development of breakthrough decarbonisation technologies?

Research Question 2 **– WHO are the main influencers of innovation?**

2. **Who are the key actors/factors influencing the development of breakthrough decarbonisation technologies?**
    a. Which actors/factors are drivers, driving innovation?
    b. Which actors/factors are obstacles, hampering innovation?

Research Question 3 **– WHY does the industry innovate?**

3. **What are the key actors' interests in and incentives to innovate in order to decarbonise?**
    a. How could these interests and incentives be influenced?

Research Question 4 **– WHAT does the industry do, in terms of innovation?**

4. **What actions for decarbonisation are currently in place?**
    a. What actions could be taken *today* for pursuing decarbonisation by means of breakthrough technology development?
    b. What actions for decarbonisation are likely to be needed in the future, in order to reach the mitigation goals?

In this report, one chapter has been dedicated to each research question, in order to enable a close elaboration of the different issues as well as the potential solutions and opportunities they imply. Research questions 1, 2, 3 and 4 are respectively analysed in chapters 4, 5, 6 and 7. The four questions are increasingly specific, where research question 1 has the broadest perspective, and research question 4 takes on a more detailed-focused approach. Hence, the actual steelmaking processes are not discussed in detail until chapter 7, which is further illustrated in Figure 2.

1.2.3. Delimitations and challenges of study

The study has an industrial focus and is aiming to develop business and innovation within the steel sector in the EU. Hence, policies are mainly considered to be relevant with regards to industry implications. It is possible that the collected data contains suggestions from the industry on implications for policy makers, but a deeper analysis of potential development of EU policy framework lies outside the scoop of this study.

The analysis mainly targets major steel producers with blast furnace steel production inside the EU. Recommendations are developed to primarily address decision makers in steel producing companies as well as steel industry organisations, and secondarily address other stakeholders should the results prove their position to be of significant relevance to the industry. Some of the recommendations will be directed to 'industry organisations' in general, involving both European industry organisations and national industry organisations.

Assuring objectivity among the respondents on a strongly political issue is a major challenge to interview-based research. Due to the high political sensitivity of steel-related issues at the time of the study, it is possible that some respondents might take the opportunity to pursue their own agenda and not answer sincerely to the questions. Also, the difficulty of setting geographical boundaries of an innovation system has proven to be a common obstacle to studies with similar research questions.[10] It is therefore expected to be difficult to analyse a whole industry as one unity, as well as to conduct a study of this magnitude within the limited time available. Analyses of innovation systems are often highly dependent on time, and the result might differ heavily between different occasions.[11] This issue is further discussed in section 2.1.3.

1.3. Outline of the report

Chapter 1 gives an introduction to the problem and lists purpose, research questions and delimitations of the study.

Chapter 2 describes the methodology and design of the study.

Chapter 3 describes the theoretical framework regarding analysis on innovation systems used in the study.

Chapter 4 contains empirical results, including respondents' answers, regarding the first research question – **WHERE does innovation take place?**

Chapter 5 contains empirical results, including respondents' answers, regarding the second research question – **WHO are the main influencers of innovation?**

Chapter 6 contains empirical results, including respondents' answers, regarding the third research question – **WHY does the industry innovate?** The chapter includes a benchmark with the attitudes of other industry organisations' towards innovation for decarbonisation.

Chapter 7 contains empirical results, including respondents' answers, regarding the fourth research question – **WHAT does the industry do, in terms of innovation?** The chapter includes a benchmark with a project on innovation for decarbonisation of another industry organisation.

Chapter 8 analyses the results presented in chapters 4-7, and formulates key recommendations to decision making stakeholders in the EU steel industry.

Chapter 9 concludes the study and summarizes the key findings.

[10] Carlsson, B. et al. (2002).
[11] Ibid.

2. Methodology

In this chapter, some classic methodology tools are presented, in order to assure the credibility of the (mainly) qualitative study. Against this background, the design of the study is developed and presented.

2.1. Credibility of study

Patton (1999) describes the credibility of a qualitative study as dependent on three key factors; validity, reliability and triangulation. Patton also describes holistic thinking as a key success factor for ensuring credibility in a report based on qualitative data, where the personal background of the researcher can have a direct effect on the data analysis.[12] In order to assure credibility of the study, the study's validity, reliability, triangulation and transferability is described in the following sections.

2.1.1. Validity and Reliability

In order to establish validity to a study, the research has to measure the right parameters. In complex research challenges, it can be difficult to collect data on a certain phenomena, and the focus of the study has to be adjusted in order to assure that the right research question is systematically approached from a sufficient perspective. Obtaining a wide perspective of the investigated problem is recommended in order to assure validity.[13]

The reliability of a study can be assured through accuracy during data collection, as well as during the analytic phase of the research process. In studies where primary data are collected through interviews, reliability can be assured by letting the respondents give feedback on a drafted summary of their contribution to the results, before the study is finalized.[14]

➡ **In order to assure validity and reliability of the study, a holistic approach to the innovation system is adopted, and respondents were given the opportunity to review their answers after the interviews.**

2.1.2. Triangulation

Triangulation is a method for ensuring comprehensiveness of a qualitative study. It involves using multiple data sources and different methods simultaneously, in order to create greater understanding of a complex problem. Whether triangulation improves the actual validity of a study is controversial, since there is no guarantee that multiple sources eliminate the risk of false conclusions.[15] Four different kinds of triangulation can be identified, according to Cohen and Crabtree (2006); *Methods triangulation, Triangulation of sources, Analyst Triangulation* and *Theory/Perspective triangulation*.[16] These can be summarized and explained as follows:

- **Methods triangulation** – Utilising different methods for data collection, for example by collecting both qualitative and quantitative data in a study.

[12] Patton (1999), pp. 1190.
[13] Höst et al. (2006), pp. 41-42.
[14] Ibid.
[15] Cohen & Crabtree (2006).
[16] Ibid.

- **Triangulation of sources** – Using the same method to collect data, but from different sources. An example is when data is collected in different settings (for example public versus private settings) or by comparing people with different points of view.
- **Analyst Triangulation** – Letting several different analysts or researchers conduct the same study.
- **Theory/perspective triangulation** – Utilising different theoretical perspectives during the data analysis. [17]

➡ **This study is limited to using *Methods triangulation* and *Triangulation of sources*, in order to assure credibility and comprehensiveness of the study.**

2.1.3. Transferability

Transferability refers to the actual applicability of a study. Research findings and context of the analyses should be repeatable, and possible to apply on other contexts or scenarios.[18]

In order to assure transferability of this study, the research process has been thoroughly described in section 2.2. The market situation depicted in this study occurred during September through November year 2015. Due to the often rapidly changing market conditions of an industry, a replication of this study is likely to reach conclusions somewhat different than those suggested by this study. However, the same research design can be applied on other time periods, or on other industries.

➡ **This study contains a documented research design, in order to assure transferability of the study.**

2.2. Design of study

The study is aiming to identify development capabilities in the field of breakthrough technology innovation for decarbonisation of the EU steel industry. A flowchart of the study design is presented in Figure 1.

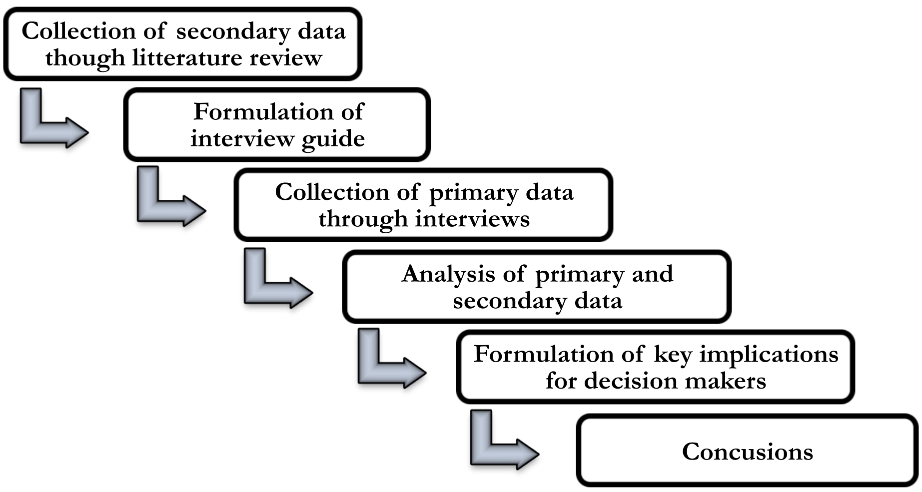

Figure 1. Design of study.

[17] Cohen & Crabtree (2006) stress that the goal of Analyst Triangulation not should be to seek consensus among the analysts, but to instead present different perspectives of analysing the data.
[18] Krefting (1990), pp. 3.

In order to map the current innovation system of the EU steel industry, the framework for analysis illustrated in Figure 2 was used. Based on this framework, an interview guide was developed and used during the interviews. The interview guide used for primary data collection can be found in Appendix A. For a detailed description of the underlying research framework, see section 3.3 in chapter 3.

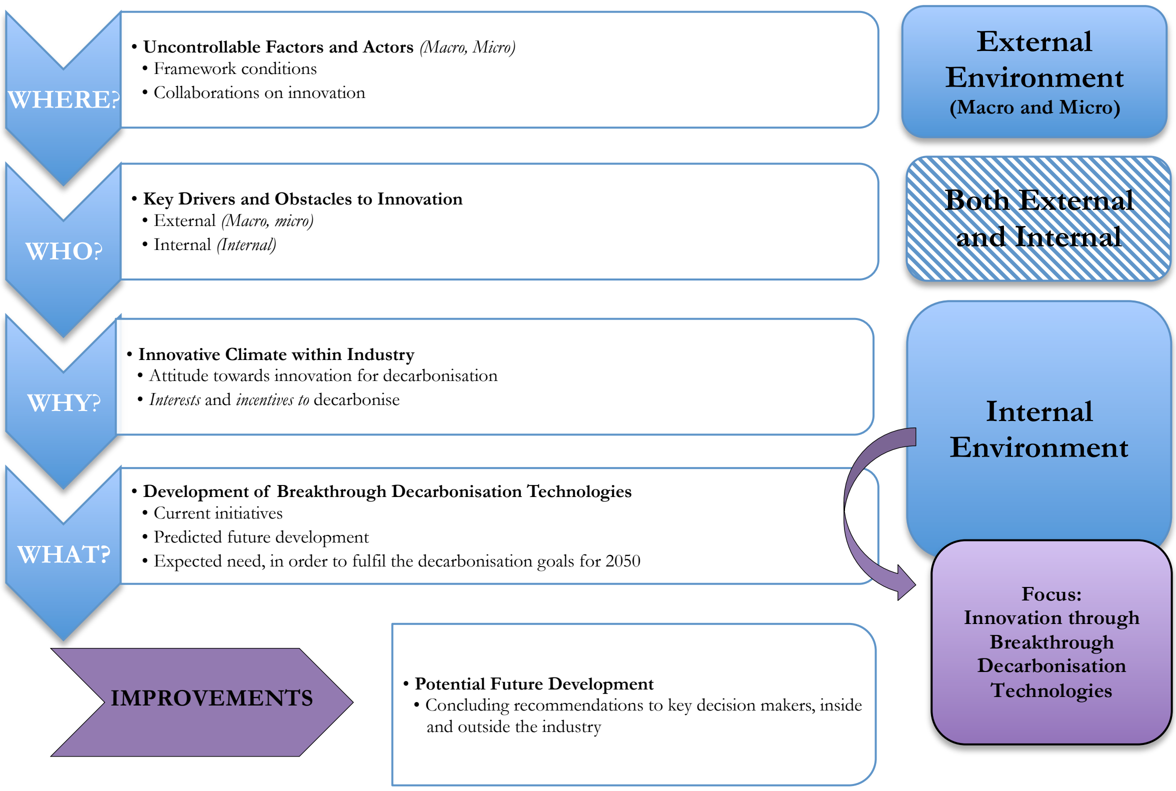

Figure 2. Framework for mapping of the EU steel industry's current innovation system, and recommendations on future development capabilities.

2.2.1. Approach of study

Studies can have a qualitative or a quantitative approach. In research with quantitative approach, numerical data is used to describe a situation, whereas qualitative research is build on linguistic descriptions mainly without statistic elements. The approach of the study is reflected in in the choice of data collection method.[19]

Interviews can be conducted with an unstructured, semi-structured or a structured approach, which is strongly connected to the approach of the study. During structured interviews, the respondents are giving pre-determined questions and the respondent is asked to choose between different alternatives. In an unstructured interview, open questions are asked and the respondent

[19] Höst et al. (2006), pp. 90.

is free to develop subjects without strong interference of the interviewer. A semi-structured interview contains both kinds of questions, giving the respondent partly open questions and partly structured questions on a certain topic.[20]

In this study, a semi-structured interview approach has been used, with open questions on wide topics and structured questions in part of the study. A quantitative element of the study has been included, in order to determine the role and importance of certain stakeholders to the industry. An overview of the framework for structured questions is provided in Figure A.1 in Appendix A.

➡ **This study is using a *Semi-structured approach*, comparing both *qualitative* and *quantitative* data.**

2.2.2. Data collection

In order to assure methods triangulation, both qualitative and quantitative data were collected. The aim of the data collection was to conduct an analysis on possible improvements of innovation through breakthrough technologies within the industry, for identification of which elements reduce/increase or eliminate/create in the innovation strategy. The data collection was mainly conducted through in-depth interviews with internal stakeholders (innovation managers etc.) and external stakeholders (experts, policy makers etc.) to the industry. An element of quantitative surveying was also included in the interview guide, as a supplement to the more extensive qualitative analysis. The study also contained an element of benchmarking, through comparison and identification of best practices in other industries, conducted through the same data collection methods as the rest of the study.

Primary data were collected through eleven in-depth interviews that took place during October and November 2015, through face-to-face meetings or over the phone. The interviews lasted 40-120 minutes, depending on the availability of the respondent, and the interview guide used in this study can be found in Appendix A. The respondents were selected according to their expertise on the EU steel industry, and were diversified after their current position in order to assure triangulation of sources. Due to the small size of the sample, no scientific trends among the respondents' current employment roles could be expected. The respondents are listed in Table 1 and out of the eleven respondents, some decided to remain anonymous. After the final text compilation all respondents were offered a chance to edit their answers, and the final text has been approved by all respondents except for two (Respondent E and Respondent G), who did not act on the offer.

As secondary data, literature reviews of scientific articles were conducted, as well as a brief analysis of public industrial documents. The data contained a combination of written documents and reports communicated by experts and by the industry. All documents are listed in chapter References. Four key documents of particular importance are listed below:

- The European Commission's Low-carbon roadmap for 2050, hereafter called '**the EC roadmap**'. Full name: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS – A Roadmap for moving to a competitive low carbon economy in 2050. [21]

[20] Ibid.
[21] European Commission (2011).

- EUROFER's roadmap for 2050, hereafter called '**EUROFER's roadmap**'.
  Full name: A STEEL ROADMAP FOR A LOW CARBON EUROPE 2050.[22]

- CEPI's roadmap for 2050, hereafter called '**CEPI's roadmap**'.
  Full name: The Forest Fibre Industry – 2050 Roadmap to a low-carbon bio-economy.[23]

- Jernkontoret's vision for 2050, hereafter called '**Jernkontoret's vision**'.

Full name: STÅL FORMAR EN BÄTTRE FRAMTID – En rapport om stålets roll för en hållbar samhällsutveckling.[24] *(Steel shaping a better future – a report on the role of steel for sustainable development.[25])*

Table 1. Respondents' current organisational base and position, including interview time and location.

Type of organisation	Current organisation	Current position	Respondent	Interview time and location
Steel producing company	ArcelorMittal	Manager	Karl Buttiens	40 minutes Brussels
Steel producing company		Manager	Respondent B	120 minutes Company's offices
European Commission		Policy maker	Respondent D	60 minutes Brussels
European Commission		Policy maker	Respondent A	50 minutes Brussels
Research group		Director	Respondent E	40 minutes Phone interview
Non-governmental organisation	Syndex	Expert	Philippe Morvannou	40 minutes Brussels
Non-governmental organisation		Expert	Respondent G	40 minutes Phone interview
National Industry organisation, Steel sector	Steel Institute VDEh at Stahl-Zentrum	Director	Dr.-Ing. Hans.Bodo Lüngen	40 minutes Phone interview
National Industry organisation, Steel sector ***(Benchmark)***	Jernkontoret	Director	Gert Nilson	90 minutes Stockholm
European Industry organisation, Steel sector	ESTEP	Secretary General	Klaus Peters	40 minutes Brussels
European Industry organisation, Pulp and paper industry ***(Benchmark)***	CEPI	Director	Bernard de Galembert	120 minutes Brussels

22 EUROFER (2013).
23 CEPI (2012).
24 Jernkontoret (2013).
25 Translated from Swedish.

3. Theoretical background and framework

In this chapter, some theoretical innovation concepts are presented, including classification of innovation, methods for measuring innovation and the structure of a technological innovation system. The theory is developed into a framework for mapping of the EU steel industry's current technological innovation system, which has been used in the effectuation of this study.

3.1. Classification of innovation in literature

There are many different definitions of innovation in literature. The models of relevance to this study are defined in the following sections.

3.1.1. Differences between invention and innovation

An invention is the finding of something, such as a concept or an idea, which was not previously known.[26] Innovation on the other hand, could be described as inventiveness put to use.[27] Innovation often occurs as a combination of newness (for example an invention or a discovery) and change, and refers to the actual implementation of a value proposition – 'getting new things done'. Hence, an innovation is more than just an invention – it is something that generates a change and that has an impact on the market structure or on the social context of an organisation.[28] If the first phone were an example of an invention in the telecommunication industry, an example of an innovation would be the development of text messaging services, which changed the way we use our mobile phones.[29] Oxford Advanced Learners Dictionary defines innovation as 'the introduction of new things, ideas or ways of doing something'.[30]

➡ **This study is limited to using the definition of innovation as 'value creation through inventiveness'.**

3.1.2. Technological innovation: products and processes

Innovations can be divided into technological and non-technological innovations. Technological innovations can be divided into product innovations and process innovations, whereas non-technological innovations refer to marketing innovations or organisational innovations.[31] *Product* innovations are innovations in *what* should be produced, or sold, or done. An example is the innovation of light bulbs or stainless steel.[32] *Process* innovations are innovations in *how* things should be produced, or sold, or done. An example is the innovation of the float glass process by Pilkington.[33] In terms of steelmaking, most breakthrough technologies are connected to innovations in the steel production process, and are hence mainly process innovations have been investigated in this study.

➡ **This study is limited to investigating technological innovations, mainly focusing on process innovation but partly also on product innovation.**

The definitions illustrated in Figure 3 are used throughout this report. The blue path in Figure 3 indicates the areas primarily relevant to development of breakthrough technologies.

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26 Thota, H., Munir, Z. (2011), pp. 157.
27 Ibid.
28 Gailly (2011), pp. 3-11.
29 Ibid.
30 Oxford Advanced Learners Dictionary (2015), keyword 'Innovation'.
31 Oslo Manual (2005), pp. 15-17.
32 Jernkontoret (2015).
33 Chaston, I. (2013). pp. 95.

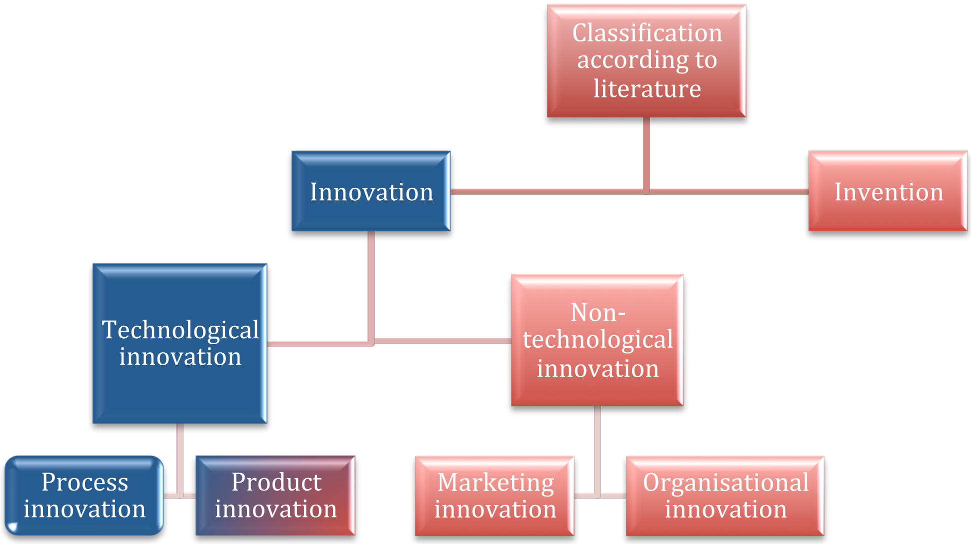

Figure 3. Classification of innovation according to literature. Blue colour indicates the primary focus of this study.

3.1.2.1. Technology Readiness Level

Technology readiness level (TRL) is a way of measuring the maturity of a technology, and it's readiness for commercialisation (alternatively operational use). TRL is commonly used by the space industry to illustrate the innovation process, and primarily applicable to space system hardware through the ISO standard ISO 16290:2013.[34] An innovation's TRL can be measured on a scale from 1-9, where TRL 1 is the basic idea and TRL 9 is commercialisation.[35] *Knowledge development* occurs at TRL 1-4 and is often driven by academic research. This phase includes basic technology research as well as research to prove feasibility. At the end of this phase, the first valley of death occurs. *Technological development* takes place at TRL 4-7, and includes technology development and technology demonstration (including scale-up of operations). The technological phase is dependent on collaborative R&D-projects. The second valley of death occurs before the last phase. Finally, the last phase is the *Business development* phase and covers TRL 7-9. These levels include system development for market launch as well as commercialisation, and here industrial actors are the key actors.[36]

An illustration of the different TRL-levels, as described by NASA, is provided in Figure 4.[37] Figure 5 shows how the technological readiness is hampered during two phases; the first and the second 'valley of death'. The first valley of death occurs around TRL 4, due to failure to invest in technological development. Projects that manage to advance past this phase are likely to reach a second phase of difficulties around TLR 7, due to failure to adapt to commercialisation.[38] Understanding an industry's TRL and identifying the valleys of death can help facilitate the innovation process.

[34] ISO (2013).
[35] UK Parliament (2012).
[36] The Centre for Process Innovation (2013).
[37] Zapata, E. (2010).
[38] UK Parliament (2012).

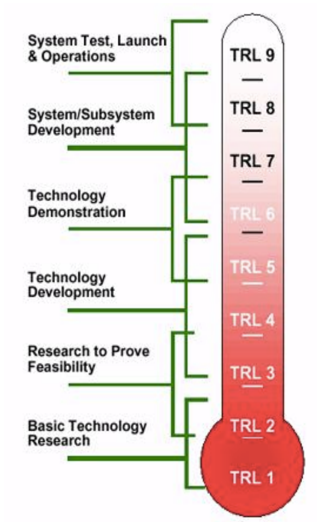

Figure 4. The NASA Technology Readiness Level scale illustrates development of technology readiness levels from basic idea (TRL 1) to commercialisation (TRL 9). *Illustration from Zapata, E.*

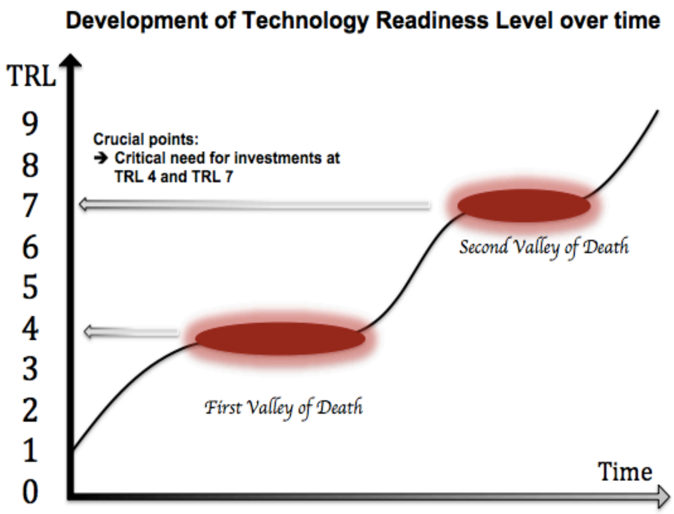

Figure 5. Development of Technology Readiness Level over time, including first and second valley of death as well as crucial points at TRL 4 and TRL 7. *Own illustration, based on data from UK Parliament.* [39]

3.1.3. Radical and incremental innovation

Innovations can be either radical or incremental. Incremental innovations are aiming to improve an existing product or process, whereas radical innovations refer to major structural changes where something completely new is adopted.[40] An example of radical innovation in the steel industry is the development of the HIsarna (se section 7.3.3), and examples of incremental innovation could be current machines being updated with the latest technology. Development of breakthrough technologies requires radical innovation and this study is therefore mainly investigating this area.

3.2. How to measure innovation?

Innovation is a continuous process and therefore hard to measure. The Oslo Manual on Innovation give the following answer to the question on what is of value to measure:

> *"Systems approaches complement theories that focus on the innovative firm, the reasons for innovating and the activities undertaken by firms. The forces that drive innovation at the level of the firm and the innovations that succeed in improving firm performance are of central importance for policy making. Questions on the implementation of innovations, the interaction of different types of innovations, and on the objectives and barriers to innovation are the source of relevant data."* [Oslo manual (2005), pp. 15.][41]

[39] Illustration (Figure 4) from: Zapata, E. (2010).
Illustration (Figure 5) based on data from: UK Parliament (2012).

[40] Gailly (2011), pp. 22-23.

[41] Oslo manual (2005), pp. 15.

3.3. The Innovation system

An innovation system is the ecosystem in which an innovation activity takes place. It contains regulatory and institutional arrangements in place, material, intellectual and financial resources, as well as processes put in place by public authorities to support innovations etc.[42] The innovation system also includes the network of innovation partners, containing actors and institutions that both spread (diffuse) and develop new technology through formal or informal collaborations.[43] Innovation systems can be divided into geographical innovation systems, sectorial innovation systems and technological innovation systems.[44] A geographical innovation system focuses on local or national institutions and arrangements, whereas a sectorial innovation system focuses on sectorial activities.[45] Bergek et al. (2015) describes a technological innovation system as follows:

> *"A technological innovation system is defined as a set of elements, including technologies, actors, networks and institutions, which actively contribute to the development of a particular technology field (e.g. a specific technical knowledge field or a product and its applications)."*[46]

The same author emphasises that interdependencies between the actors create synergy effects in the innovation system.[47] According to Heimerics (2015), a technological innovation system can be described as follows:

> *"Technological Innovation System can be defined as the set of actors and rules that influence the speed and direction of technological change in a specific technological area."*[48]

➜ **This study is limited to investigating technological innovation systems, in order to provide recommendations on breakthrough technologies.**

3.3.1. Mapping the current innovation system of the EU steel industry

In order to evaluate the current technological innovation system of the EU steel industry, the framework in Figure 6 has been used. Most incumbent methods for evaluation of technological innovation systems are based on complex data analytics and require detailed set of indicators (for example through the Seven Functions Framework).[49] As this study is aiming to provide an overview of the innovative opportunities in the industry, a new framework has been developed, which takes on a wider and more comprehensive approach to the innovation system, and maps the EU steel industry as a whole. The framework has been named **The 4W-framework for mapping of the technological innovation system**. The 4W-framework is based on theoretical innovation concepts (see section 3.1-3.2) and contains four key areas of interest; *where*, *who*, *why*, and *what*. The external environment describes ***where*** innovation stakes place, and can be divided into macro environment and micro environment. The internal environment is a combination of the innovative climate within the EU steel industry (***why*** innovation takes place) and the current or future process innovations for decarbonisation of the EU steel industry (***what*** innovations are or will be taking place). The drivers and obstacles to process innovation for decarbonisation of the EU steel industry describe ***who*** are the key influencers affecting innovation, and contain both external and internal actors. Here, an obstacle should be considered an actor or a factor acting as a reverse force, actively preventing process innovation for decarbonisation from taking place within the industry.

42 Gailly (2012), pp. 99-108.
43 Tidd, J. et al. (2001), pp. 197-236.
44 Hekkert et al. (2007), pp. 416.
45 Heimeriks, G. (2015).
46 Bergek, A. et al. (2015), pp. 2.
47 Ibid.
48 Heimeriks, G. (2015).
49 Hekkert et al. (2011), pp. 4.

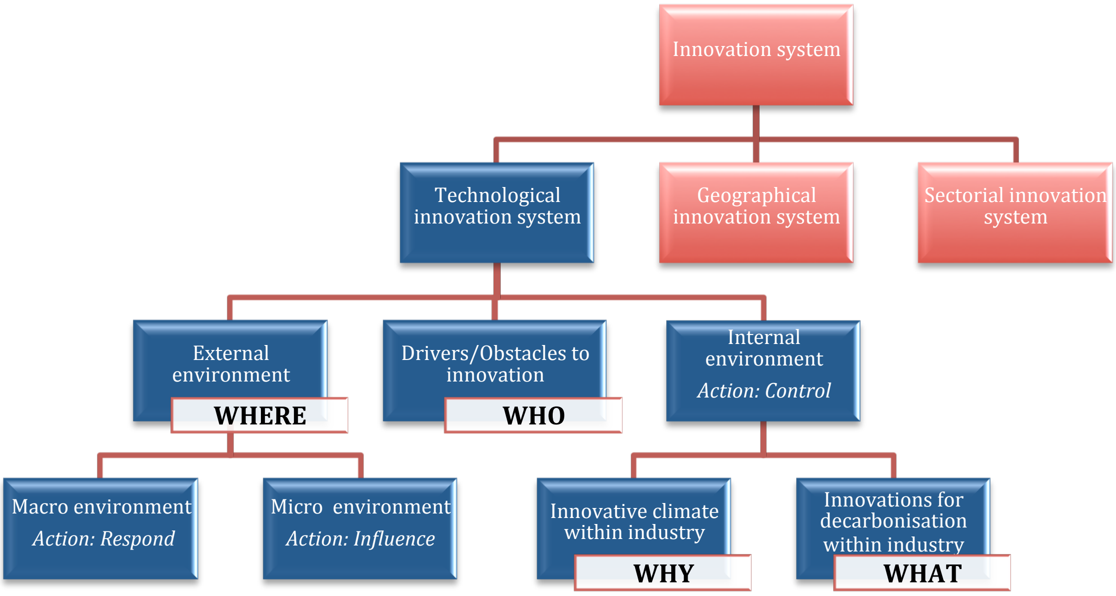

Figure 6. The 4W-framework for mapping of the technological innovation system in the study.

3.3.2. WHERE - External environment

A firm's external environment can be divided into macro environment and micro environment.[50] In this study, the external environment has been analysed, in order to answer Research Question 1 – *Where does innovation take place?*.

3.3.2.1. Macro environment

The macro environment consists of external framework conditions, which directly or indirectly affects the EU steel industry. It contains uncontrollable factors, and a firm is recommended to develop a strategy on how to *respond* to such factors.[51] The macro environment can for example be described through the PESTLE framework, listing the following factors; Political, Economical, Social, Technological, Legal and Environmental.[52] To the EU steel industry, the macro environment of the innovation system is mainly connected to current growth on the EU steel market, as well as European regulation on decarbonisation.

3.3.2.2. Micro environment

The external micro environment contains actors in the firm's value chain, and is also uncontrollable. However, these actors can be influenced to some extent, and the firm is recommended to develop a strategy on how to *influence* the actors in the micro environment. Examples of actors commonly used in the micro environment are the company itself and its Suppliers, Intermediaries, Customers, Competitors and public.[53] In order to fully understand the micro environment of a steel producer, all parts of the steel producer's value chain need to be taken into consideration. An illustration of the mining and metals value chain by the World Economic Forum is illustrated in Figure 7. To the EU steel industry, the most relevant issues in the micro environment of the innovation system are connected to collaboration with other actors in the value chain, e.g. circular economy and stakeholder communication.

50 Kotler, P. & Armstrong, G. (2001), pp. 90.
51 Jain, A. K., (2009) pp. 61-75.
52 Johnson, G. et al (2009), pp.25.
53 Jain, A. K., (2009) pp. 61-75.

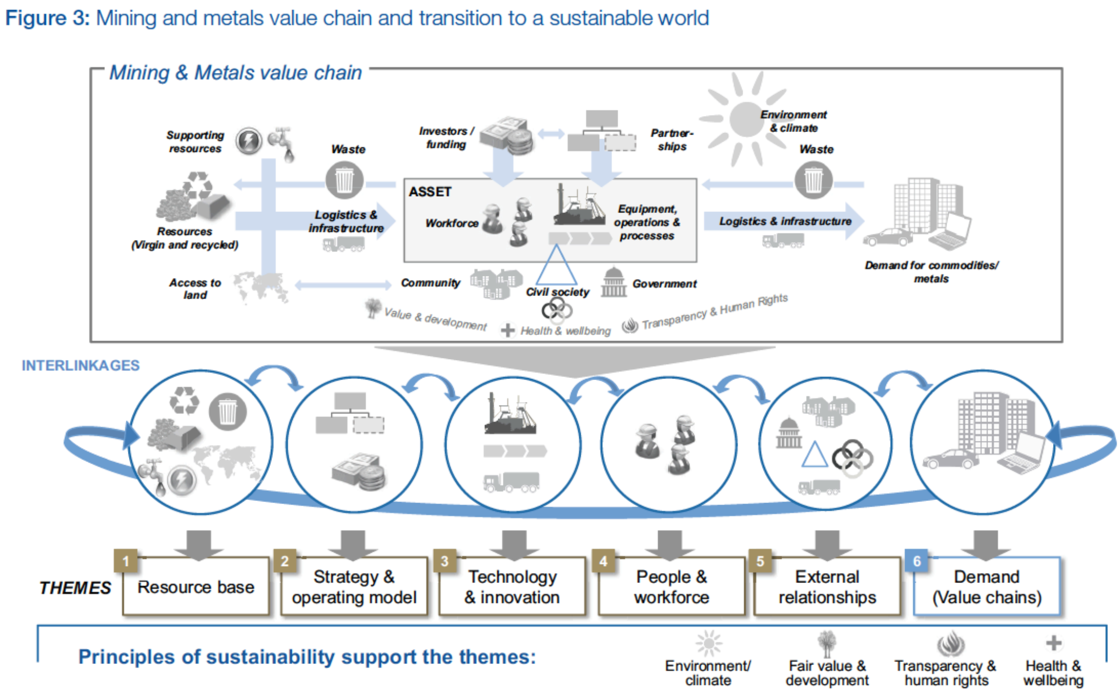

Figure 7. The value chain of the steel industry. *Illustration from World Economic Forum.*[54]

3.3.3. WHO - Influencers of innovation

As described in section 3.2, it is essential to understand which actors are driving or hampering innovation in order to evaluate a firm's current innovation capacity. These actors are called influencers of innovation. In some cases, an influencer can act both as a driver and an obstacle of innovation at the same time. An example is a top management that gives directive to the R&D-department to increase focus on innovation research, but at the same time decides to decrease the budget for such research. Influencers of innovation can be factors or actors affecting the firm on three different levels; macro environmental, micro environmental or internal level.[55]

The World Economic Forum (2015) suggests the following macro environmental factors as influencers of change in the mining and metals sector:

- Environmental, such as climate change and a growing concern for the environment.
- Technological, such as an intensified rate of technological change.
- Societal, with rising concerns about artisanal mining, abrupt generational change, increased 'democratisation' and a higher demand for fairness.
- Geopolitical, such as potential resource nationalisation.
- Geographical, such as mining in remote undeveloped regions and declining grades.[56]

On a micro environmental level, the following actors can be identified in the EU steel industry's value chain (see Figure 7); Upstream actors (such as business partners, trade groups or suppliers), downstream actors (such as customers and end users) or competitors and industry organisations (affecting the firm strategy and operating model). Other important actors in the micro environment could for example be industry organisations, consultants, think-tanks or media.

A firm's internal environment contains factors or actors that the company can control as part of its strategy. Examples of actors commonly used in the internal environment are top management,

[54] World Economic Forum (2015), pp. 11.
[55] Kotler, P., Armstrong, G. (2001), pp. 90.
[56] World Economic Forum (2015), pp. 10.

finance, purchasing, production, accounting and R&D.[57] Among internal actors and factors shaping innovation, cost structure, access to resources and employee competencies, are listed in the Global CEO Study 2006 by IBM.[58] In a study on CEO's opinion on innovation conducted by the BCG, a risk-averse culture is said to be the strongest obstacle of technological development within a firm.[59]

In this study, the drivers and obstacles to innovation have been analysed, in order to answer Research Question 2 – *Who are the main influencers of innovation?*. A summary of the factors and actors expected to have significant impact on the EU steel industry's development of breakthrough decarbonisation technologies is illustrated in Figure 8. The illustration is based on above mentioned literature findings.

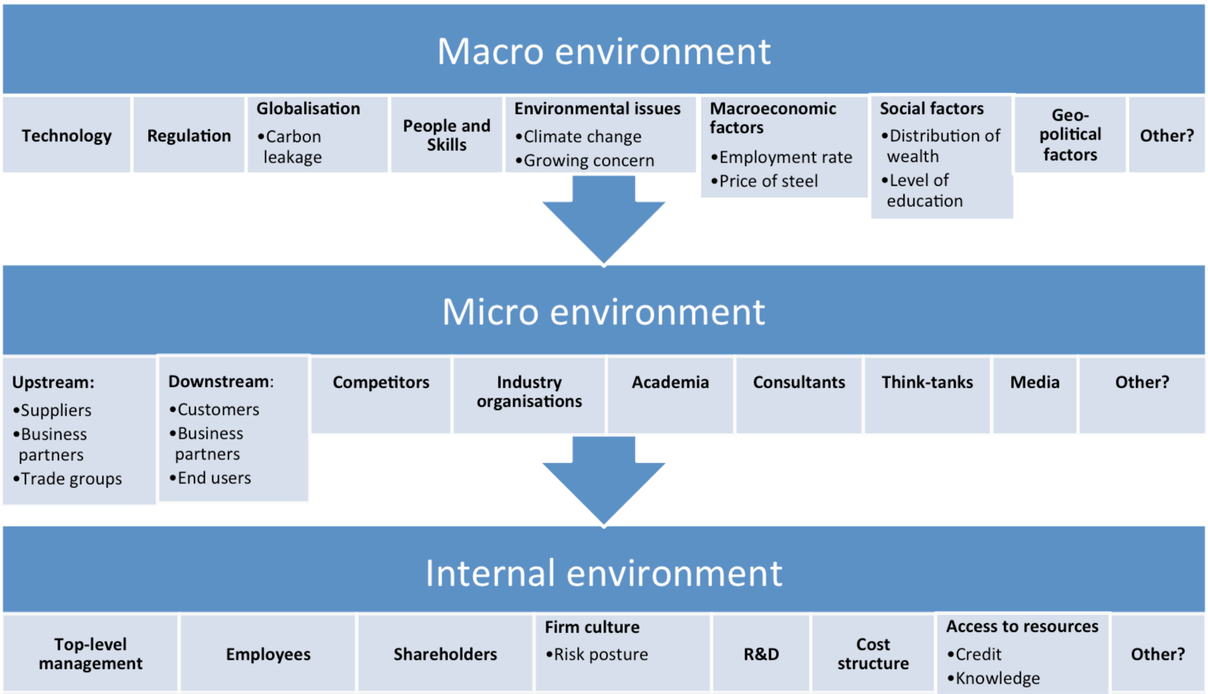

Figure 8. Summary of potential influencers of innovation to the EU steel industry.

3.3.4. WHY and WHAT - Internal environment

A firm's internal innovative environment can be defined through ***what*** the company does, and ***why*** they do it. The internal environment is controllable, and the general recommendation is that the company should focus on *controlling* the internal innovative activities. In this study, the innovative climate within the industry has been analysed, in order to answer Research Question 3 – *Why does the industry innovate?*. Here, the key actors' interests in and incentives to innovate in order to decarbonise must be identified and analysed. Furthermore, the Research Question 4 – *What does the industry do, in terms of innovation*? is also expected to be answered by studying the internal environment. The objective is to identify which actions should be taken today, in order to fulfil the decarbonisation goals until year 2050. Hence, two key issues must be analysed; what decarbonisation initiatives are currently in place, and what initiatives are likely to be needed in the future in order to reach the mitigation goals. Here, current technology, current innovative decarbonisation activities and investment in innovation are crucial areas of interest to the EU steel industry.

[57] Jain, A. K., (2009) pp. 61-75.
[58] IBM Global Business Service (2006), pp. 26-27.
[59] Boston Consulting Group (2009), pp. 11.

4. Results Part 1 – WHERE does innovation take place?

This chapter addresses research question one – 'WHERE does innovation take place?', and is aiming to map the current external environment of the EU steel industry, as well as to describe under which circumstances innovation takes place. The chapter is mainly based on empirical information collected through interviews with stakeholders to the industry and provides an overview of the main outcome of the interview results on this topic. A compilation the interview answers this chapter is based on can be found in Appendix C.

4.1. Macro environment

The macro environment in which the EU steel industry operates is characterised by weak growth and strong international competition. Many respondents describe lack of financial assets as a major barrier for decarbonisation initiatives. At the same time, EU is aiming to become an attractive region for investors and a forerunner in decarbonisation.

The respondents describe the global steel market as a **highly competitive market**, where **Chinese price dumping** is a severe threat to European steel producers. The **weak growth** of the EU steel industry does not enable European investors to make the necessary major investments, and decarbonisation is currently not a main priority. The industry has faced several similar crises during the past decades. As a response, some respondents suggest a change in the steel production strategy, with **decreased focus on bulk** products and increased focus on highly specialised products. However, other respondents emphasise the importance of keeping bulk steel production inside the EU, due to customer demand.

CO_2 emissions are a global problem and cannot be dealt with only on local level. One respondent recommends that the EU steel industry should '**think globally, act locally**', and start with viable decarbonising improvements on a local level instead of awaiting a global consensus in the matter. EU policy makers are aiming to make **EU a forerunner in decarbonisation** and as a consequence, strict EU regulations on CO_2 emissions risk driving steel producers out of the region, creating so-called **carbon leakage**. Some respondents argue that despite the risk of carbon leakage, breakthrough technologies still have to be developed within the EU in order to ensure competitiveness in the long run.

Due to a significant presence of **multinational steel producers** on the EU steel market, there is a possibility that steel producing companies choose to *develop* breakthrough technology inside the EU, but later *implement* the technologies outside the EU where conditions are better. From a global environmental perspective, this is a positive phenomenon as it transfers technology and knowledge to regions with fewer resources for technological development. However, some respondents, refers to the phenomenon as '**knowledge leakage'**, where EU would be contributing (financially and politically) to the development of breakthrough technologies that will never be implemented within the region. The issue is connected to the fact that breakthrough technologies are easier implemented during construction of new plants, than by restoration of incumbent ones. The issue illustrates the strong international competition on the world steel market, and how remaining competitive currently is a stronger priority to the EU steel industry than development of new breakthrough decarbonisation technologies.

A compilation of the respondents' thoughts on the matter can be found in Appendix C. The primary outcomes of the interviews regarding the steel industry's macro environment are summarised in Table 2.

Table 2. Primary outcomes of interviews, regarding the macro environment in which the EU steel industry operates.

Primary outcomes of interviews	
Topic	● *Key implications* ➜ *Actions to undertake* ✖ *Warnings*
The EU steel industry in crisis	● Low profit margins and lack of financial assets decrease the innovative capability in the EU. ● Competition and over-supply forces EU to re-evaluate market opportunities. ● Chinese price dumping is a threat to EU producers, but not sustainable in the long run. ● Closure of inefficient EU steel plants might be inevitable.
	➜ Ensure access to financial assets. ➜ Invest in innovation of breakthrough technologies. ➜ Investigate the possibility of moving into high-value products and specialisation in CO_2 mitigating technologies, through value chain management and increased consumer involvement.
	✖ Do not expect to be able to completely abandon bulk steel production inside the EU.
Global perspective	● CO_2 emissions are a global problem, which complicates policy making on CO_2 mitigation. ● EU ambitions on CO_2 mitigation efforts are high, and successful. ● Radical CO_2 mitigation efforts, including implementation of breakthrough technologies, are easier outside EU.
	➜ Both policy makers and steel producers must consider the whole system while developing CO_2 mitigation strategies. ➜ 'Think globally, act locally' and focus efforts on a national level.
	✖ -
EU as a forerunner of decarbonisation, and the risk of carbon leakage	● Risk of carbon leakage due to strict regulation on CO_2 emissions.
	➜ Keep internal development of breakthrough technologies. ➜ EU policy makers must provide both political and financial support to the steel industry.
	✖ Do not expect that strict EU regulation on CO_2 emissions will be reason enough for steel producers to leave the EU.
'Knowledge leakage'	● Instead of considering knowledge transfer a solely positive phenomenon the industry sometimes expresses a fear of 'knowledge leakage', due to the presence of multinational steel producers in the EU. ● Development of breakthrough technologies is expensive, but cheaper than buying a new technology developed by someone else.
	➜ Keep internal development of breakthrough technologies
	✖ Do not expect the EU to benefit if technological development takes place outside the EU.

4.2. Micro environment

The micro environment in which the EU steel industry operates is characterised by a complex energy system, involving a long chain of downstream actors and poor stakeholder communication. Several respondents describe the lack of collaboration between policy makers and steel producers, as well as no end-user willingness to pay for decarbonising efforts, as major obstacles to innovation through breakthrough technologies.

Steel is a commodity product with a **long downstream value chain**, creating low end-user involvement in the steel production process. End-user awareness and possibilities to increase end-user involvement are currently low, and several respondents suggest that an **increased end-user involvement** could change demand and help facilitate initiatives for innovation through breakthrough technologies. Another option could be to evaluate an introduction of a **VAT on carbon**. An illustration of the value chain is presented in Figure 7 in chapter 3.

Steel is a **strategic commodity** produced in large volumes, and the respondents describe the product as essential for ensuring construction of housing and infrastructure in a region. Due to the importance of the product and the **large amount of EU citizens employed** in the sector, steel production is a highly political issue, and many different stakeholders are seeking to defend their **own interests** in the strategy of the industry.

Several respondents emphasise that the steel industry is part of a **complex energy system**, and a small change in the production process will affect the whole system. A holistic approach[60] to steel production is therefore recommended, in order to fully understand the effects of a technological development, both internally at the plant and externally towards other industries.

The respondents agree that **collaboration is essential** in order to develop breakthrough technology in the EU steel industry. Sharing risks and costs are key issues that can be addressed through collaborative initiatives. The ULCOS[61] consortium is currently the most important initiative for development of breakthrough technologies for decarbonisation in the EU steel industry. Some respondents suggest a **revitalisation of ULCOS**, as a possibility for improved decarbonisation efforts.

As previously mentioned, the steel producers' **end-user communication** is currently very limited. A thorough description of the influential network between stakeholders is illustrated in section 5.2. Regarding collaboration between policy makers and industry actors, most respondents call for **improved cooperation and communication** as crucial issues in order to improve decarbonising efforts. Some respondents suggest that the steel industry has proven to be reluctant to cooperate with policy makers in the past, and that this has damaged the relations between policy makers of the European Commission and the industry actors. Industry organisations and steel producers must improve their collaborative efforts in order to support decarbonising initiatives and development of breakthrough decarbonisation technologies in the future. At the same time, EU policy makers must aim for creating good conditions for the steel industry to cope with the harsh international competition. As part of the solution, policy makers and steel producers must **synchronise their timeframes**, in order to avoid antagonising each other's efforts. Here, the steel industry's **industrial organisations** have to step forward and facilitate the collaboration.

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[60] A holistic approach takes the entire system into account while developing CO_2 mitigation strategies, since complex inter-linkages can make small changes have a substantial affect on other parts of the energy system.
[61] ULCOS stands for *Ultra-Low Carbon dioxide Steelmaking.*

A compilation of the respondents' thoughts in the matter can be found in Appendix C. The primary outcomes of the interviews regarding the steel industry's macro environment are summarised in Table 3.

Table 3. Primary outcomes of interviews, regarding the micro environment in which the EU steel industry operates.

Primary outcomes of interviews	
Topic	● *Key implications*
	➡ *Actions to undertake*
	✖ *Warnings*
The value chain	● Low end-user involvement, due to a long downstream value chain, creates low consumer awareness on steel's contribution to CO_2 emission and an unwillingness to pay for emission reductions.
	➡ Increase end-user awareness on CO_2 emissions. ➡ Increase end-user involvement in the production process, aiming to create a demand for low-emission steel products. ➡ Evaluate the introduction of a VAT on carbon.
	✖ -
Steel - A strategic commodity	● The current situation in the EU steel industry is a highly political issue, affecting not only industrial actors but EU as a whole. ● The steel industry and the manufacturing sector are closely aligned, and hence decisions influence several EU actors.
	➡ Policy makers and steel producers must collaborate in order to keep a high employment rate in the EU.
	✖ Stakeholders letting their own interests hamper innovation are clearly harmful to the industrial development.
The circular economy of steel production	● The steel industry is part of a complex energy system, where circular economy is already a reality. ● Complex energy systems further aggravate the decarbonisation challenge.
	➡ Policy makers must take on a more holistic and long-term approach to emission mitigations.
	✖ Regulation on small parts of a big system risk having an adverse impact.
Collaboration on innovation	● None of the current steel producers have the resources to alone carry out any major initiative on breakthrough technology innovation, and collaboration is therefore essential. ● Development of breakthrough technology requires collaboration, through shared risk and costs. ● ULCOS is considered to be the main initiative for development of breakthrough technologies. ● The ULCOS HIsarna is currently the most promising part of the project, but much more time and money is needed for further development.

	➡ Improve collaborative efforts, including communication and cooperation, with stakeholders throughout the value chain. ➡ Evaluate a revitalisation of ULCOS. ➡ Industry organisations must take responsibility for initiating stakeholder collaboration.
	✖ -
Stakeholder communication	• The EU steel industry has previously shown a strong unwillingness to communicate and collaborate with EU policy makers. • Some steel producers have pressured policy makers to relax legislations on emissions, threatening otherwise to move production out of the EU. • EU policy currently demands the EU steel industry to decarbonise beyond its capabilities.
	➡ Communicate clearly that the current situation is 'everybody's' problem – both the industry's and the policy makers', for example through an industry-wide vision. ➡ Synchronise timeframes of decarbonisation targets, between steel industry and (EU and national) policy makers. ➡ Industry organisations must take responsibility for moderating the dialogue between steel producers and policy makers.
	✖ A harsh rhetoric between policy makers and the industry damages collaborative abilities and hamper innovation. ✖ Do not expect that increased legislative pressure on the industry will lead to more (or better) innovation.

5. Results part 2 – WHO are the main influencers of innovation?

This chapter addresses the research question two – 'WHO are the main influencers of innovation?', and is aiming to identify the key actors and factors influencing innovation through breakthrough decarbonisation technologies in the EU steel industry. The chapter is mainly based on empirical information collected through interviews with stakeholders to the industry and provides an overview of the main outcome of the interview results on this topic. A compilation the interview answers this chapter is based on can be found in Appendix D.

5.1. Key influencers

Some of the respondents were invited to discuss obstacles and drivers to innovation, based on the framework in Figure A.1 in Appendix A as a support. All respondents were asked to speak freely on the topic, and based on the respondents' explanations some factors/actors were identified to be more important than others. A compilation of the respondents' answers is provided in sections D.1, D.2 and D.3 in Appendix D.

The respondents have a relatively unanimous view on which key factors and actors are most important as influencers of breakthrough technology development. However, the respondents' opinions differ on whether these key factors and actors are *drivers* or *obstacles* of innovation. The drivers and obstacles can be divided into three different categories; Macro environmental factors, Micro environmental actors and Internal actors and factors.

Macro environmental factors

The respondents agree that the main obstacle for decarbonisation is the current **lack of sufficient technology**, although technology cannot be considered a hampering factor per se. Instead, **regulation** is the most frequently mentioned factor affecting the steel industry's ability to decarbonise. The opinions on regulation differ – several respondents agree that it is a driver of innovation, whereas others consider it to be hampering. The opinion to whether it is a driver or an obstacle varies, depending on the respondent's role in the industry. Several respondents suggest that the current regulatory framework has to be elevated in order to assure that regulation works as a driver of innovation, instead of as an obstacle. Among the macro environmental factors, other important obstacles are **macroeconomic factors**, which are strongly connected to **globalisation**. Most respondents agree that the current lack of growth in the EU, in combination with competition from China, is strongly hampering the EU steel producers' ability to innovate. A few respondents suggest that **environmental issues** are currently driving process innovation, due to a sustainability trend in Europe and other parts of the world. Environmental issues mainly affect downstream actors, as well as regulation.

Micro environmental actors

Industry organisations are currently described by the respondents as the most important micro environmental actor, but also as an obstacle of process innovation and development of breakthrough technology for decarbonisation. The hampering effect is mainly connected to what several respondents describe as "a negative attitude towards decarbonisation" and "difficulties in collaboration between industry organisations and policy makers". Some respondents also emphasise the need of a progressive mindset among industry organisations, as well as the industry organisations' ability to affect top-level management of the steel companies. Actors **upstream** in the value chain are described as drivers of breakthrough technology development, as they are providers of strategic resources (high-quality raw material, technological equipment, etc.). Most respondents agree that **competitors** can both drive and hamper innovation. An example of how competition can drive initiatives for innovation is the ULCOS consortia. Actors **downstream** in the value chain are currently not actively driving the development of breakthrough technology. However, several respondents emphasise the great potential of end-user as drivers of innovation in the future. A higher end-user demand for 'sustainable steel products' or willingness to pay for cleaner production processes (connected to the macro environmental sustainability trend) is expected to have the possibility to strongly influence demand and behaviour of downstream actors in the future. **Academia** is currently not at all described as an actor of importance to the innovation capabilities of the steel industry. However, academia has the potential to become a driver of innovation, by affecting the industry but also by enlightening downstream actors about the need for decarbonisation.

Internal factors and actors

The respondents describe the **lack of access to resources** as a strong barrier for the steel industry to overcome. However, it is a factor that is hard to affect rather than a direct obstacle, and could only to some extent be controlled by increased collaboration with upstream producers. There is consensus among the respondents regarding the importance of the steel producers' **top-level management** in decarbonisation of the industry. Opinions on whether management is a driver or an obstacle of process innovation for decarbonisation differ, but most respondents emphasise the role of the management in determining firm culture and implementing their values in industry organisations. Strong inter-linkages between the top-level managements' core values and the industry organisations' core values can be identified, and the top-level management can be influenced by the industry organisation, or vice versa. Both **shareholders** and **firm culture** can affect a firm's decarbonisation strategy, and act either as a driver or an obstacle. Here, the top management has the possibility to, to some extent, turn both shareholders and firm culture into drivers of innovation for decarbonisation. **Employees** are in a less favourable position to facilitate change, but can also drive innovation if supported by the top-management. Many respondents bring up a skilled workforce (through training and recruiting of young talent) as a key success factor in improving innovation for decarbonisation.

5.2. Inter-linkages between influencers

In this section, the key influencers identified through the empiric data collection have been taken into consideration. Other influencers (such as geo-political skills, think-tanks, etc.) are not further analysed, since they are not expected to generate any main incentive as a driver or obstacle of innovation.

Two of the key issues hampering innovation are said to be the lack of *Access to resources* as well as the lack of sufficient *Technology*. These two factors, however, are not driving or hampering the innovation abilities per se, but can instead be described as the key issues to be overcome by the industry. The role of access to resources is further discussed in chapter 4, and the role of technology is further discussed in chapter 7.

Several respondents emphasise the direct inter-linkages between macro environmental and micro environmental factors and actors. The complexity of the system, as well as the most important inter-linkages according to the respondents, is illustrated in Figure 9. The illustration shows the role of the influencer (according to the respondents), as well as the influencer's ability to affect other influencers in the system. In the figure, the top row contains macro environmental influencers, the middle row micro environmental influencers, and the bottom row the internal influencers of innovation. The overall importance level of each influencer is derived from the tables in section 5.3, where four influencers have been rated to have 'very high overall level of importance'; Regulation, Industry organisations, Downstream actors and Firm management. In the figure, these four influencers have been marked with a red circle, illustrating that they form the key nodes in the complex system. The actions of these four influencers can therefore be expected to have a substantial impact on the full system, and thereby also on the EU steel industry as a whole.

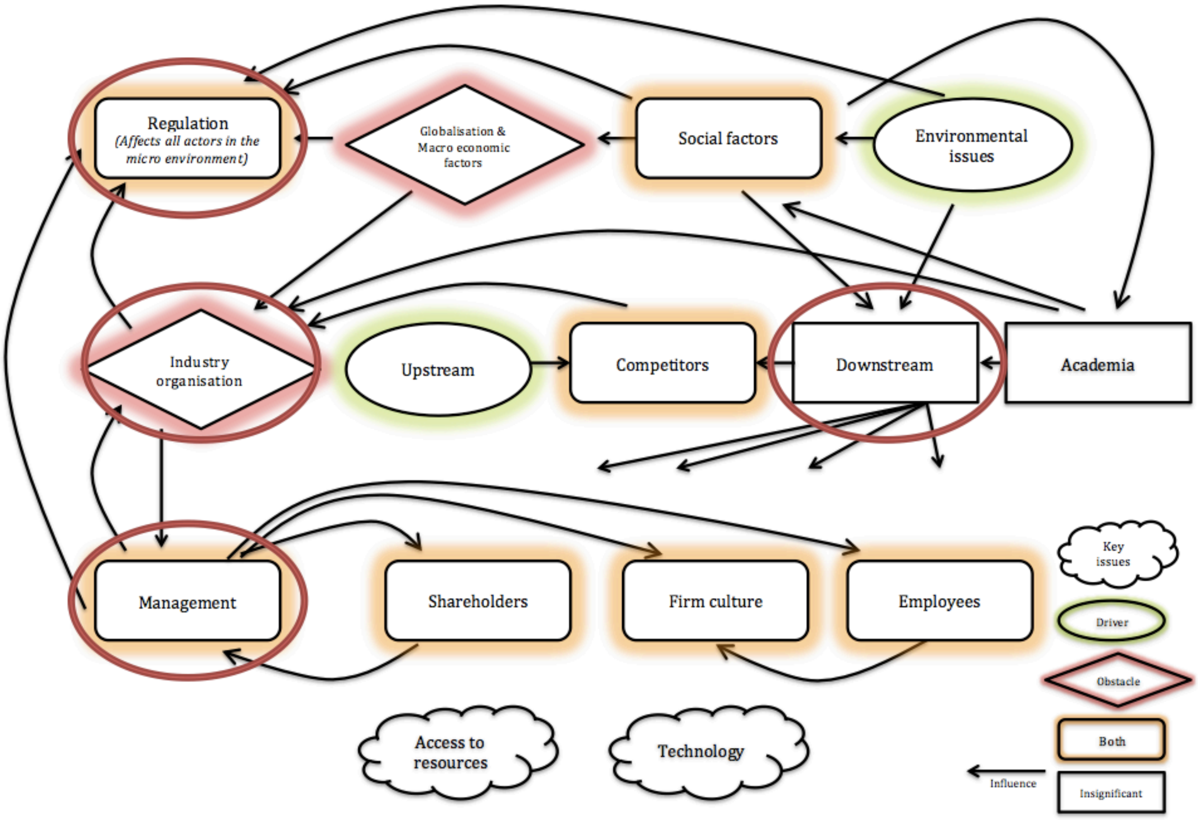

Figure 9. Identified key nodes among the influencers, considered to be especially influential to other actors and factors in the system.

5.3. Overall importance of influencers

The total level of importance of a factor or actor can be described as a combination of the factor's/actor's general level of importance and its ability to influence other factors/actors. The empirical data indicate how these two criteria vary between the different influencers. An overview of the different influencers' general level of importance, derived from the two criteria, can be found in Figure B.1-B.13 in Appendix B. The general levels of importance, as well as the current role of the key influencer, have been summarised in Table 4, 5 and 6. The content of the three tables is also illustrated in Figure 9 above.

Table 4. Current impact of macro environmental factors on innovation for decarbonisation of the EU steel industry.

Factor	Regulation	Macroeconomic factors & Globalisation	Social factors	Environmental issues
Current role as obstacle or driver	Both obstacle and driver	Obstacle	Both obstacle and driver	Driver
Overall level of importance (derived from Figure B.1-B.4 in Appendix B)	Very high	High	High	Low

Table 5. Current impact of micro environmental actors on innovation for decarbonisation of the EU steel industry.

Actor	Industry organisation	Upstream	Competitors	Downstream	Academia
Current role as obstacle or driver	Obstacle	Driver	Both obstacle and driver	Insignificant	Insig-nificant
Overall level of importance (derived from Figure B.5-B.9 in Appendix B)	Very high	Moderate	Moderate	Very high	Low

Table 6. Current impact of internal factors and actors on innovation for decarbonisation of the EU steel industry.

Actor/Factor	Top-level management	Shareholders	Firm culture	Employees
Current role as obstacle or driver	Both obstacle and driver	Both obstacle and driver	Both obstacle and driver	Both obstacle and driver
Overall level of importance (derived from Figure B.10-B.13 in Appendix A)	Very high	Moderate	High	High

6. Results part 3 – WHY does the industry innovate?

This chapter addresses the research question three – 'WHY does the industry innovate?', and is aiming to map the part of the current internal innovation system connected to a steel producer's motivation to develop breakthrough technology for decarbonisation. The chapter is mainly based on empirical information collected through interviews with stakeholders to the industry, and provides an overview of the main outcome of the interview results on this topic. The chapter also includes a brief analysis of the attitude towards decarbonisation, expressed in the external industry roadmap, as well as a benchmark against two other industry organisations. Since this is mainly a qualitative study, the results of interviews contain some elements of interpretation and, thus, are usually not completely free from some analysis. A compilation the interview answers this chapter is based on can be found in Appendix E.

6.1. Current motivation for decarbonising initiatives and breakthrough technology development

The EU steel industry's interest in decarbonisation involves attitude and willingness to engage in decarbonising efforts. In order to facilitate a transformation, the *interest* has to be combined with a strong *incentive* to actually carry out the desired change. The EU steel industry's current interests and incentives to conduct innovation for decarbonisation are described in the following sections. A summary of the findings is provided in Table 7.

6.1.1. Interest in decarbonisation

Most respondents bring up the EU steel industry's **attitude** towards decarbonisation as one of the key factors affecting the industry's possibilities to improve decarbonisation efforts. In general, the respondents say that there is a need for improvement in the industry's **rhetoric** and attitude towards decarbonisation. Several respondents express a frustration over the industry's many excuses and **unwillingness** to take a greater responsibility for increasing decarbonisation efforts. Among the key recommendations to the steel industry, the respondents call for a **change in approach**, including a stronger willingness to decarbonise as well as a greater responsibility for the development process.

In order to mitigate the emissions from steel production, the respondents agree that the steel industry must also show a willingness to **cooperate**, both within the industry and with external actors. Meanwhile, most respondents describe **ULCOS** as an example of a successful collaboration, initiated by the industry itself. The current role of the project is slightly disputed – some respondents emphasise that ULCOS need to be revitalised, rather than used as an excuse from the industry not to further increase the efforts.

The **industry organisations** are playing a central role in facilitating the decarbonisation of the industry. Different sectors' industry organisations have shown different approaches to climate issues. EUROFER is not described as a progressive European industry organisation, and is recommended to adapt a more prominent role in facilitating decarbonisation of the EU steel industry. The current attitude of the organisation is described as expressing a **'victim-culture'**, where the organisation considers itself to be suffering from decisions by other institutions, rather than taking any own initiatives to facilitate a change. Instead, the respondents call for a change in approach, and recommend the industry to **'pick the winners'** and **support reforms on sustainable carbon pricing**.

6.1.2. Incentives for decarbonisation

The EU steel industry does currently not find the incentives for developing breakthrough technology for decarbonisation strong enough. Most of the respondents agree that the main incentive for the steel industry to decarbonise currently is **purely financial**. Since the bottom line for the steel producing companies is to create profit, money plays a key role in the decarbonisation challenge. However, many respondents emphasise that the current carbon pricing system is still not well enough adjusted to pose any true incentive to the industry.

Table 7. The EU steel industry's interest in and incentives to decarbonise.

Primary outcomes of interviews	
Topic	● *Key implications* ➜ *Actions to undertake* ✖ *Warnings*
The EU steel industry's *interest* in decarbonisation	● The respondents agree that the EU steel industry has a very pessimistic approach to decarbonisation and that the current willingness to engage in development of decarbonising activities is low. ● ULCOS is an example of successful collaboration on innovation and decarbonisation. ● Industry organisations play a key role in facilitating the development process and in setting a common industry approach to decarbonising activities.
	➜ Undertake a positive approach to decarbonisation. ➜ Develop a strong innovative and progressive mindset, aiming to become the facilitators of change. ➜ Take on greater responsibility in driving decarbonising efforts. ➜ EUROFER, and other industry organisations, must take a more prominent role as facilitators of change. ➜ 'Pick the winners' and focus on the most progressive steel producers. ➜ Support reforms on more sustainable carbon pricing.
	✖ Current attitude is harmful to the industry's ability to collaborate and communicate its efforts. ✖ Avoid creating a 'victim culture'. ✖ Do not use ULCOS as an excuse not to increase innovative efforts.
The EU steel industry's *incentives* to decarbonise	● The main, and possibly only, current incentive for decarbonisation is financial, but the current carbon pricing system does not pose any strong reason for the industry to decarbonise.
	➜ Carbon pricing must be adjusted to create a stronger incentive.
	✖ -

6.2. Benchmark against other industry organisations

In order to understand the EU steel industry organisation EUROFER, a benchmark against two other industry organisations has been conducted. The EU paper industry organisation CEPI[62] is described as a forerunner in decarbonisation among the EU industry organisations. As the paper industry differs from the steel industry in many aspects (for example by having a much larger ability to decarbonise due to the fundamental technology of paper production), also another benchmark, against the national steel organisation Jernkontoret[63], has been conducted.

In order to create further understanding of the different industries' communication of their interests and incentives, a brief comparison of the industry organisations' external documents on decarbonisation has been conducted (two *Roadmaps* and one *Vision*), as presented in section 6.2.1. Best practices and lessons learn from CEPI and Jernkontoret can be found in section 6.2.2.

6.2.1. Comparison of attitude towards decarbonisation (external documents)

As a response to the EC roadmap, most EU industry organisations have developed their own roadmaps containing sector-specific analyses and a statement from the industry on how it is expecting to address the decarbonisation challenge. The national industry organisation Jernkontoret (Sweden) is a member of EUROFER and has not developed any roadmap of its own, but instead created an industry-wide vision in order to communicate their interests and incentives in decarbonising initiatives. The three documents are briefly described below.

EUROFER

EUROFER's roadmap is characterised by thorough calculations and detailed data on available routes to decarbonise the industry. The language is formal and the analysis is concrete with well-founded argumentation, clearly addressing policy makers or professional stakeholders familiar with steelmaking and the EU steel industry. This leaves limited room for visionary expressions or vague statements that address a more common public. In the roadmap, EUROFER clearly communicates that decarbonisation is a very challenging task, and that the industry expects policy makers to conduct a series of actions in order to facilitate the transition to a low carbon society. The document recurrently emphasises that the EC goals are impossible to achieve, unless policy makers change the current framework conditions.

Extract from EUROFER's Roadmap
A Steel Roadmap for a Low Carbon Europe 2050
Page 4: Foreword, paragraph 1 and 2.

"The European steel industry is determined to deliver a positive contribution to a more sustainable economy in Europe by providing innovative types of steel needed for low carbon solutions in a variety of sectors and by reducing its own CO_2 emissions.

Only with a modern, innovative and profitable steel industry in Europe can the EU's targets for a sustainable, carbon-lean and competitive economy be met. EU policy makers need to provide the right framework conditions and infrastructure to enable industry to contribute effectively whilst remaining competitive on a global scale."

[62] CEPI is The EU industry organisation for pulp- and paper production.
[63] Jernkontoret is the Swedish industry organisation for iron- and steel production.

CEPI

CEPI's roadmap is visionary and does not describe the expected measures and strategies in such detail, as does EUROFER's roadmap. CEPI shows a strong determination to be the facilitators of change, and the document is written in a positive spirit, with a high level of engagement in decarbonisation issues. The language is informal and the content is easy to follow, also for a reader without previous knowledge of paper production.

Extract from CEPI's roadmap
The Forest Fibre Industry 2050 Roadmap to a Low-Carbon Bio-Economy
Page 6: Why the roadmap? - Introduction, paragraph 5, 6 and 7

"We accept that modelling and scenarios cannot accurately predict the world of tomorrow. Nevertheless, we believe there is value in looking this far ahead. We need our own answers to questions about what technology, finance, raw materials and policy will be required in the future. 2050 seems far away, but in fact encompasses just two investment cycles for most of our industries. Decisions cannot wait long.

As competition for energy and resources grows worldwide, sectors and regions that flourish will be those that can extract the highest value from scarce raw materials, using the least energy.

We aim to find the optimal balance between the use of raw materials - wood, residues, pulp and recycled wood and paper – the optimal recycling system and the lowest carbon solutions. As an industry at the core of the bio-economy, we believe we have a crucial role to play in the transformed industrial ecology of a decarbonised world."

Jernkontoret

Jernkontoret has not developed any roadmap of its own, but has instead created a vision, in order to become an active participant in the sustainable society. The vision clearly communicates a willingness from the industry to be facilitators of change and takes on a visionary approach to the decarbonisation challenge. The vision does not provide any details or arguments on how the high ambitions are expected to be realised, but communicates clearly also to an unaware audience that the industry is committing to do what it takes in order to improve its current decarbonisation efforts.

Extract from Jernkontoret's Vision:
Steel shapes a better future – The steel industry's vision 2050
Page 2: English leaflet, paragraph 1 and 2

"Every day the steel industry in Sweden contributes with its products to society worldwide. The steel industry now intends to become an even more active participant in the ongoing shift to a sustainable society – with a greater responsibility for people and the environment. In March 2013, the steel industry in Sweden therefore decided to adopt an industry-wide vision leading up to 2050.

The Steel Industry´s Commitment:
- **WE LEAD TECHNICAL DEVELOPMENT**
Our research and innovation revolutionise technology for tomorrow´s society. Our steel constantly challenges the frontiers of engineering.
- **WE NURTURE CREATIVE INDIVIDUALS**

Our working environment fosters new solutions for communities through global collaboration. Our creativity constantly challenges the limits of contemporary thinking.
- **WE CREATE ENVIRONMENTAL BENEFITS**
Our production uses resources so efficiently that only products of value to the community leave our plants. Our ambition constantly challenges the limits of the possible."

A subjective comparison of the main differences between the two roadmaps (EUROFER and CEPI) and the vision (Jernkontoret) is provided in Table 8.

Table 8. A comparison of EUROFER's and CEPI's roadmaps, as well as Jernkontoret's vision.

	EUROFER	**CEPI**	**Jernkontoret**
Document	**Roadmap**	**Roadmap**	**Vision**
Type of organisation	European industry organisation	European industry organisation	National industry organisation (Sweden)
Target group	Professionals	Key stakeholders	A public audience
Approach	Pessimistic	Visionary and enthusiastic	Visionary and determined
Language	Formal	Informal	Very informal
Layout	Formal	Inspirational	Visionary
Level of detail	Very high	Low	Very low
Level of well-founded argumentation	Very high	Low	Very low
Level of engagement in decarbonising issues	Moderate	High	High
Level of devotion to facilitate the development	Low – Mainly someone else's responsibility	Very high – In our own interest	High – Our responsibility

6.2.2. Best practices and lessons learned from CEPI and Jernkontoret

The aim of this benchmark is to identify some key success factors on how industry organisations can create and facilitate initiatives for innovation through emission mitigating breakthrough technology within an industry. The findings are expected to be applicable on EU steel industry organisations, such as for example EUROFER. A compilation of the interviews composing the background of this benchmark is available in Appendix E. A summary of the findings is provided in Table 9.

CEPI

CEPI's introduction of decarbonising innovation initiatives started with the development of the roadmap in 2012, and the aim was primarily **to save money** and **improve the production processes**. The organisation also considered a change in approach necessary in order to survive on a highly competitive market, and saw possibilities to reach side-benefits though the decarbonisation programme, such as **improved public opinion** and **strengthen relations** with policy makers. In response to the EC Roadmap, CEPI decided to develop even more ambitions goals than was expected of them, not only aiming to decrease emission levels but to also increase value added of their products. Decarbonisation is now considered a necessary task in order to develop the industry and survive against harsh competition. As a result of the decarbonisation efforts, CEPI has managed to develop **several new breakthrough technologies** during just a few years, that have led to both new patents and forming of consortia within the industry. Another side-benefit has been that the decarbonisation efforts have **united the industry** and improved the public perception of the industry's sustainability efforts. CEPI has also gained substantial trust among the decision makers in the industry, as well as towards EU policy makers. CEPI's decarbonising initiatives are further described in section 7.5.

Jernkontoret

Jernkontoret increased its decarbonisation efforts in year 2013, with the launch of an industry-wide vision for 2050. The idea was to **increase focus on decarbonisation**, as well as to **communicate** what the industry already does in terms of sustainable efforts. **Improving the public image** of the Swedish steel industry was one of the underlying needs identified, leading up to the increased decarbonising efforts. Today, decarbonisation is no longer considered to be anyone else's problem, and the industry is taking an outspoken **responsibility** for driving the development. Through the increased focus on decarbonisation, as well as improving external **communication** of such efforts, Jernkontoret has been able to improve its **relations** with Swedish policy makers as well as experts. The industry has also managed to speak with a **unanimous voice** towards its stakeholders.

Table 9. Lessons learned from CEPI and from Jernkontoret.

Primary outcomes of interviews	
Topic	● *Key implications* ➔ *Actions to undertake* ✖ *Warnings*
Lessons learned from CEPI	● Saving money and changing the industry's public image were the main reasons behind CEPI's decarbonising initiatives, as well as to gain advantages from the side-benefits such initiatives bring. ● CEPI's decarbonising initiatives have unified the industry and created a clear organisational culture of sustainability awareness. ● CEPI's decarbonising initiatives have improved the public image of the industry, as well as relations between the industry and EU policy makers.
	➔ Several side-benefits can be derived from the introduction of decarbonising innovation initiatives.
	✖ Do not assume that savings and development of new process innovations are the only benefits of decarbonising activities.
Lessons learned from Jernkontoret	● Improved public image was one of the main reasons behind Jernkontoret's decarbonising initiatives. ● Jernkontoret considered it crucial for the industry to take a greater responsibility in the decarbonising challenge. ● Jernkontoret's decarbonising initiatives have unified the industry. ● Jernkontoret's decarbonising initiatives have improved the public image of the industry, as well as relations between the industry and policy makers.
	➔ There are several other incentives to launch decarbonising initiatives, than just savings and development of new process innovations. ➔ Introduction of an industry-wide vision, in order to unite the industry and improve external communication and relations.
	✖ Do not assume that savings and development of new process innovations are the only benefits of decarbonising activities.

7. Results part 4 – WHAT does the industry do, in terms of innovation?

This chapter addresses the research question four – 'WHAT does the industry do, in terms of innovation?', and is aiming to describe current technological challenges in decarbonisation of the steel making process, as well as the investments needed for development of breakthrough technologies in the industry. The chapter is mainly based on empirical information collected through interviews with stakeholders to the industry, and provides an overview of the main outcome of the interview results. A compilation the interview answers this chapter is based on can be found in Appendix F.

7.1. Steel production today

Steel production can be divided into primary steel production, with usage of primary raw materials in the production process, and secondary steel production, where old steel scrap is recycled into new steel products. In practice, many steel mills use a combination of both. The life cycle follows a flowchart illustrated in Figure 10.

Figure 10. Flowchart illustrating the current life cycle of steel. *Illustration from World Steel Association.*[64]

The current steel production process can follow several different routes. A brief overview is provided in Figure 11, and is further discussed in sections 7.1.1-7.1.3.

[64] Illustration from: World Steel Association (2015b).

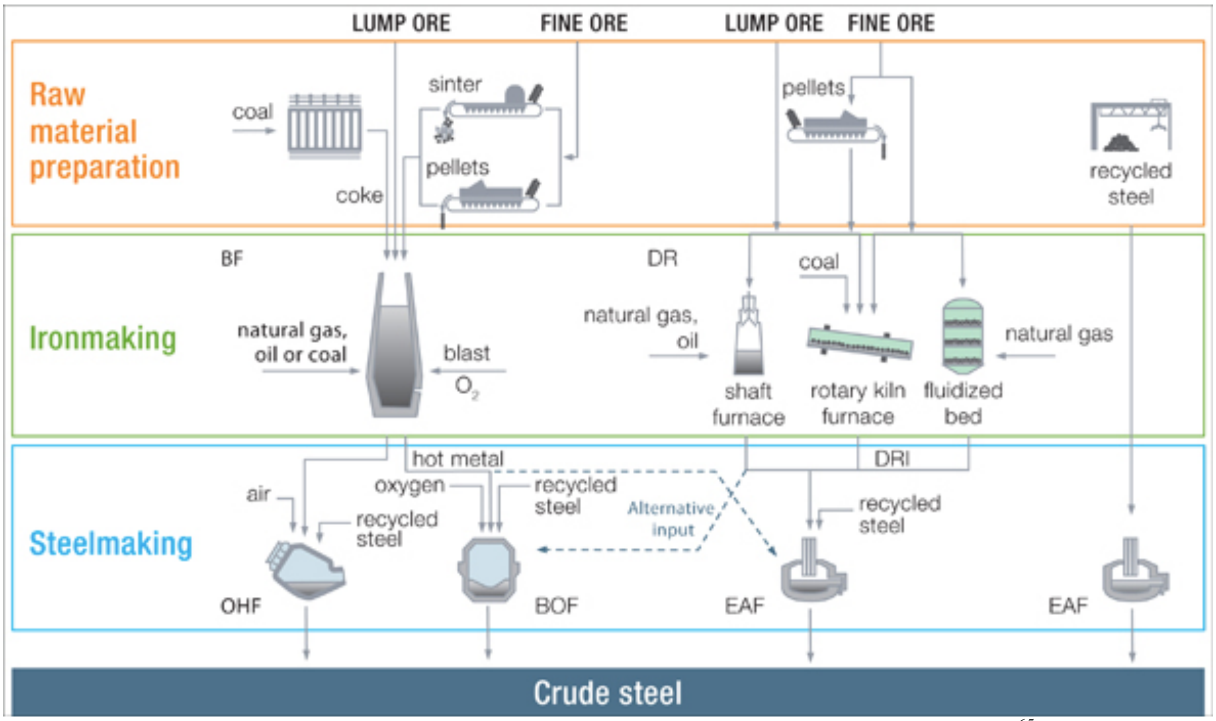

Figure 11. Different steel production routes. *Illustration from World Steel Association.*[65]

7.1.1. Primary steel production today

Primary steel production is defined as creating steel products from primary raw materials. It is most commonly conducted in a **blast furnace-basic oxygen furnace (BF-BOF)**. The process emits substantial amounts of CO_2, and requires a high amount of energy. Around 70% of the world steel production is based on the BF-BOF.[66] The BF-BOF route is further described in section 7.3.1.

Steel can also be produced in an **electrical arc furnace (EAF),** using either scrap or primary raw materials for steel production, or a combination of both. Around 29%[67] of all steelmaking is conducted in an EAF.[68] The EAF route allows for direct reduction (DRI) of iron to steel, for example through usage of natural gas, such as methane gas. The EAF route is further described in section 7.3.2.

7.1.2. Secondary steel production today

Steel products have an **average life expectancy of 38 years**, with a wide variety from 10-60 years depending on the product.[69] After usage, the steel product becomes scrap. Steel is 100% recyclable and new products can be created out of old scrap, through so-called **secondary steel production**. In year 2090 the world is expected to have produced enough primary steel for enabling a significant global shift towards a business model based on recycling, so that almost half of all new steel products are produced through secondary steel production.[70] Secondary steel production is typically conducted in an electric arc furnace (EAF), with **high amounts of electricity** used to melt the scrap products.

[65] Illustration from: World Steel Association (2015c).
[66] World Steel Association (2015d).
[67] The remaining 1% of world steel production is conducted with an open heart furnace (OHF). The method is uncommon and very energy intensive, and not of interest to this study.
[68] World Steel Association (2015d).
[69] Allwood, J. (2016).
[70] Allwood, J. (2012), pp. 65.

7.1.3. Differences between the BF-BOF and the EAF route

The BF-BOF route emits four times as much CO_2 and consumes almost three times more energy than the EAF route. A comparison between the BF-BOF route and the EAF route is provided in Table 10.

Table 10. Material needed in order to produce one tonne of crude steel with the BF-BOF route and the EAF route, including CO_2 emissions.

Resources and emissions in production of 1 000 kg crude steel		
	BF-BOF	**EAF**
Resources needed (kg)[71]		
- Iron ore	1 400	-
- Coal	800	16
- Limestone	300	64
- Recycled steel	120	880
Energy usage[72]	13 500 MJ	5 000 MJ
CO_2 emissions created[73]	1 600 kg	400 kg

7.2. Current decarbonisation activities

The industry has carried out several projects on development of breakthrough technology, the most recent one being the **ULCOS** project. The ULCOS project is an **industry-driven initiative** for development of breakthrough technologies, and currently four key technologies are investigated; **Ulcored** (steel production through DRI[74]), **HIsarna** (a new kind of furnace), **Top gas recycling blast furnace** (reutilisation and storage of off-gases) and **Ulcowin** (steel production through electrolysis).[75] Several respondents describe ULCOS as the most important initiative for decarbonisation and development of breakthrough technologies. The respondents also agree that ULCOS technologies remain the currently best technological solutions to the challenge of process innovation in the long run.

Apart from ULCOS, the usage of end-of-pipe technologies, such as CCS or CCU is one of the current focus areas to the industry, as well as **usage of hydrogen gas as reduction agent**. The respondents describe **CCS** as a way for the steel industry to 'buy time', but will in the end only be a temporary solution to the steel industry, and incentives to invest development of in the technology are therefore weak. **CCU**, on the other hand, could be a major opportunity for development of **new business models**.

7.3. How extensive is the technological challenge?

According to the respondents, the EU steel industry is already utilising all technologies available to improve their decarbonisation efforts. Yet, there are **limited margins for improvement** through incremental innovation, and **radical innovation initiatives are needed** as a complement to incumbent technologies**.** Some respondents suggest that steel producers need either cheap electricity, or access to CCS/CCU next to their production sites, in order to decarbonise to the extent needed for fulfilling the goals until 2050.

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[71] World Steel Association (2015a), pp. 18.
[72] University of Cambridge (2016), pp. 1.
[73] Ibid.
[74] DRI stands for *Direct-Reduced Iron,* and is further described in section 7.3.2.
[75] ULCOS (2015a).

The current available technologies are **not yet sufficient** alternatives for fulfilling the decarbonisation goals for 2050, according to the respondents. Possible improvements could be to produce steel through **fewer production steps**, or **without carbon** in the process. One core difficulty with development of new technologies is that steel production **requires a certain amount of carbon** in the final product. Even if steel production could be conducted without usage of carbon in the production process, carbon would still need to be added to the steel since it is needed for the strength of the product. The presence of carbon also reduces the temperature needed in the production process.

Another issue is that new breakthrough technologies are likely to be easier implemented during construction of new steel plants, rather than through restoration of incumbent ones, and **implementation** is therefore expected to be a great challenge to the EU steel industry.

An overview of the outcomes of the interviews is available in Table 11.

7.3.1. The BF-BOF route

In the blast furnace, where most of the CO_2 emissions occur, CO_2 mitigation could be conducted through three main alternatives:

- **Exchange the coal or coke for charcoal from biomass.**
- **Enrich the H_2 off-gases,** for usage in other processes.
- **Clean the CO_2 off-gases**, for usage or storage.

Many EU blast furnaces are already optimised almost as much as possible The ULCOS *Top gas recycling blast furnace* is a technology where CO_2 off-gases are cleaned and re-used in the blast furnace. The technology is currently available in semi-industrial scale, but European development of the technology was halted as the steel producer ArcelorMittal closed EU's larges project in 2012, due to lack of funding.

7.3.2. The EAF route

Decarbonising the arc furnace is relatively easy with today's technology. The arc requires a lot of electricity, but as long as the electricity is produced through renewable energy sources substantial emission reductions can be achieved.

A shift to steel production through **DRI** in combination with the EAF route, instead of through BF-BOF, generates a significant CO_2 mitigation. Some respondents argue that this is the best alternative theoretically available today, as long as H_2 gas produced from natural gas or electrolysis is used in the DRI process. In order to generate any real emission mitigating effect, the H_2 would need to be produced without CO_2 emissions, using renewable energy resources in the production of H_2 with electrolysis. Previous large-scale DRI projects have turned out **not to be financially viable** given current market conditions.

7.3.3. The ULCOS HIsarna

The ULCOS ***HIsarna*** method is a unique concept of a new furnace, creating a completely different steelmaking route. No steel has yet been is produced with the HIsarna since the technology still is in its development phase, but many respondents describe it as one of the **most promising** new technologies currently available. The process contains fewer production steps, since the method **does not require coke and sinter** but can instead produce steel directly from coal and iron ore fines. Refining of the raw materials in coke plants and sinter plants are therefore no longer needed, resulting in substantial emission reductions. Furthermore, the HIsarna **off-gases** have a very high CO_2 content, and do therefore not require any further cleaning before usage in for example CCS or CCU. The technology is currently under development in the EU, and the current challenge is to perform an **upscaling** of the technology.

7.3.4. Electrolysis

Today, steel production through **electrolysis** only exists on a **laboratory scale**. Steel produced with this technology is strong and less sensitive to humidity. Since no carbon is used in the production process, carbon would have to be added in order to maintain the strength of the steel. The major disadvantage with the technology is connected to scale – the method requires large areas (instead of large volumes), and the **upscaling** is therefore expected to be problematic. An example is the ULCOS project *ULCOWIN*.

7.3.5. CCS and CCU

CCS is not yet available in the large scale needed for the EU steel industry to utilise the technology. The respondents say that CCS could be used as an **interim solution**, enabling the steel industry to mitigate emissions temporarily, while developing breakthrough technologies needed for permanent decarbonisation. Nevertheless, the probability that the EU steel industry will be developing CCS is low – the industry is more likely to be inclined to **utilise** the system, once it is ready. For CCS, one of the key hindrances is the low availability of suitable storage, as well as managing the costly **transportation** of CO_2 gases to these facilities.

Several respondents say that the EU steel industry must engage in improving **industrial symbiosis** in the EU, and describe **CCU** as an optimistic alternative. Some examples of successful CCU already exists in the Netherlands[76], and creating a market for off-gases would give the EU steel industry a great opportunity in development of **new business models.**

Table 11. Primary outcomes of interviews regarding the technological challenge.

Primary outcomes of interviews	
Topic	● *Key implications* ➡ *Actions to undertake* ✖ *Warnings*
How extensive is the technological challenge?	● Limited margins for improvement are available and radical innovation is needed. ● The ULCOS HIsarna is currently the furthest developed, and likely also the most promising, technology available inside the EU today. ● The EU steel industry is currently stuck in the first valley of death on the TRL-scale. ● After technological development, the next major investment will be connected to commercialisation of the new technology.
	➡ Focus efforts on radical breakthrough innovation. ➡ Invest in innovation. ➡ Evaluate opportunities for capture, storage and re-usage of off-gases. ➡ Evaluate an increased focus on DRI and secondary steel production, as an alternative to the blast furnace. ➡ Evaluate new business models for CCU and industrial symbiosis.
	✖ Do not assume that development of new innovation initiatives is enough – also implementation will be a significant challenge.

[76] LoCaRe (2011).

7.4. Investing in innovation

There is unanimity among the respondents regarding the **strong need for investments** in development of breakthrough technologies. At the moment, there is little room for more incremental innovation or further development of incumbent technologies in the EU steel industry, and instead a strong need for **radical innovation** or creation of **new business models**. EU's current rate of investment cannot compete with other regions' and the EU steel producers are struggling to deal with their **low profits** and **long investment cycles**. The industry has already tied up capital in incumbent plants with long lifetime, and do not make enough profit to be able to conduct any substantial decarbonising improvements themselves. Some respondents emphasise the importance of continuous development, and the **current crisis** in the UK steel industry is used as an example of what harm lack of investments can do to the industry.

Regarding utilisation of current funding schemes, the steel industry is believed to **already utilise available financial instruments to the fullest**. One of the most crucial roles of the EU in the steel industry's decarbonisation challenge is to **grant access to capital** for innovation and implementation of new breakthrough technologies. Current financial instruments are not described as advantageous today, however, the EU steel industry is said to be utilising the available funding schemes to the fullest. Some examples of financial instruments are NER300/400, The Research Fund for Coal and Steel, The Investment Plan as well as the EU ETS (see section F.3.3 in Appendix F). One of the key recommendations to the industry is to consider the **EU ETS[77] an opportunity, not a treat**. A global emission trading system could be reality in the future, and EU could gain first-mover advantage by grasping this opportunity. Some respondents recommend that the industry should pledge to invest in sustainable innovation, for example through reinvestments of profit from sold emission allowances into decarbonising activities. The outcomes of the interviews are summarised in Table 12.

7.4.1. Technology Readiness Level

One respondent is discussing the EU steel industry in the context of Technology Readiness Level (TRL), and finds that the industry currently is **stuck in the first valley of death** (around TRL 4). The current TRL is illustrated in Figure 12. **Substantial investments will be needed**, in order to overcome the current failure to invest in technological development, and the industry needs substantial support from financial EU instruments (for example FP 7, SPIRE, European Fund for Strategic Investments and the EU ETS). From a long-term perspective, the industry also has to develop a strategy on how to commercialise new technologies, in order to overcome the predicted second valley of death (around TRL 7) and manage to put the technologies on the market.

[77] The 'EU ETS' refers to the EU Emissions Trading System, where emission allowances can be traded for a price determined by the market.

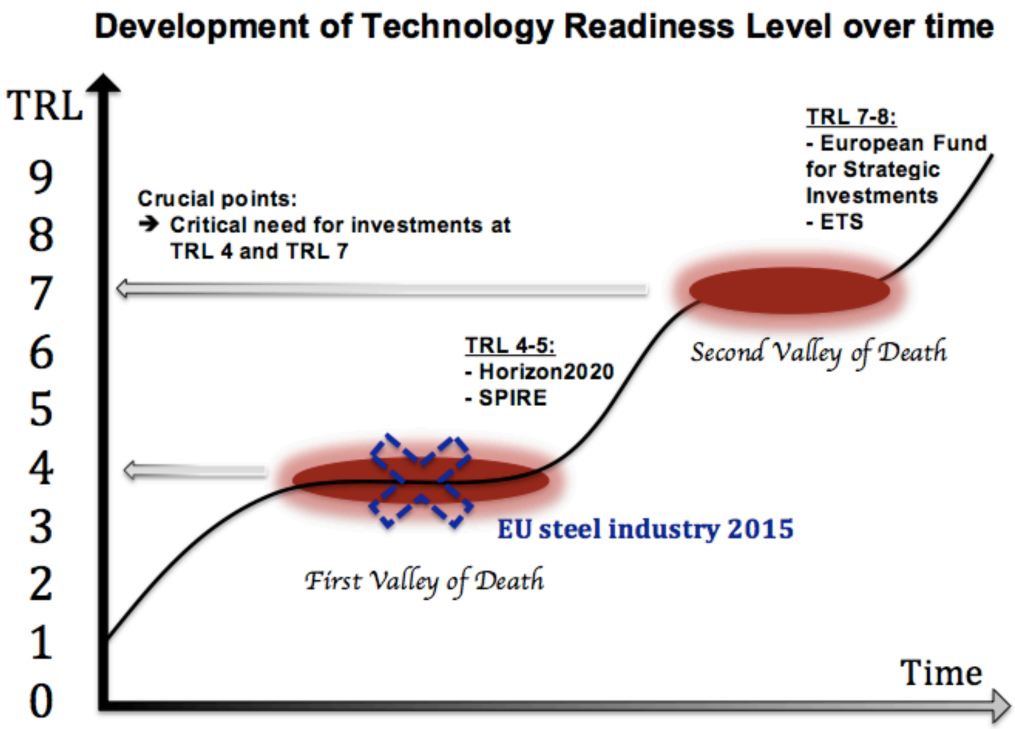

Figure 12. Development of Technology Readiness Level over time, including available EU funding schemes[78] and the current TRL level of breakthrough technology in the EU steel industry.

Table 12. Primary outcomes of interviews regarding investments in innovations.

Primary outcomes of interviews	
Topic	● *Key implications*
	➔ *Actions to undertake*
	✖ *Warnings*
Investments in innovations	● The EU steel industry is currently utilising EU funding schemes to the fullest.
	➔ Grant access to capital and invest in innovation. ➔ Focus efforts on creation of new business models. ➔ See the EU ETS as an opportunity, not a threat.
	✖ Do not underestimate the need for innovation – lack of development is likely to be very harmful for the whole industry.

[78] EU ETS is not an EU funding scheme, but profit from sold emission rights could be utilized correspondingly.

7.5. Benchmark: The Two Team Project

In order to identify best practices for development of breakthrough technologies, a project called the **Two Team Project (TTP**) has been investigated in this section. The TTP was an initiative for development of innovative decarbonisation concepts in the paper industry, carried out by CEPI in 2012-2013. The aim was to identify breakthrough technologies by letting two **teams of stakeholders**, from within and outside the paper industry, compete against each other in an inspirational **innovation challenge**. The initiative included an element of **open innovation**.

The idea was introduced by CEPI and was initially met with **scepticism** among the member organisations. With a limited budget, key stakeholders and experts were invited to participate as competing team members on a **voluntary** basis, and seven meetings at different locations were organised. Eight new breakthrough technologies for paper production were identified, and a jury chose one concept as the final winner.

The TTP did not only generate **technological concepts**, but also **political benefits** for the paper industry. Several disruptive concepts resulted in licences and consortia for further development of the technologies. **Relationships** with stakeholders and policy makers improved drastically as a result of the TTP, and the current challenge ahead is how to find funding for the **massive investments needed** to implement the new technologies.

Lessons learned – key success factors of the TTP

- **Stakeholders' involvement gives valuable input** – Bringing in competences from outside to natural network is a key asset to new and innovative thinking.

- **Mixed groups are the most prosperous** – Fostering regional diversity and putting participants outside their comfort zone inspires to think outside the box.

- **Long-term work more beneficial** – Long-term commitment to decarbonisation will decrease initial scepticism and increase the possibility of a successful project launch.

- **Mindset is everything** – The willingness of the participants is the core ingredient of a successful project.

- **Innovation does not have to be costly** – when participants see the benefits of collaborative initiatives, they can be willing to engage in a project on voluntary basis. The real costs are often connected to implementation, rather than to innovation.

- **Remember that people count** – innovation is nothing abstract, but in fact the result of people’s wishes and ideas. You need an enabling environment for your staff or stakeholders to promote innovation within your organisation.

7.6. Forecast and improvements needed for fulfilling the goals until 2050

None of the respondents state with confidence that the EU steel industry is likely to fulfil the goals for 2050. Some respondents describe the aim for 80% emission reductions until 2050 as absolutely **impossible to achieve**, whereas others suggest modest percentages, such as 40% or 65%, as a possible best-case scenario. The main limitation is the **lack of time**, since 2050 is only a few investment cycles away. The **lack of predictability**, with uncertain market conditions as well as unclear political instruments currently under development, is another strong barrier, as well **as lack of financial assets** to invest in innovation.

In combination with available **CCS/CCU**, the respondents predict the emission reductions to be significantly higher. Also, **DRI** using sustainable raw material could be one of the solutions enabling the fulfilment of the goals, according to one respondent.

The role of scrap in the future is predicted to become more important, according to some respondents. One respondent suggests that EU steel producers have an advantage over Chinese producers in scrap production, and that the **business opportunity** of a growing steel demand in Africa and India could be captured through **increased secondary steel production**.

Steel is often described by the industry itself as an '**enabler of emission mitigations**', and two of the respondents emphasise the mitigating effects that high-quality steel production can provide further down the value chain. Also the importance of **access to high-quality raw material** is emphasised, and one respondent suggest increased pressure on raw material suppliers in order to generate emission mitigations.

8. Analysis

In this chapter, an analysis of the results presented in chapter 4-7 is conducted. Some key recommendations to decision makers, within and connected to the EU steel industry, are formulated based on the four research questions. Following the structure of the chapters, the recommendations are divided into four parts; where, who, why and what.

8.1. Recommendations for decision makers

From the results presented in chapter 4-7, several key recommendations to decision makers have been identified.

8.1.1. WHERE

The results show that increased collaboration with stakeholders is a key to transition into a low-carbon society. Collaboration between industry actors and policy makers is especially important, as well as an increased end-user involvement. At the same time, policy makers must develop policies that consider the complexity of the energy system of steel production.

From Table 2 and 3 in chapter 4, the following recommendations to decision makers can be derived:

<u>**All actors**</u> are recommended to support the EU steel industry in acquiring access to financial assets, for example through loans, co-financing and risk-sharing initiatives. Furthermore, actors must **invest in innovation**, in order to keep development of breakthrough technologies inside the EU. It is important to bear in mind the saying **'No pain, no gain'**, since actors should not expect EU to benefit if technological development takes place outside the EU. Furthermore, all actors should aim at a **'Think globally, act locally'**-mindset, and focus efforts on a national level while bearing in mind the full production system. It is also essential to avoid **letting own, countervailing interests hamper progressive innovation**, as this can be clearly harmful to the industrial development.

<u>**Steel producers**</u> are recommended to work towards an increased end-user involvement, and thereby enabling **increased end-user awareness** on CO_2 emissions. **Increase end-user involvement in the production process** could help creating a demand for low-emission steel products. Furthermore, **collaborative efforts should be improved**, including communication and cooperation, with stakeholders throughout the value chain. The producers must take responsibility for initiating stakeholder collaboration and should evaluate a **revitalisation of ULCOS**. The conventional role of bulk steel production could be developed, and the steel industry has clear opportunities if producers focus efforts on investigating the possibility of **moving into high-value products** and specialisation in CO_2 mitigating technologies. However, producers cannot expect to be able to completely abandon bulk steel production inside the EU.

<u>**Industry organisations**</u> must improve their **rhetoric** and their **collaboration** with policy makers and other stakeholders, For example, **timeframes of decarbonisation targets** must be better synchronized between the steel industry and (EU and national) policy makers. Furthermore, industry organisations must take responsibility for **initiating and moderating the dialogue** between steel producers and policy makers. It is also highly recommended that industry organisations formulate a **long-term industry VISION for decarbonisation** of the EU steel industry. Vision must clearly communicate that the current situation is 'everybody's' problem – both the industry's and the policy makers', and that the industry is willing to do its part.

Policy makers should take on a more **holistic approach** to emission mitigations, by considering the whole system when developing CO_2 mitigation strategies. In this context, the possibility of introducing a **VAT on carbon** could be evaluated. Policy makers must also provide both **political and financial support** to the steel industry, and collaborate with steel producers in order to keep a high employment rate in the EU. Furthermore, the false assumption that increased **legislative pressure** on the industry solely will lead to more (or better) innovation must be eliminated, as regulations on small parts of a big system risk having an adverse impact. On the other hand, policy makers should not expect that **strict EU regulation** on CO_2 emissions will be a strong enough reason for steel producers to completely abandon the EU – steel producers are likely to remain in the region despite the higher risk of **carbon leakage**.

8.1.2. WHO

In order to develop recommendations to decision makers, the key influencers have been analysed with regards to their current role as driver or obstacle, overall level of importance and the industry's expected ability to introduce measures for influence each factor/actor. For each key influencer, a goal has been formulated as well as expected criteria for reaching the set goal. The analysis is presented in Table 13, 14 and 15.

Table 13 shows that making regulation a strong driver is a key message derived from the respondents' answers, as a response to the macro environment.

Table 13. Recommended strategies for **response** to macro environmental factors, with the most important measures highlighted in blue.

Factor	Regulation	Macroeconomic factors & Globalisation	Social factors	Environmental issues
Current role as obstacle or driver	Both obstacle and driver	Obstacle	Both obstacle and driver	Driver
Overall level of importance (derived from Figure B.1-B.4 in Appendix B)	Very high	High	High	Low
Industry's expected ability to introduce measures for influencing this factor/actor?	Moderate	Very low	Moderate	None
Suggested goal	⇨ **Regulation becomes a strong driver**	⇨ Macroeconomic factors & globalisation becomes a non-hampering influencer	⇨ Social factors becomes a driver	⇨ Environmental issues maintain role as a driver
Expected criteria for reaching goal	⇨ Improved collaboration between industry and policy makers ⇨ Industrial support of sustainable carbon pricing	⇨ EU remains competitive against other regions ⇨ Major investments in innovation (state and industry)	⇨ A European culture supporting decarbon-isation ⇨ A European culture supporting innovation	⇨ Take advantage of the current sustainability trend ⇨ Maintained aim to make EU a forerunner of decarbonisation

Table 14 shows that making industry organisations, downstream actors and academia strong drivers are key measures that can be derived from the respondents' answers, in order to influence the micro environment.

Table 14. Recommended strategies for **influence** of micro environmental factors, with the most important measures highlighted in blue.

Actor	Industry organisation	Upstream	Competitors	Downstream	Academia
Current role as obstacle or driver	Obstacle	Driver	Both obstacle and driver	Insignificant	Insignificant
Overall level of importance (derived from Figure B.5-B.9 in Appendix B)	Very high	Moderate	Moderate	Very high	Low
Industry's expected ability to introduce measures for influencing this factor?	Very high	High	Moderate	Moderate	Moderate
Suggested goal	⇨ **Industry organisations become strong drivers**	⇨ Upstream actors maintain role as drivers	⇨ Competitors becomes drivers	⇨ **Downstream actors become strong drivers**	⇨ **Academia becomes a strong driver**
Expected <u>criteria</u> for reaching goal	⇨ Improved collaboration between industry and policy makers ⇨ Improved collaboration with other industries ⇨ An industry-wide VISION for decarbon-isation of the EU steel industry is created ⇨ The industry is aiming to be publically perceived as 'sustainable'	⇨ Maintained close collabo-ration with upstream actors	⇨ Strong collaborations throughout the industry ⇨ Improved project coordination by industry organisation	⇨ Improved collaboration with downstream actors ⇨ Increased end-user involvement ⇨ Increased transparency in the production process ⇨ Take advantage of the current sustainability trend	⇨ Improved collaboration between industry and academia ⇨ Academia aims to raise public awareness on the need for decarbon-isation of carbon-heavy industries

Table 15 shows that making top-level management a strong driver is a key measure derived from the respondents' answers, as a tool for control of the internal environment.

Table 15. Recommended strategies for **control** of internal factors, with the most important measures highlighted in blue.

Actor/Factor	Top-level management	Shareholders	Firm culture	Employees
Current role as obstacle or driver	Both obstacle and driver	Both obstacle and driver	Both obstacle and driver	Both obstacle and driver
Overall level of importance (derived from Figure B.10-B.13 in Appendix B)	Very high	Moderate	High	High
Industry's expected ability to introduce measures for influencing this factor?	Very high	Low	Very high	Very high
Suggested goal	⇨ **Top-level management becomes a strong driver**	⇨ Shareholders become drivers	⇨ Firm culture becomes a driver	⇨ Employees becomes drivers
Expected <u>criteria</u> for reaching goal	⇨ Top-level management supports and facilitates decarbonisation activities ⇨ Industry takes on a positive and long-term approach to decarbonisation	⇨ Improved shareholder attitude towards innovation and decarbon-isation	⇨ Improved firm culture has support from top-level management ⇨ Improved firm culture has support from employees	⇨ Improved employee attitude towards innovation and decarbonisation ⇨ Access to a skilled workforce (through training and recruiting)

All stakeholders must aim at making the following three influencers key drivers of innovation for decarbonisation; Regulation, Industry organisation, Downstream actors, Academia and Top-level management. As illustrated in Figure 9 (section 5.2), top-level management is in a good position to influence both industry organisations and policy makers, but also all internal actors within the firm. Downstream actors can be influenced by academia and by social factors such as current trends. Hence, from the analysis in Table 14, 15 and 16, **four key influencers** suitable for facilitating the desired transition can be identified; **Steel producers, Industry organisations, Policy makers and Academia.**

<u>All actors</u> are recommended is to maintain the aim to make **EU a forerunner of decarbonisation**. Furthermore, **improved collaborative efforts** must be prioritised, within the industry as well as between the industry and external actors. Some specific actors are academia, other sectors, policy makers, as well as upstream or downstream actors. It can also be concluded that **major investments in innovation** will have to be conducted, both by state and by industry.

<u>Industry organisations</u> must formulate a **VISION** and take on a positive, long-term approach to decarbonisation, as well as communicate this vision externally. Furthermore, the industry has to **increase transparency** in the production process, both towards policy makers and towards end users.

<u>Steel producers</u> are recommended to **improve innovative culture** and awareness of the need for decarbonising efforts within firm. Here, **top-level management** has to step forward and facilitate a change in corporate culture and strategic approach to decarbonisation. In addition, steel producing companies should increase efforts to **recruit talents** and **conduct employee training** on innovation for decarbonisation. Steel producers could also benefit from evaluating possibilities to **increase competitiveness** on a highly globalised market through decarbonising innovations.

<u>Academia</u> is recommended to strongly aim at **increasing public awareness** on the need for decarbonisation of carbon-heavy industries.

8.1.3. WHY

The results show that the main incentive for the EU steel industry to work with decarbonisation today is purely financial, and that these financial incentives currently are very week due to a low carbon price and lack of customer willingness to pay for sustainable steel. However, several side-benefits have proven to come from decarbonisation initiatives in other industry organisations. The key to this transformation is a change in approach, including a stronger willingness to decarbonise the industry and a clear communication of this willingness towards a public audience. An illustration of the different industry organisations' willingness and ability to decarbonise, included a recommended strategy for EUROFER, is illustrated in Figure 13.

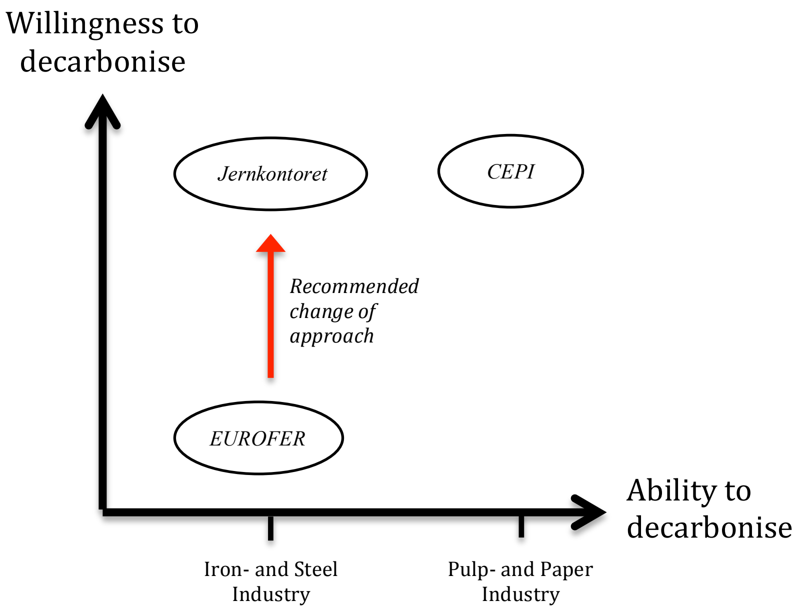

Figure 13. The three industry organisations' willingness and ability to decarbonise, including a recommended change of approach in EUROFER's communication.

From the analysis, the following recommendations can be derived:

All actors are recommended to strive towards an increase willingness among industry actors and within industry organisation to decarbonise the industry. The rhetoric on decarbonisation must be improved, and all actors should undertake a more positive and long-term approach to innovation for decarbonisation of the industry. Furthermore, efforts to communicate current decarbonising efforts, also to a public audience must be increased, and the aim should be to raise public awareness on the need for decarbonisation of energy-intensive industries.

Industry organisations must start supporting reforms on sustainable carbon pricing. As it is hard to change a whole sector at once, the industry organisations are recommended to 'Pick the winners' and work together with the most progressive steel producers and organisations to let them lead the way. In particular, **EUROFER** is recommended to develop an industry-wide VISION for decarbonisation of the EU steel industry, as a complement to the roadmap. EUROFER must also undertake, and communicate, a stronger willingness to decarbonise the EU steel industry.

8.1.4. WHAT

The TRL illustration in Figure 12 (section 7.4.1) suggests that the EU steel industry currently is experiencing the first valley of death, around TRL 4. According to literature, the recommended actions to overcome the first valley of death are investments in technological innovation in combination with collaborative R&D-projects. In order to enable major investments, public institutions have to step forward and share the risk connected to investment in breakthrough technologies.

From the analysis, the following recommendations can be derived:

All actors are recommended to **invest** in technological innovation, as well as to increase collaboration on innovative initiatives. **The EC goals of 80% emission reductions until 2050 will be impossible to achieve, if not all actors act in close collaboration to enable implementation of decarbonising initiatives in the EU.** Therefore, further deep emission reductions must be facilitated through introduction of measures to handle the current lack of time, lack of predictability and lack of financial assets.

Policy makers should aim at granting **access to capital** and **facilitate investments** in innovation. EU legislation must primarily support the industry, in terms of **upscaling and commercialisation**, in order to overcome the second valley of death. Policy makers are recommended to evaluate possibilities to give the industry access to affordable energy, or access to natural gas, to **enable a paradigm shift towards increased EAF steelmaking**. Legislation could be used as a tool for enabling access to **high-quality raw material**. Furthermore, policy makers must also evaluate possibilities of making (affordable) **CCS available** to the EU steel industry, and thereby giving the industry well-needed extra time to mitigate emissions while new breakthrough technologies are being developed.

Steel producers are recommended to invest in innovation, for example through **reinvestments of profit from sold emission allowances** into decarbonising activities. Focus should preferably be on efforts towards radical, rather than incremental, innovation. Steel producers have major opportunities to grasp in terms of creation of **new business models**, for example through CCU and increased industrial symbiosis. Other long-term business opportunities lie in increased focus on **DRI and secondary steel production**, as an alternative to the BF-BOF route. Furthermore, the business opportunities for capture, storage and re-usage of off-gases must be evaluated. Steel producers must also expect implementation of breakthrough decarbonisation technologies to be a great, and costly, challenge.

Industry organisations are recommended to evaluate conducting a project similar to the Confederation of European Paper Industries' project the *Two Team Project*. There could also be major benefits from a revitalisation of ULCOS. Furthermore, the industry organisations must see the **EU ETS as an opportunity,** not a threat, and aim at gaining **first-mover advantage** through experiences from an emissions trading system relative other regions.

9. Conclusions

In this chapter, the study is concluded and the key findings are summarised. Research questions 1-4 are answered and the final recommendations to decision makers are listed, as well as some suggestions for future research.

9.1. Answers to research questions

Research question 1-4 are answered in Table 16 and the key findings are summarised.

Table 16. Answers to research questions 1-4.

Research question		Answer	Detailed description
1	**WHERE does innovation take place?**	Innovation takes place in a highly competitive environment, characterised by low growth and high international competition. EU is aiming to be a forerunner in decarbonisation, prompting high performance in EU steel plants and creating a risk for carbon leakage. There is a slight fear within the industry that 'knowledge leakage' will spread European breakthrough innovations globally and thereby reducing EU competitiveness. Incumbent industrial collaboration on innovation for decarbonisation of the EU steel industry, such as for example ULCOS, is currently not sufficient and is in strong need of improvement. The same applies to collaboration between EU policy makers and industrial actors, where the rhetoric has sometimes been harsh. The industry has previously shown a strong unwillingness to decarbonise and lacks sufficient resources for further development without substantial support from policy makers.	Pages 17-21
2	**WHO are the main influencers of innovation?**	The main drivers are currently Environmental factors and Upstream actors, and the main obstacles are Industry organisations as well as Globalisation and Macro economic factors. Regulation, Social factors, Competitors, Top-level management, Shareholders, Firm culture and Employees are all both drivers and obstacles of breakthrough technology development.	Pages 22-25
3	**WHY does the industry innovate?**	The current interest in facilitating the development of breakthrough decarbonisation technologies is low, and the EU steel industry's approach to the decarbonisation challenge is pessimistic. Money is currently the main incentive for decarbonisation, although the current instruments for carbon pricing are not high enough to pose any real motive for the industry to develop. Benchmarking on other industry organisations shows that there can be clear side-benefits of increased decarbonisation efforts, such as improvements of public image, more constructive relations with policy makers and stronger unity of the industry.	Pages 26-31
4	**WHAT does the industry do, in terms of innovation?**	The EU steel industry is currently utilising all technologies available and radical innovations are needed. ULCOS remains the main initiative for decarbonisation to date and major investments in technological development are needed. CCS could be used to 'buy time' by mitigating emissions while the industry is developing new breakthrough technologies, but CCS technology is not likely to be developed by the steel industry itself. CCU and new business models of industrial symbiosis are key recommendations, as well as increased focus on DRI research and secondary steel production.	Pages 32-40

9.2. Implications for decision makers

The respondents agree that the emission goals for 2050 are most likely impossible to achieve. However, they are also convinced that the industry must actively strive towards fulfilling the goals, despite the weak prospects. From the analysis in chapter 8, the following recommendations can be derived. These recommendations address the four identified key influencers of innovation in the EU steel industry, listed in section 8.1.2; Steel producers, Industry organisations[79], Policy makers[80] and Academia.

9.2.1. Recommendations to Steel producers

- **Management must step forward** and undertake a more positive and long-term approach to decarbonisation of the industry.
- Improve **innovative culture** within the industry, to facilitate research on breakthrough decarbonisation technologies.
  - Foster innovative culture, within the company and the industry.
  - Aim for continuous improvement in development of breakthrough technologies.
  - Recruit talents and train employees.
  - 'Think globally, act locally' – start with viable improvements on a local level.
- Evaluate **new business opportunities** (long-term approach).
  - Consider CO_2 off-gases a commodity, and move towards new business models for CCU through industrial symbiosis.
  - Develop strategies for increased steel production from scrap and evaluate increased production of specialised goods.
  - Increase end-user involvement – create a willingness to pay for 'sustainable steel'.
- See the **EU ETS as an opportunity.**
  - Capture first mover advantage relative to the rest of the world.
  - Support reforms on sustainable carbon pricing.
  - Re-invest EU ETS money into innovation for decarbonisation.
- **Invest** in innovation.
- **Improve collaboration** with actors throughout the value chain and **increase transparency** of carbon intensive parts of the production process.
  - Assure access to high-quality raw materials.

9.2.2. Recommendations to Industry organisations

- Do not wait for the CEO's to step forward - **be the facilitators of change** and convince the CEO's to join your initiatives.
  - 'Pick the winners' – focus on the most progressive actors and collaborate with these, other actors will follow with time. Move away from 'lowest common denominate'-approach.
- Support reforms on **sustainable carbon pricing.**
- Formulate a **long-term VISION** for decarbonisation of the EU steel industry, aiming to:
  - Improve collaboration with internal and external actors.
  - Clearly communicate the industry's willingness to improve the situation.
  - Improve public opinion; Aim for being 'the sustainable steel industry'.

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[79] The recommendations are mainly directed to EU industry organisations, for example EUROFER, but can to a great extent also be applied by national industry organisations.

[80] The recommendations are mainly directed to EU policy makers, but can to some extent also be applied by national policy makers.

- **Improve collaboration.**
    - Initiate closer collaboration between industry and policy makers.
    - Initiate closer collaboration between producers.
        - Evaluate a revitalisation of ULCOS.
    - Initiate closer collaboration with other industries, such as CCS/CCU research on market opportunities together with the chemistry and plastics industry.
- **Raise public awareness** on the need for decarbonisation of carbon intensive industries.
    - Increase end-user involvement and take advantage of the current sustainability trend.

9.2.3. Recommendations to Policy makers

- Maintain the aim to keep **EU a forerunner in decarbonisation**.
- Undertake a more **holistic approach to CO_2 emissions.**
    - Consider the whole energy system in order to develop successful innovation-driving regulations, for example regarding carbon pricing.
- **Work together with the steel industry** to facilitate change, rather than solely imposing strict regulation on producers.
    - Be aware that increased pressure is not necessarily driving, but can also hamper, innovation.
    - Improve communication and collaboration.
    - Synchronise timeframes.
    - Support the industry in coordination of decarbonisation activities.
- Consider evaluating a different model for **allocation of resources** (energy, hydrogen, natural gas, high-quality raw material, time, financial assets) to drive innovation through breakthrough decarbonisation technologies in energy intensive industries.
- **Invest in innovation** and share risks connected to major investments with the industry.
    - Support the industry throughout the development process, in order to enable commercialisation of breakthrough decarbonising technologies.
    - Further foster the EU 'innovative mindset'.
    - Avoid creating a risk-averse culture – re-evaluate current investment initiatives and investigate the opportunity to 'allow businesses to fail'.

9.2.4. Recommendations to Academia

- Take a more prominent **role as a driver** of innovation for decarbonisation, and aim at being a successful enabler of breakthrough process technology development.
- Improve efforts to **raise public awareness** on decarbonisation and encourage further end-user involvement.

9.3. Concluding discussion

The overall objective of this study has been to outline some key success factors for development of breakthrough innovation initiatives fostering decarbonisation of the EU steel industry. The focus has been on long-term decarbonisation, until 2050, and the recipients of the analysis are stakeholders who are acting within or in connection to the industry. In order to meet the objective, the research questions were formulated around four key research areas; *where*, *who*, *why* and *what*. This framework, named the 4W-framework, is different from traditional ways of mapping the innovation system, as incumbent models often aim at generating tangible data rather than providing a wide overview of an industry as a whole. The 4W-framework contributed to the clarity of the industrial analysis, and can easily be applied also to other industries, for example in future research projects on decarbonisation of other energy intensive sectors. Hence, the study has also contributed to future science, by creating a framework that can be used to scientifically map technological innovation systems for industrial decarbonisation.

The formulated implications for instant actions and reforms listed in section 9.2 are aiming to improve the industry's innovative efforts, in order to facilitate the process of decarbonising the EU steel industry until year 2050.

Most implications for decision makers identified through this study are connected to the need for improved collaboration, especially between industry actors and policy makers. The industry is currently facing several challenges, due to strong international competition, high risk of carbon leakage and weak growth in the EU steel industry. As the industry's current interest in decarbonisation is low and the incentives to decarbonise are purely financial, policy makers are key mitigation enablers and must focus efforts on investing in innovation and developing successful funding schemes.

Also industry organisations and top-level management of steel firms are key actors, who must take a greater responsibility in driving the development of breakthrough decarbonisation technologies. Notable is that academia is not currently described a driver of innovation. Despite numerous articles and research conducted on innovation through breakthrough decarbonisation technologies, academia does currently not manage to communicate findings that comprise any true incentives for the EU steel industry to decarbonise. Furthermore, industry actors are recommended to initiate improved stakeholder communication and increased transparency in the production process, as well as to develop an industry-wide vision for development of long-term decarbonisation efforts.

Several business opportunities can be identified, from which the EU steel industry could be expected to profit strongly in the long run, should these opportunities be captured. New markets for by-products could emerge through further development of industrial symbiosis, and an increased end-user awareness regarding the environmental impact from steel production could open up for a market demand of 'sustainable steel' with low carbon footprint. Bringing the EU steel industry into the circular economy should be a key priority to all stakeholders, in order to mitigate CO_2 emissions from steel production.

In this study, no further analysis regarding the actual operability of the recommended actions has been conducted. A recommendation for future research would therefore be to explore which actions are best suited for implementation within a foreseeable future. Furthermore, an environmental impact study of some of the key recommendations would be desirable, in order to decarbonise the steel industry and move EU towards a low-carbon society where sustainable steel is a key commodity.

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Appendices

Appendix A – Interview guide

Appendix B – Figures on overall importance level of influencers

Appendix C – Compilation of interview answers to research question 1:
WHERE does innovation take place?

Appendix D – Compilation of interview answers to research question 2:
WHO are the influencers of innovation?

Appendix E – Compilation of interview answers to research question 3:
WHY does the industry innovate?

Appendix F – Compilation of interview answers to research question 4:
WHAT does the industry do, in terms of innovation?

Appendices C-F are mainly compilations of interview answers, but the information has occasionally been corroborated with secondary sources. The interviews were conducted in September through November year 2015. All interviews were carried out in English, apart from the interviews with Nilson and Respondent E, which have been translated from Swedish. The respondents' current organisational base and position are listed in Table 1, chapter 2.

Appendix A - Interview guide

Interview topic: *Innovation through breakthrough decarbonisation technologies in the EU steel industry.*
Location/Phone interview, Date, Time.

Respondent	Researcher
Name Position Organisation Contact details:	**Matilda Axelson** Student of Industrial Engineering and Management Lund University Contact details:

Agenda – Total time XX minutes (or as much time as the respondent can spare)

- **Introduction XX.XX**
  - Short presentation of project, objectives and definitions
  - Confidentiality of information about organisation and respondent's name
- **Interview starts XX.XX**
- **Short summary of answers XX.XX**
  - Clarification of some answers
  - Questions from respondent
- **Interview ends XX.XX** (Excess time until XX.XX)

Main objective with interview:

- The interview is qualitative with open questions, and the respondent is asked to answer according to the respondent's personal experience and opinion.
- The aim is to map the current innovation system within the EU steel industry, and to identify some key recommendations to the industry on how to further nurture process innovation for decarbonisation.
- Main interview question:
  - *In your opinion, what needs to be done with regards to innovation through breakthrough decarbonisation technologies, in order to mitigate CO_2-emission until 2050?*

Confidentiality:
The respondent will receive a summary of the answers after the interview. After having had time to review the summary, the respondent is welcome to choose to remain anonymous in the report.

Topic	Questions
Main question:	Main questions to be answered during the interview:
In your opinion, what needs to be done with regards to process innovation in order to fulfil the CO_2-emission goals for 2050?	○ What are the main **barriers** preventing the EU steel industry from reaching the decarbonisation goals?
	○ What does the steel industry **need** in order to overcome these barriers?
	○ What **actions** do you recommend should be undertaken today, in order to enable the industry to fulfil the decarbonisation goals in the future? ▪ Who should be responsible for conducting these actions? *(E.g. Steel producers, Industry organisations, EU policy makers...)*
(XX minutes) **Time checkpoint XX.XX**	○ Which actors or factors are the **drivers and obstacles** of process innovation for decarbonisation of the EU steel industry today, and what are their incentives? ▪ *Please see **support framework** in Figure A.1.*
	○ Do you have any general **recommendations** to the industry?

Support questions – if time allows

	The future of process innovation?
Evaluating the future of breakthrough technology development processes? **(XX minutes)**	• Which potential future process innovations **would you wish to see** in the future? • Which potential future process innovations **do you think we will see** in the future? o What **key activities** do you think are needed in order to **drive this development/fill the gap** between your wish and your forecast?
	What is the attitude towards process innovation within The Organisation? *(The Organisation refers to the industry organisation of which the respondent has the most experience.)*

Innovative culture - internal attitude towards development of breakthrough technologies within The Organisation?
 	
(XX minutes)
Time checkpoint XX.XX
	• How would you describe The Organisations general attitude towards **process innovation** for decarbonisation?
	    o What are The Organisation's **interests** towards decreasing CO_2 emissions until 2050?
	        • *'Want' or 'Must'-approach?*
	    o What are The Organisation's **incentives** to decrease CO_2 emissions until 2050?
	        • *'Carrot' or 'Stick'-approach?*
	• Does The Organisation have the **resources** needed to perform this change?
	    o If no, how could The Organisation acquire these resources?

Support framework for identification of influencers – if time allows

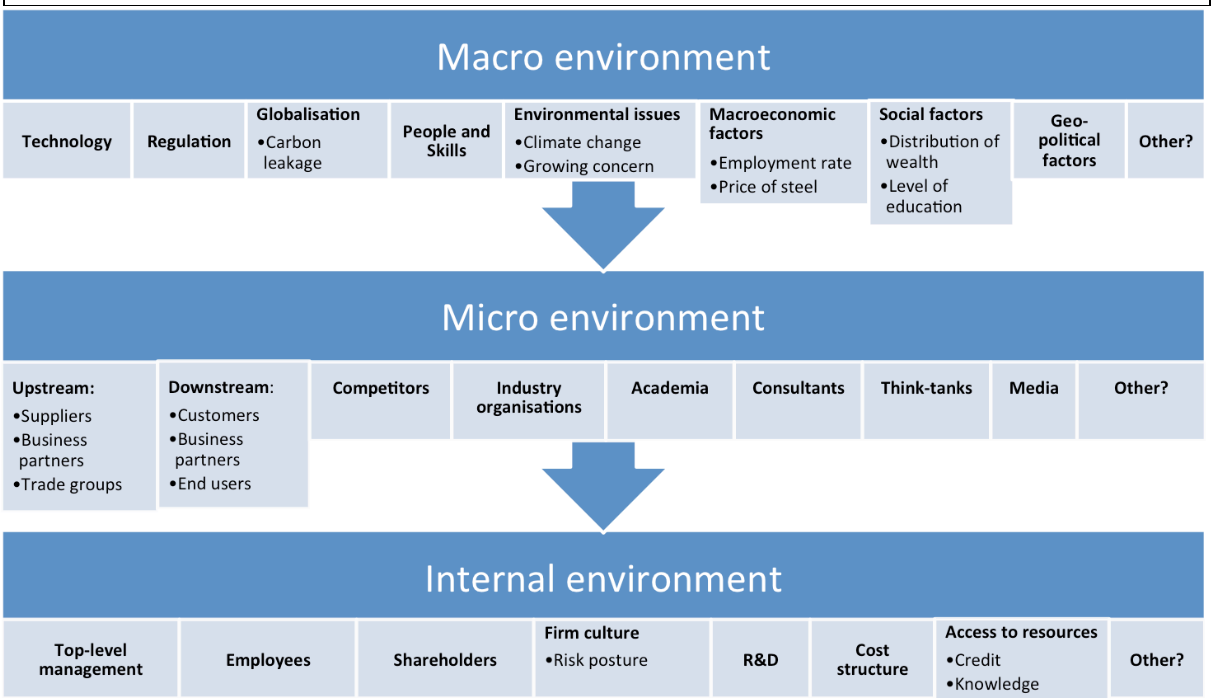

Figure A.1. *Support framework for identification of drivers and obstacles to innovation, within the EU steel industry's macro, micro and internal environment.*

Appendix B – Figures on overall importance level of influencers

The overall importance level of the different macro environmental, micro environmental and internal influencers can be derived from Figure B.1-B.13.

Macro environmental factors

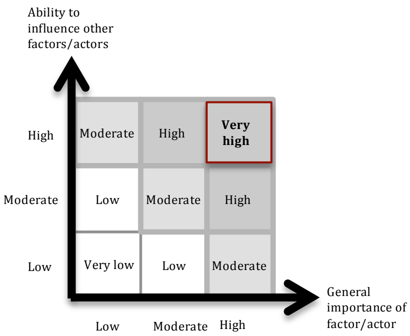

Figure B.1. *Overall importance level of Regulation*

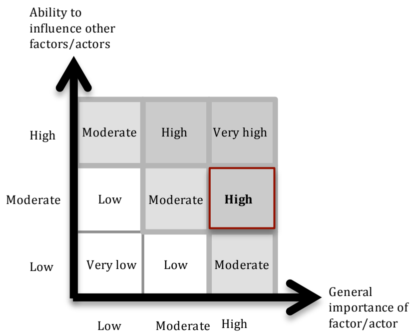

Figure B.2. *Overall importance level of Globalisation & Macroeconomic factors*

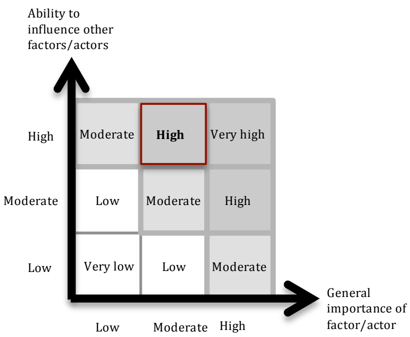

Figure B.3. *Overall importance level of Social factors*

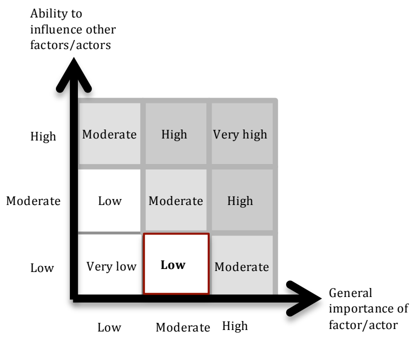

Figure B.4. *Overall importance level of Environment*

Micro environmental actors

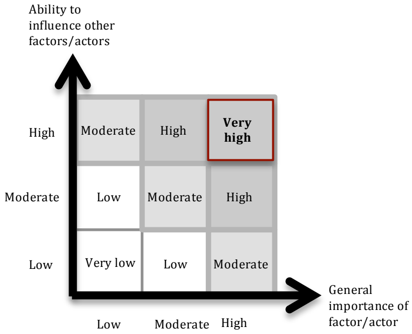

Figure B.5. *Overall importance level of Industry organisation*

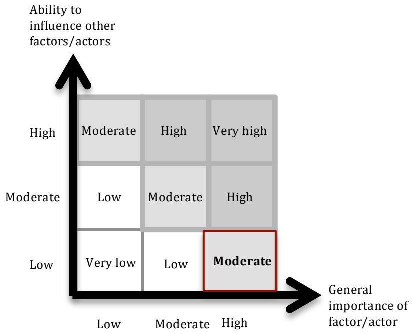

Figure B.6. *Overall importance level of Upstream actors*

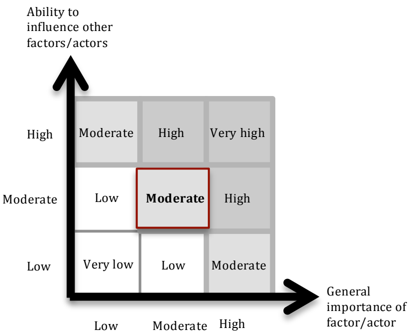

Figure B.7. *Overall importance level of Competitors*

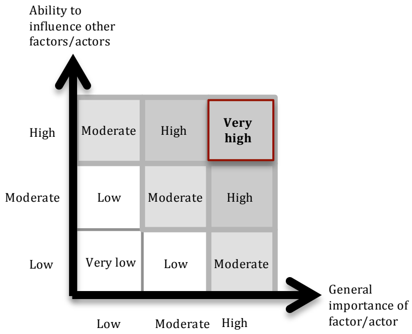

Figure B.8. *Overall importance level of Downstream actors*

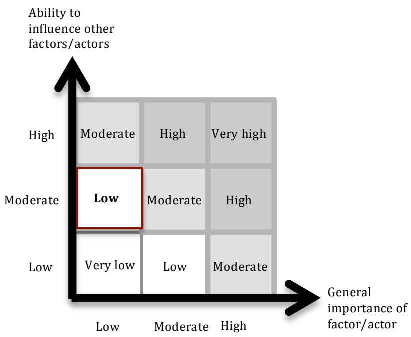

Figure B.9. *Overall importance level of Academia*

Internal actors

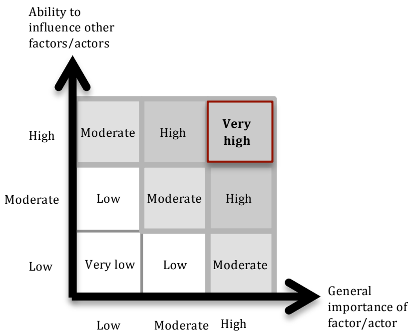

Figure B.10. *Overall importance level of Top-level management*

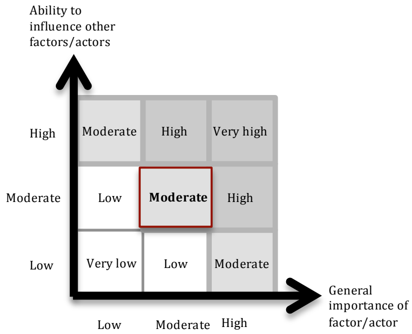

Figure B.11. *Overall importance level of Shareholders*

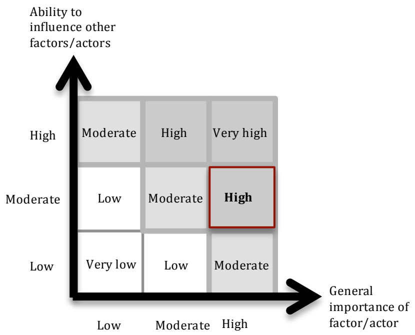

Figure B.12. *Overall importance level of Firm culture*

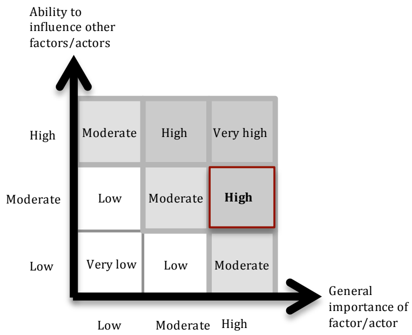

Figure B.13. *Overall importance level of Employees*

Appendix C - Compilation of interview answers regarding Research question 1 - *WHERE does innovation take place?*

C.1. Macro environment

C.1.1. The EU steel industry in crisis – overcapacity and the future role of bulk steel

Several respondents describe lack of financial assets as a major barrier to decarbonisation initiatives. The current profit margin in the EU steel industry can be approximated to around 4%. In order to be equal to comparable industries, the steel industry would need a profit margin of around 16%.[81] The EU steel industry is an industry in crisis, and between June 2015 and February 2016, more than 5000 steel jobs were lost in the UK alone.[82] Some sources suggest that around 40 000 European steel jobs have been lost during the past years.[83] Hence, EU steel producers are currently not in a financial position to make the major investments needed to develop, and later implement, breakthrough technologies. Most respondents agree that lack of access to financial resources is a key issue that must be overcome in order to further foster process innovation and other decarbonisation initiatives.

Traditional steelmaking conduced in large scale in for example China puts pressure on the EU steel industry to switch focus towards specialised products and innovation through breakthrough technologies.[84] Meanwhile, due to a peak the Chinese construction sector, Chinese steel production has grown rapidly during the past 15 years, creating overcapacity on the global steel market.[85] China's current overcapacity in steel is so large that it exceeds the actual capacity of the whole EU steel industry, which makes it nearly impossible for the EU to compete with Chinese products.[86] Morvannou says that in the ongoing steel crisis, steel prices have dropped very low due to Chinese overcapacity, which in turn has lead to increased imports of Chinese steel both in Europe and worldwide. The situation is forcing steel producers to continue to limit their investments, and reluctant to invest also in the most energy efficient alternatives.[87] Chinese production is mainly focused around large volumes of bulk steel, and a way to meet this competition could be to move towards higher product specialisation. However, there is dissent among the respondents on the subject of bulk steel production. EU steel producers' activities are divided between profitable highly specialised products and less profitable high volume products.[88] Research has shown that during a recession, bulk steel production in the EU decrease whereas high and medium value added products increase with around 50% as a response. Production must hence be better planned in order to meet the demand, whereas profit margins also need to be taken into consideration.[89]

According to Respondent B, there is currently a trend among EU steel industry actors to move into more specialised non-commodity products.

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[81] Respondent D (2015).
[82] International Business Times (2016).
[83] CNN (2016).
[84] Respondent A (2015).
[85] Allwood (2016).
[86] Respondent A (2015).
[87] Morvannou (2015).
[88] Nilson (2015).
[89] Respondent A (2015).

> ”The profit margin lies in specialised products that are hard for competitors to imitate. Still, part of the commodity products have lower value, but as long as it is profitable to sell we will keep producing bulk steel. I believe that European producers will have to accelerate into producing more high value products rather than bulk steel in the future, since that is the segment where we can remain competitive on a world market.”[90]

Several respondents recommend a switch from bulk steel to higher refined products, decreasing produced volume and increasing value added, as a response to Chinese competition. Others argue that EU steel producers are dependent on keeping the high volume steel products in their product portfolio due to customer demand. Nilson emphasises the importance of offering a local supply of bulk steel, due to high market volatility. During recession, customers turn to local suppliers in order to minimise transportation time and costs, and a producer can therefore improve customer relations by also offering (sometimes less profitable) bulk steel. Another aspect is that if the currently low costs of transportation by ship would increase, it is possible that the steel producers in closest proximity to their customer will gain more market shares. Hence, Nilson reasons that the industry should not neglect the value of offering high volume steel products, even though that is currently not the most profitable product segment.[91]

According to Nilson, another aspect of the current crisis is that a rise in energy prices will affect Chinese steel production similarly to how it affects EU steel producers. Without further industrial development there is indeed a risk that several EU steel mills have to shut down, but at the same time many Chinese steel mills will be facing the same fate. The Chinese steel market is not based on a market based price model and the Chinese advantage is not related to cost or scale, but the price of Chinese steel products is lower than the price of the commodities themselves.[92] Nilson describes the current situation as follows:

> “Chinese products are not cheaper due to economies of scales or due to especially efficient production. Instead, their steel industry is supported by subsidies from the Chinese government, aiming to bring the market price down and knock out international competition. China is making a loss today, with the objective of gaining market shares for the future.”[93]

Some respondents argue that the current overcapacity will imply an unconditional need for closure of a significant proportion of European steel plants, should the market conditions not drastically change. Hence, following the current market situation, jobs are bound to be lost in the steel industry regardless of carbon policy and carbon pricing. As the top-level management of steel producing firms are economically rational, some plants will be forced to increase their efficiency due to bad performance at the current market, which could be a determining factor in choosing where new technologies should be implemented.[94]

C.1.2. The dilemma of a common policy on CO_2 emissions

Due to the diversity inside the EU in terms of resources and opinions, it is hard for the EU steel industry as a whole to take one general ‘European’ stand in the issue of decarbonisation.[95] In the EU steel sector, some countries want to move faster towards emission mitigation than others and it is hard to establish common EU policies on the matter.[96] Reaching a global consensus would,

[90] Respondent B (2015).
[91] Nilson (2015).
[92] Ibid.
[93] Nilson (2015), translated from Swedish.
[94] Respondent G (2015).
[95] Respondent B (2015).
[96] Respondent G (2015).

understandably, be even more complicated. An alternative approach could be to 'Think globally, act locally' and focus efforts on national level, which offers more room for tailored business strategies on decarbonisation. [97]

An even more significant obstacle with an EU regulation on CO_2 emissions than internal diversity, is that the entire world is sharing the same atmosphere. Some environmental issues are of a local nature and can be handled on a regional level, which simplifies collaboration between policy makers, industry and public opinion. An example is particulates pollution or smog, which can raise local awareness and help forming regional opinion on emission issues. CO_2 emissions, on the other hand, are a global problem of significant importance to the climate change issue. Hence, global collaboration is essential in order to mitigate CO_2 emissions, however significant the difficulties of implementing a global strategy may be.[98] Respondent E emphasises the difficulty of reaching an agreement that several countries can ratify – creating a common EU policy is hard enough, and on world level it is even more challenging – but says that it is essential to see to the whole system while developing CO_2 mitigation strategies.[99]

C.1.3. EU as a forerunner of decarbonisation

Many of the respondents consider the EU steel industry to be world leading in developing CO_2 mitigating activities. The EU steel industry is outstanding in performance regarding sustainability and has many of the best performing steel plants in the world.[100] An example is ArcelorMittal's steel plant in Ghent in Belgium, which has achieved a reduction of 3-4% CO_2 emissions during the past years.[101] In comparison, Peters mentions the example of China, where meeting a goal of around 20% emission reductions could be achieved since the technology is not yet state of the art, which would make it easier to accomplish an improvement in emission mitigations.[102] Another aspect is that implementation of CO_2 mitigating technologies in the EU steel industry would be highly expensive, since the mills are integrated in complex energy systems and one small change affects the whole system (this issue is further discussed in section C.2.3).

C.1.4. Carbon leakage

EU is actively aiming to be world leading in CO_2 mitigation.[103] However, many respondents agree that it can be troublesome to use regulation in order to force the EU steel industry to be a forerunner in decarbonisation. Reducing emissions in the production process is a way of increasing competitiveness towards actors outside the EU, but requires some measure of guaranteeing that steel can be produced inside the EU without risk of carbon leakage.[104] Compared to the rest of the world, many EU steel producers are already performing well and have significantly lower emissions than their non-EU competitors. Hence, these producers do not want to be forced to decarbonise faster than the rest of the world and fear that they will suffer from disadvantages due to international competition. If production conditions in the EU are unfavourable for the industry, the global steel producers might choose to move their production to countries with softer regulation on emission. This is called carbon leakage, meaning that a too strict EU regulation on CO_2 emission could actually increase the overall global emission levels, rather than decrease them.[105]

[97] Respondent B (2015).
[98] Peters (2015).
[99] Respondent E (2015).
[100] Peters (2015).
[101] Respondent D (2015).
[102] Peters (2015).
[103] Lüngen (2015).
[104] Ibid.
[105] Nilson (2015).

Given the current market conditions, there is also a risk that steel produced in the EU becomes less attractive than steel from non-EU countries, creating another form of carbon leakage. The technology of Chinese steel plants is currently not as sustainable as steel production technology used in the EU. The Chinese steel industry has developed quickly with high emission levels in the plants, and an increased European imports from China would increase the total emissions on a global scale.[106] A consequence of too strict regulation could for example be that EU exports will be substituted with steel from worse performing countries, leading to increased rather than decreased overall global emission levels.[107]

C.1.5. 'Knowledge leakage'

Knowledge and technology transfer from the EU to other regions would improve overall global emission levels, and is therefore usually considered a positive outcome in the global climate debate. However, some respondents describe a slight fear within the industry that 'knowledge leakage' will spread European innovations globally and thereby reducing EU competitiveness towards other countries. The industry fears that foreign-owned multinational steel producers could develop new steelmaking processes inside the EU, using European financial instruments and skills, but then decide to implement the new processes outside the EU once breakthrough technologies have been discovered. Having acknowledged this risk, Peters emphasises the importance to the EU steel industry of these process innovations being developed inside the EU.[108]

> "I believe that breakthrough technologies in steel production have to be developed within the borders of the EU. Even if the implementation would later take place outside the EU, it is still better that European managers end engineers have gained information and experience from these processes during the development stage. If we would choose to let the development process take place outside the EU from the beginning, we would later have to buy that new technology when it is fully developed, which in the end would be even less beneficial for the EU. The technology will indeed be very expensive to develop, but it would be much more expensive to buy it back from outside the EU in 20 years from now. We have to continue working on development of breakthrough technology inside Europe, since it is our best alternative available."

Slow growth puts the EU steel industry at a disadvantage compared to international competitors, where higher growth rates make it easier to set up new sites in other regions. Furthermore, breakthrough technologies are easier implemented in new than in existing sites, further aggravating the EU steel industry's ability to compete with other regions in terms of attractiveness of implementation.[109] Even if a stricter regulatory framework on emissions would be implemented, Respondent D believes that EU would remain an attractive region to the steel industry.

"Despite a high carbon price, industry actors still consider EU to be the best region for steel production, given other considered factors. For example, EU has higher costs than some other regions, but at the same time EU offers good access to skilled workforce and close proximity to customers."[110]

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[106] Ibid.
[107] Respondent G (2015).
[108] Peters (2015).
[109] Ibid.
[110] Respondent D (2015).

C.2. Micro environment

C.2.1. The value chain of steel

Several respondents bring up the issue of a long chain of actors downstream in the value chain as the reason behind the low end-user involvement in steel production. Since the majority of all produced steel products are sold through an intermediary, the possibilities of end user involvement are limited. End users do not know much about the carbon footprint of the steel products they are using, and do also not care enough about it to pose an incentive for the steel producer.[111] That, in addition to a vast international involvement in the value chain, makes it difficult for a steel producer to pass on costs to the end user, without risking that downstream intermediaries turn to foreign, cheaper, producers instead. According to the polluter pays principle, a manufacturer is obliged to take responsibility for the environmental impact of its production.[112] However, some research suggests that sectors that cannot transfer the emission costs downstream the value chain could potentially introduce a VAT on carbon. From a consumer perspective it is easy to observe exhaust pipes from an industrial factory and claim that producers have to pay, but if a private person would be required to receive emission permits for building a house out of steel (and other materials), the common awareness on decarbonisation issues would rise.[113]

C.2.2. Steel – a strategic commodity

Steel is a commodity of strategic importance to countries with steel production, and local governments are often doing their best to protect their own position and interests.[114] Since steel is a strategic product, the EU has a strong incentive to secure supply by keeping production inside the EU, which to some extent gives the steel industry leverage over EU policy makers. In comparison, other sectors of non-strategic commodities could disappear from Europe overnight, and EU policy makers would not likely be willing to make any sacrifices to save them. At the same time, the public awareness is higher when it comes to closing down steel plants than closure of plants in sectors with fewer employees, where cut-downs do not create so much of a buzz in media and in the local community.[115]

Also multinational steel producers play a key role in the development, since they are to a high extent setting their own criteria on their own plants. Hence, producers have a key responsibility in maintaining a high efficiency and low emissions in all their production facilities.[116] One of the key issues that the steel industry, together with EU policy makers, has to tackle is the inevitable need for closure of inefficient European steel plants. The social pressure on keeping plants running (efficient or not) is strong, since a layoff would affect the society as a whole. Here, policy makers and steel producers have to come together to develop a feasible solution.[117] Nilson emphasises the close cooperation between manufacturers and steel producers in the EU.

> " If competition would outrival the EU steel industry that would also have a massive negative impact on the EU manufacturing sector. The severity of the current situation might therefore be larger than it might seem at first glance."[118]

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111 Ibid.
112 OECD (2015).
113 Buttiens (2015).
114 Nilson (2015).
115 De Galembert (2015).
116 Nilson (2015).
117 Respondent A (2015).
118 Nilson (2015), translated from Swedish.

C.2.3. Steel production in the circular economy

Circular economy has recently become a commonly used buzzword in some sectors, but is already one of the core values founded in the history of steel production. To the EU steel industry, the closed loop economy[119] is already a reality. The steel producers have worked actively to 'close the loop' during the past decades, and wherever possible, the excess energy or off-gases from steel production are made use of in other steps of the production process.[120] Several respondents emphasise that the steel industry is part of a complex energy system, both internally at the plant and externally towards other industries. However, the complexity of the steel production energy system further complicates the possibilities to decarbonise the industry.

A closer cross-sectorial collaboration between industrial actors will increase efficiency and improve emission mitigation, but can also increase risk due to higher dependency on other actors in the system.[121] An example of a symbiotic industrial system is the INES eco industrial park in the Rotterdam harbour (The Netherlands), where several actors are collaborating in order to improve efficiency and reduce emissions and waste.[122] Another example is Tata Steel's plant in Ijmuiden (The Netherlands), where process gases from steel production are sold to a neighbouring power plant and blast furnace slag is sold to a cement plant, in close proximity to the steel plant.[123] Also the city of Luleå (Sweden) buys excess off-gases from the nearby SSAB steel plant are either reused in the furnace or transported to the local power plant, to be used for heating of thousands of households. Parts of the off-gases are also used to dry peat for the peat industry.[124]

Because of this complex energy system, it is important to analyse whether a change in the production process really decreases the overall emissions. Respondent E calls for a more holistic approach where the entire system is taken into account, since a small change in the furnace can have a huge impact on the overall performance. Also Buttiens emphasises the importance of considering the whole energy system, and not only the impact from steel production, while conducting research on breakthrough technologies for decarbonisation. For example, by minimising off-gases from steel plants, less energy will be produced in connected power plants. If the new replacement energy would be produced through usage of for example fossil fuels, the overall environmental impact of the conversion would not necessarily be improved.[125]

C.2.4. Industrial collaboration on CO_2 mitigating innovations

Due to the large cost of process innovation in the steel industry it is almost impossible even for the biggest steel producers to alone initiate development of breakthrough technologies of any significant scale. By forming consortia for process development, such as ULCOS, the steel industry can gather sufficient resources through sharing both costs and risks between industry stakeholders.[126] Lüngen explains that the EU steel industry's biggest actors are contributing a lot of effort and resources into research and development, as well as conducting collaborative initiatives with for example research institutes.

Most respondents agree that the ULCOS consortium is the main initiative for development of breakthrough technologies for decarbonisation of the EU steel industry. Lüngen describes ULCOS as the largest initiative towards decarbonisation of steel production, not only in EU but

[119] The term 'closed loop economy' is sometimes used synonymous with the term 'circular economy'.
[120] Peters (2015).
[121] Respondent B (2015).
[122] De Lange et al. (2012).
[123] Respondent B (2015).
[124] Respondent E (2015).
[125] Buttiens (2015).
[126] Respondent B (2015).

also in the world. The ULCOS-project is no longer as active as it was some years ago, and some actors are currently seeing a need to revitalise the development of process innovation in the EU steel industry.[127] Almost all the major EU steel companies were involved in the project, and out of the four main ULCOS technologies the HIsarna is currently the one that has proven to be most promising.[128]

C.2.5. Stakeholder communication

Regarding stakeholder communication, most respondents bring up the deficient dialogue between policy makers and industry actors in the EU steel industry. Communication with other actors in the micro environment is further discussed in Appendix D and in Appendix E.

Collaboration between policy makers and industry actors

Nilson, as well as other respondents, describe improved stakeholder communication as a crucial part of the solution if the industry should ever be able to decarbonise, and emphasises the importance of having a shared industry-wide vision. The EU steel industry has suffered several crises during the past decade. As a result, the industry has often been seen making strong demands on policy makers in order to mitigate the financial losses and save jobs, but has shown fewer concrete actions in terms of investments in decarbonisation.[129] According to Respondent G, one of the industry's main arguments for a mild EU emission policy is that if a strict carbon policy forces multinational giants out of the EU, hundreds of thousands of European jobs will be lost. At the same time, the multinational giants are using the same arguments in other parts of the world.[130]

> "An example is Arcelor Mittal, which is currently not only undermining carbon pricing in the EU but also in South Africa – they say exactly the same things about jobs and carbon leakage in South Africa as they do in the EU, which could imply that it's more a matter of rhetoric than of concrete arguments."[131]

Morvannou explains, that during the past years there has been a tough debate between EUROFER and the European Commission, and several respondents verify that the steel industry has previously shown an unwillingness to collaborate. EUROFER has decided to set up its own benchmarking model and as with all statistics, the outcome depends on which factors are included, and how data is presented.[132] At the same time, the past years' decline of the steel market is partly connected to the great boom years that preceded it, and Respondent A argues that the current state is actually a turn back to 'normal'.[133] When the required emission reductions are set through a benchmark against historic data, the choice of year to benchmark against becomes crucial. By benchmarking against years with high emissions due to high production levels, when the real production is actually much lower due to a currently lower demand, the actual required emission mitigation volumes become lower and hence easier for the industry to reach. The norm among the industries is to provide the European Commission with emission data, which constitutes the basis for the distribution of emission allowances and is recorded in a benchmark-document. The so-called *Hot metal benchmark* however, which includes steel production, is not based on public data. The EU steel industry has decided to keep their emission data to themselves and develop their own benchmark, instead of sharing it openly with EU policy makers through the standardised system. Out of 53 industry benchmarks, the *Hot metal benchmark*

[127] Respondent E (2015).
[128] Respondent D (2015).
[129] Morvannou (2015).
[130] Respondent G (2015).
[131] Ibid.
[132] Ecofys (2009).
[133] Respondent A (2015).

is the only one that is not based on official numbers. This lack of cooperation has created tension between the EU steel industry and the involved DG's of the European Commission, leaving a lot to be desired in terms of dialogue and collaboration.[134] (The EU ETS is further discussed in section F.3.3.)

However, the cooperation between the European Commission and the EU steel industry looks very different depending on which DG is involved. One respondent explains that different DG's have different experiences from their collaboration with the steel industry, and the level cooperation works very differently depending on which DG is involved.[135] Respondent E does not believe that any actor is currently hampering the development process, but that there is a strong need for society and industry to join forces and establish a concrete action plan. The main obstacle, which is financing of breakthrough technology development, has to be solved through strong collaboration and a sincere willingness to cooperate.[136] Respondent B emphasises that innovation through breakthrough technologies of the magnitude needed in the EU steel industry cannot be done only by industry alone, but requires close collaboration between state, society and industry.

Respondent G describes the current situation as complicated as the EU steel industry is currently stuck in a 'catch 22' which they do not seem to be able to solve without support from EU policy makers. Development of new breakthrough technologies requires both political and financial support.[137] Policy makers in the EU must therefore create good conditions for the steel industry to survive the upcoming years, and at the same time put pressure on steel producers to monetise.[138] Also Respondent E calls for a stronger collaboration between state and industry, in order to find ways to finance new emission-mitigating processes in the industry.

> ”I believe decarbonisation of the steel industry is one of the central issues that needs to be solved in order to build a sustainable society.”[139]

Coping with different timeframes

Lüngen stresses the importance of active collaboration and mutual support between state and industry. The industry needs time to develop sufficient technologies, but also financial support. Development of new processes are so costly that it is impossible for any single producer to conduct such research and development alone in today's economical situation. Furthermore, there has to be a way to guarantee that the EU steel industry can keep competitive towards competitors from outside EU. Improved collaboration between industry and stakeholders would also be beneficial in terms of coordination; the EU steel industry needs support in getting organised and in managing decarbonisation projects, and here the state and the industry organisations could play a supporting role in the process.[140] Successful CO_2 emission mitigation requires a strong platform for collaboration between policy makers and industry actors. Here, organisations such as the RFCS[141] or Estep[142] could play a significant role in hosting workshops and enabling funding coordination.[143]

134 Respondent A (2015).
135 Respondent D (2015).
136 Respondent E (2015).
137 Lüngen (2015).
138 Morvannou (2015).
139 Respondent E (2015), translated from Swedish.
140 Lüngen (2015).
141RFCS stands for Research Fund for Coal and Steel
142 ESTEP stands for European Steel Technology Platform
143 Lüngen (2015).

Nilson stresses the importance of improving collaboration between policy makers and industry actors in order to reach the decarbonisation goals, especially regarding time perspective of implementation.

> ”My wish for the future is that we will develop a more well-synchronised timeframe of mitigation goals, in order to ensure a coordinated schedule between politicians and private actors. One of the core issues in the cooperation between policy makers and steel producers today is that they operate in different time cycles – the industry is bound by its investment cycles and policy makers are bound by their election periods. Hence, there is a conflict of interest regarding the implementation of policy instruments, since these different cycles rarely coincide.”[144]

For example, a policy maker might have to take an immediate stand in a certain issue in order to please the public opinion. At the same time, the industry is operating through a market based development process based on supply and demand, which sometimes makes it necessary to halt the implementation of an action until the timing is absolutely perfect. Hence, there is a risk that policy makers harm the innovation process through imposed deadlines by legislation. As an example, Nilson explains that the steel industry actor's sometimes are in a situation where they cannot perform well enough to reach the goals set out for a certain year, but if they would be allowed to continue in their own pace they might be perfect a few years later instead.[145]

[144] Nilson (2015), translated from Swedish.
[145] Ibid.

Appendix D – Compilation of interview answers regarding Research question 2 – *WHO are the main influencers of innovation?*

D.1. Macro environmental factors

The respondents' thoughts regarding influence from macro environmental factors on development of breakthrough technologies are outlined in the following sections. One respondent emphasise the direct inter-linkages between macro environmental and micro environmental factors and actors, and considers all macro environmental factors somewhat influential, due to the complexity of the system.[146]

D.1.1. Technology

Lack of sufficient technology is the main obstacle to breakthrough technology development in the steel industry today, according to several respondents.[147] However, the interviews conclude that lack of sufficient technology is mainly a consequence of other factors (for example lack of resources or competencies), rather than being a hampering factor per se. The technological challenge is therefore considered to be a key issue rather than a key influencer, and is further discussed in Appendix F.

D.1.2. Regulation

The majority of the respondents mention regulation as the most important factor for innovation. One respondent emphasises that the opinion on whether regulation is a driver or an obstacle is likely to vary depending on who you ask - the respondent's role in the industry will affect the answer, due to regulation on decarbonisation being a currently sensitive political issue.[148]

Several respondents argue that regulation is driving innovation. Respondent D describes regulation as the most prominent key factor affecting process innovation in the EU steel industry. Regulation on for example carbon pricing plays a crucial role in driving or hampering process innovation. Respondent D, among other respondents, says that carbon pricing has potential to be a strong driver of process innovation, but that it currently is not, due to unsuccessful pricing in terms of under-priced carbon.

Other respondents, including Peters, emphasise that industry actors often do not agree with the regulation framework imposed on them. Political decision makers, and especially politicians with a strong environmental agenda, are sometimes eager to create instruments to impose innovation on the industry. Several of the respondents argue that this strategy can in fact have the opposite effect. Buttiens emphasises that it is not necessarily successful to impose innovation through regulatory instruments.

> "My impression is that policy makers sometimes believe that if you push an industry hard enough, it will open its wallet and improve its emission mitigating efforts overnight. However, innovation is a process that you cannot fully control, and simply demanding from companies to create something that do not exist will not lead anywhere."[149]

Also Nilson says that strict regulation can hamper innovation.

[146] Respondent B (2015).
[147] Lüngen (2015).
[148] Respondent G (2015).
[149] Buttiens (2015).

> "We have to aim for eliminating the false perception that increased pressure on the industry will stimulate innovation positively. In reality, it is possible that you end up stimulating negative events instead."[150]

D.1.3. Globalisation and Macroeconomic factors

There are strong inter-linkages between globalisation and macroeconomic factors, and these can both drive and hamper innovation. However, most of the respondents describe these factors as strong obstacles, mainly due to the current economic situation in the EU. Lüngen argues that it is of highest importance for the steel industry to be able to remain competitive on the world market, but the global steel market today is not favouring breakthrough technology in the EU.

D.1.4. Social factors

Social factors, such as the culture and mindset of the EU, can both drive and hamper innovation through breakthrough technologies. One strong obstacle to process innovation in the EU steel industry is, according to Peters, *the European risk-avoiding culture*. Peters sees a risk in the trend that decision makers today are insistently asking for proven results before making a financial commitment.

> "Regardless of whether you turn to a private investor or are applying from one of the EU funding schemes, you have to provide a thorough analysis or a fully developed business case, proving that the investment will be used for a low-risk project, before getting access to financial assets. This is contradictory to the very idea of innovation, and feeds an innovation system where failure is not accepted."[151]

As an example, Peters mentions the NER300 investment plan, where an applicant first had to perform a full-scale project and would then be refunded retroactively if all the pre-set parameters were met according to plan. A potential consequence is that innovators end up being offered investment opportunities only for low-risk projects that are highly unlikely to fail, which further encourages a risk-averse culture. This approach can be clearly harmful to the innovative culture within an organisation or to the whole EU steel industry today.[152]

Peters refers to *the EU innovative mindset* as a driver of innovation, and mentions this as one of the key potentials that could make the EU steel industry competitive on the global market.

> "Innovation requires more than just having a bright idea and start working on it – it also requires realising your idea and continuing to develop it until you have a full business running. During an innovation process, there are often many reasons to give up along the way, but our innovative mindset keeps us eager to develop also in areas where we might not have the best technology or skills. In the European culture, we also share an idea that change is, generally speaking, a positive thing. We have a bit of a 'New is good'-approach, which makes us inclined to follow through with an idea rather than giving up because of a setback."[153]

D.1.5. Environmental issues

Environmental issues are described as a driving factor in the development of breakthrough technology. As the available environmental space decreases, companies get an even bigger incentive to adapt to cleaner production, Respondent G explains. Respondent E considers the current sustainability trend a clear driver of process innovation in the EU steel industry. Compared to a few decades ago, when climate issues were easily ignored, there is currently a societal attitude devoted to sustainability, stating that environmental issues have to be solved, in

[150] Nilson (2015), translated from Swedish.
[151] Peters (2015).
[152] Ibid.
[153] Ibid.

one way or another. What was previously driven purely by economic incentives has now changed towards a more sustainability-driven societal development, where customers are sometimes prepared to pay a little more for a product as long as it has been produced in an environmentally friendly way. The same trend is reflected in the public appearances of companies, where sustainability reports are now part of the company's annual report, and it is possible that this trend will have an even deeper impact on the steel industry in the future.[154]

D.1.6. Other factors (People and skills, Geo-political factors, other)

The respondents do not describe any other actors, such as people and skills or geo-political factors, as significant obstacles or drivers to development of breakthrough technologies. One respondent says that geo-political factors can both drive and hamper innovation.[155] People and skills is brought up as an important factor, but in terms of internal environment rather than in the macro environment (see section D.3.4). These factors have, thus, not been considered to be 'key influencers' in the analysis of this report.

D.2. Micro environmental actors

The respondents' thoughts regarding influence from micro environmental factors on development of breakthrough technologies are outlined in the following sections.

D.2.1. Industry organisations

Most respondents describe the attitude of an industry organisation as one of the key factors that can hamper or drive decarbonisation. However, most respondents refer to the current attitude of EUROFER as hampering. Respondent G explains that industry organisations often take on a hampering approach to innovation, in the way it is defending all its members regardless of the members' efficiency or level of progressive development.

> "When the industry organisation takes the stand also for the least environmentally efficient producers who own the plants generating the most pollution, you create a culture of *lowest common denominate*. The steel industry will never be better than its trade federation, but an individual steel producer can also be performing worse than what the trade federation is aiming for. Hence, an industry organisation must act as a proactive force fostering development, if there should be any kind of change implemented at all."[156]

D.2.2. Upstream

According to Respondent D, actors upstream in the value chain constitute one of the main factors affecting the development of process innovation. Among these actors it is mainly the raw material suppliers that are driving or hampering process innovation, through pricing of their commodities.[157] Also technology suppliers[158] can be significant drivers of innovation and play an important role in the innovation procedure, by acting as a bridge between academia and industry.[159] It is often the technology suppliers, or upstream sub-contractors, that play a key role in modernisation of machines, and hence part of the technological development occurs upstream in the value chain.[160] However, some respondents say that this development must be initiated by the customer, in this case the steel industry, and that the technology suppliers will not innovate

[154] Respondent E (2015).
[155] Respondent B (2015).
[156] Respondent G (2015).
[157] Respondent D (2015).
[158] Also called '*Equipment suppliers*'.
[159] Peters (2015).
[160] Morvannou (2015).

unless there is a demand for new breakthrough technologies. Nilson argues that today's technology suppliers are delivering state of the art products and that the access to good-quality construction material already is sufficient. The actual construction of new production processes could hence be expected to work smoothly, once the underlying breakthrough technology is developed.[161]

D.2.3. Competitors

Some respondents consider competitors to be obstacles to innovation, whereas others argue that competitors can be driving a firm's innovation in different ways; either through collaboration with competitors, or through competition against them. Either way, competitors would be a driver rather than an obstacle to innovation.[162] Several respondents mention ULCOS as a successful example of competitor-driven innovation, where the main firms decide to collaborate with their competitors in order to develop the industry's breakthrough technology for decarbonisation.

D.2.4. Downstream

Respondent D describes actors downstream in the value chain (such as customers and end users) as important to product innovations, but not necessarily relevant in the development of process innovation. One reason is that approximately 60% of all steel is sold through retailors as intermediaries, which aggravates communication between producer and consumer.[163] However, Respondent E emphasises the current increase in consumer involvement and transparency in the production process.

> "Today, the customers' expectations of transparency in the production process are met through for example Life Cycle Assessment or other kinds of product certifications. The customers demands more from a product today than they did ten years ago, in terms of sustainability, and it is possible that this trend might have an effect also on steel products in the future."[164]

Even though the steel industry has a long downstream value chain, the end user still has some possibilities to communicate expectations on the raw material. An end user buying a car might want to consider that the weight of the car – which depends on the quality and weight of the steel – will have a direct effect on the car's fuel consumption. The industry is currently not able to notice such demand directly from the end user, but the intermediaries (for example the car retailer or the car manufacturer) may notice this wish and has the possibility to transfer the demand upstream in the value chain, back to the steel producer. According to Respondent E, such bottom-up demand was earlier created through economical incentives for the end user, whereas the past decade has seen a switch towards a more sustainability-driven end-user demand that is likely to persist in the nearest future.

Customers could possibly act as drivers of breakthrough technology development in the future. An increased demand for products produced though low-carbon processes could drive innovation and speed up the decarbonisation process. Peters argues that end users are not yet important to decarbonisation of the steel industry, but have the potential to play such a role in the future. The end user is already asking for a 'greener' or 'more sustainable' product, but does not yet show any increased willingness to pay for it.[165] Also Respondent G discusses the future role of end users and their possibility of involvement in the production of steel products. Today,

161 Nilson (2015).
162 Respondent B (2015).
163 Respondent D (2015).
164 Respondent E (2015), translated from Swedish.
165 Peters (2015).

it is possible to label zero-energy buildings and thereby make the end users aware of the environmental impact of the house they live in. However, there is not yet any equivalent labelling of a building's commodities, including the steel used to build the house. If the end user would demonstrate an increased interest in transparency of the production process this could bring forth the development of such labelling in the future, and thereby making the environmental impact of steel production tangible to the end user.[166]

The influence on the public image of a company can be another driver of innovation, which is strongly connected to the wishes and demands of downstream actors.[167] Respondent B emphasise the role of end-user involvement and states that as long as the customers do not change their demand, the industry will not change.

Emission mitigation can also occur by the use of end-of-pipe-technology. In order to facilitate this development, the industry would need a market for off-gases used in CCU (CO_2 Capture and Usage), for example the chemical products market, through improved collaboration with downstream actors. CCS (CO_2 Capture and Storage) would be another option if accepted by the policies and the population.[168]

D.2.5. Academia

None of the respondents describe academia as a direct driver or obstacle of breakthrough technology. For example, Respondent B says that academia is a rather neutral actor. Peters explains that even though researchers and public funding can be drivers of fundamental research, there is usually a level of commercial development before research leads to breakthrough technology innovation (see section 7.4.1).

D.2.6. Other actors (Consultants, Think-tanks, Media, other)

Other actors, such as consultants, think-tanks or media, are not described as significant obstacles or drivers by the respondents. These actors are primarily said to play a role in organisation of industrial events, such as arranging workshops or initiating panel discussions.[169] Morvannou emphasises the role of the union in affecting the overall strategy of steel producing companies. The steel industry employs a large amount of people, and a decline in EU steel production or a radical change in the production methods can have a strong impact on many people's lives. Demands from the union can hence significant affect the industry's ability to decarbonise.[170] These factors have, thus, not been considered to be 'key influencers' in the analysis of this report.

D.3. Internal actors and factors

The respondents' thoughts regarding influence from internal actors and factors on development of breakthrough technologies are outlined in the following sections.

D.3.1. Top-level management

Many respondents emphasise the top-level management's decisive role in development of breakthrough technologies, since this is where the company's strategy is determined. Top-level management of steel firms are strongly affecting the firm culture and can also have a significant impact on the agenda of industry organisations. Respondent G calls for a more forward-thinking leadership in order to decarbonise the EU steel industry, and emphasises that the top-level

166 Respondent G (2015).
167 Respondent B (2015).
168 Lüngen (2015).
169 Ibid.
170 Morvannou (2015).

management most likely understands that climate change is a real problem of our time, just as a majority of the European society does today.

> "The industry's underlying wish for decarbonisation is probably already present, but the big question is who will start the development process, and when. The current expressed attitude towards decarbonisation has to change, and the industry's top management should be playing a key role in driving the development forward."[171]

Respondent E, too, explains that the top-level management is playing a key role in the progress of process development. During a think tank session for CEOs, recently organised by World Steel Association, decarbonisation was brought up as one of the top issues that the steel industry needs to work with. Respondent E emphasises the importance of CEO's stepping forward and creating a clear common vision for the steel industry, in order to reach the decarbonisation goals. The top-level managers have to stress the importance of decarbonisation, as well as take the role of moderating the debate in order to facilitate the development process. Respondent E believes that it is the CEO's of the industry who have to join forces and invite policy makers to a dialogue, and they also have to be prepared to do their fair share of the challenge.

D.3.2. Shareholders

Shareholders can be both drivers and obstacles to innovation through breakthrough technologies. Respondent B says that the opinion of shareholders strongly influences the firm culture. If shareholders are simply profit-focused they can be hampering innovation, whereas a strong corporate stand in innovation (or other issues) could strongly drive innovation. Here, top-level management are best positioned to affect the shareholders, and vice versa.

D.3.3. Firm culture

An innovative firm culture will help drive innovation, and could otherwise hamper the development process. Firm culture is strongly connected to the decision makers' attitude towards risk, and risk aversion can have a hampering effect on the development of breakthrough technologies. Corporate culture can also determine whether an organisation will proactively try to take control of an unwanted situation, or simply consider itself a victim of the decisions made by other industrial actors.[172]

D.3.4. Employees

Many respondents bring up the importance of having a skilled workforce as a potential key driver in the process of developing breakthrough technologies. Recruiting talents to the steel industry is one of the key issues that the industry has to prioritise, in order to facilitate the innovation process. Finding employees with the right competence and a willingness to work with decarbonisation issues is essential in order to drive the development and facilitate change.[173] Maintaining a skilled workforce, either through training or through recruiting, is a challenge necessary to master in order to drive the development of breakthrough technologies within the firm.[174] Buttiens emphasises the importance of recruiting young talents to the steel industry.

> "The steel industry needs to recruit the young and the bright, in order to foster innovation and development of new breakthrough technology. The young talents that are currently attracted to Apple and Google need to turn to the steel industry instead, and the challenge ahead is to find a way to attract them."[175]

[171] Respondent G (2015).
[172] Respondent B (2015).
[173] Respondent E (2015).
[174] Morvannou (2015).
[175] Buttiens (2015).

D.3.5. Other actors and factors (Cost structure, Access to resources, other)

Other internal factors, such as cost structure and access to resources, are not described as significant drivers or obstacles to breakthrough technology innovation. Access to good quality of raw materials is a key issue that the industry has to manage, in order to mitigate CO_2 emissions. According to Morvannou, the EU steel industry is currently emitting more CO_2 per produced tonne steel than it did a decade ago, due to low quality of raw materials and lack of investment. However, the factor is so strongly dependent on other influencers, that it could be considered to be a key issue rather than an influencer per se.

Neither are research and development described as driving or hampering. One argument raised is that an R&D-department does not drive innovation, since it works on behalf of others.[176] Other respondents describe the R&D-department as more important, given its influence on steel producing companies' innovation capabilities.

These factors have, thus, not been considered to be 'key influencers' in the analysis of this report.

[176] Respondent D (2015).

Appendix E – Compilation of interview answers regarding Research question 3 – *WHY does the industry innovate?*

E.1. Interest in decarbonisation

Several respondents describe the EU steel industry's interest in innovative initiatives for decarbonisation as generally low.

E.1.1. Current attitude and rhetoric

According to most respondents, the EU steel industry is having a reluctant attitude towards increasing efforts in innovation for decarbonisation of the industry. One respondent describes the approach of the steel industry as 'pessimistic', especially in terms of willingness and partly also in terms of ability to decarbonise. Some respondents call for a more constructive rhetoric in the discussions, and express frustration over the fact that the industry is not more engaged in decarbonising issues. Respondent B describes the attitude of some actors on the steel market as expressing something of a 'victim culture', where some actors consider themselves victims to policy makers' decisions and as having no power to change their own situation. This mentality can hamper the development of the industry, and the respondent believes that the EU steel industry actors must oppose themselves from such attitude, and instead take hold of their own destiny instead of relying on EU support.[177] The sometimes deficient dialogue between industry organisations and EU policy makers is further described in section C.2.5.

According to Respondent G, steel producers and their industry organisations often use the risk of external competition as an excuse not to work on decarbonisation. The steel industry's current attitude towards EU policy makers is that if the industry does not get the permits it needs to keep producing, there is a risk that the industry moves production to non-EU countries and hence 300 000 jobs could be lost inside the EU. Policy makers therefore often get the impression that there is clear unwillingness from the industry to work actively with decarbonisation.[178]

> "However justified such fears might be, the problem is that these risks are met in an untargeted manner across the board of the industry. Instead of actively developing a constructive solution, the industry is putting a lot of effort into convincing policy makers to create regulations in their favour. The steel industry wants to be allowed to emit CO_2 almost for free, and almost until eternity. I agree with many of the obstacles of decarbonisation that the steel industry brings up, but I am frustrated in how they are not engaging more in this issue."[179]

E.1.2. Need for change in approach

Many respondents call for a significant change in approach among the EU steel industry actors and its industry organisations. Respondent G says that there is a strong need for a general attitude change when it comes to decarbonisation activities.

> "Based on the assumptions that society agrees the climate threat is real and current, and that EU needs to maintain a high employment rate in the steel industry, I would like the steel industry to adopt a more constructive and forward-thinking approach in this regard."[180]

[177] Respondent B (2015).
[178] Respondent G (2015).
[179] Ibid.
[180] Ibid.

The approach towards decarbonisation differs between different EU steel producers today, according to Nilson. Many producers already have a progressive view on decarbonisation and it is therefore important to focus most time and resources on these best-practice producers.[181]

> "In the process of decarbonising the EU steel industry it is a crucial key success factor to be able to 'pick the winners'. Start working with the most progressive producers and give them the resources they need to become even better – other actors will either incapacitate themselves or be willing to join the process at a later stage when they have had time to observe the forerunners."[182]

Respondent E calls for strong communication from the industry, where the industry should state that decarbonisation is 'our problem' and list concrete actions to be undertaken on prioritised matters.

> "The EU steel industry has to start considering the opportunities of decarbonisation, instead of focusing on the threats."[183]

E.1.3. ULCOS and the willingness to cooperate

Lüngen describes the ULCOS project as an example of how the steel industry has proven willingness to develop breakthrough technologies in the past and also in the future. In addition to generating valuable results, Nilson says that in the past, ULCOS was frequently used by the industry as a bit of an excuse, urging policy makers not to increase pressure on the steel industry because they 'already have their hands full with ULCOS'. However, the approach has improved and is more constructive today.

According to Respondent B, the ULCOS project was an example of a proactive and forward-thinking initiative for decarbonisation taken by the EU steel industry. At the time it was unknown how the EU ETS would develop, and the steel industry actors recognised the urgency and the need to facilitate the development of breakthrough technology. During the past years, some setbacks and a general decline of the EU steel market have led to a decreased activity in some parts of the ULCOS projects, and also a decreased enthusiasm per se.[184]

E.1.4. The role of industry organisations

EUROFER is not described as a progressive European industry organisation, and many respondents describe that the organisation previously has shown a strong unwillingness to collaborate. One respondent even suggests that the World Steel Association has a slightly more progressive approach towards decarbonisation than EUROFER. [185] Several respondents emphasise the importance of EUROFER in facilitating a transition to a low-carbon society. According to Respondent G, EUROFER could play a key role in driving the development in the whole EU steel industry from the current unwilling approach, towards a progressive and long-term thinking attitude.

> "The current approach could potentially be damaging, and at this point I believe that EUROFER's policy makers have to step in and drive the process forward together with the top management of the industry."[186]

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[181] Nilson (2015).
[182] Nilson (2015), translated from Swedish.
[183] Respondent E (2015), translated from Swedish.
[184] Respondent B (2015).
[185] Nilson (2015).
[186] Respondent G (2015).

E.2. Incentives for decarbonisation

Money is describes as the main, and possibly only, real current incentive for the industry to decarbonise.

E.2.1. Money

Several respondents emphasise that steel producing companies' main priority is always to make money. Respondent D says that similarly to other manufacturing industries, issues such as reducing CO_2 emissions could therefore never be the main priority to the steel industry.

> "The bottom line for a company will always be to make money, and if you don't manage to make CO_2 mitigation commercially viable it will always be playing a secondary role in their agenda."[187]

Respondent D describes the current carbon price as too low to generate any real incentive for decarbonisation. Hence, it is currently not driving investments in innovation.[188]

> "When it comes to financial instruments, carbon pricing has the potential to be a driving incentive for change. The difficulty lies in that the carbon price has to be high enough to create a significant incentive to decarbonise, but at the same time low enough not too demolish the industry."[189]

Most respondents express similar thoughts regarding carbon pricing, and one respondent wishes that the EU steel industry would support more reforms on sustainable carbon pricing.

Most respondents agree that without money, innovation will not happen. However, Respondent B argues that the access to money can help driving innovation, but might not be a crucial factor.

> "Breakthrough innovation often happens in lack of time and lack of money, otherwise the urgency needed to drive innovation is not there."[190]

E.3. Benchmark: Jernkontoret

Nilson explains that for a long time, the general attitude in the Swedish steel industry was that the society needs steel to develop, and in order to produce steel one has to accept that, consequently, emissions will occur. However, this attitude has changed during the past decade.[191]

> "The Swedish steel industry has finally come to terms with that there is no way to avoid the climate issue anymore. There have been enough excuses already and as an industry we can no longer ignore the fact that we need to take our responsibility in the decarbonisation challenge. Today we know that decarbonisation is our problem – we need to tackle this issue like any other and be a driving force in CO_2 mitigation."[192]

In 2013, Jernkontoret decided to develop a vision for 2050, containing statements that the member steel producers would be willing to support. The idea behind the vision for 2050 was based on discussions on the image of the Swedish steel industry, Nilson explains. The industry actors felt that they were progressing actively in terms of sustainability and decarbonisation, but that the public opinion did not share this view. Two teams were set up to work in parallel on different ideas with extensive input from different kinds of stakeholders. They eventually reached the conclusion that the steel industry needed a shared vision in order to change the public image of steel production. Nilson explains that a side benefit from the vision 2050 is that the steel industry clearly communicates to external sources that it has the intension to remain operative through sustainable production for decades ahead.

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[187] Respondent D (2015).
[188] Ibid.
[189] Ibid.
[190] Respondent B (2015).
[191] Nilson (2015).
[192] Ibid.

Since the launch of the vision, Jernkontoret has already seen a concrete change. One example is that the relationship between Swedish steel producers and Swedish policy makers is continuously improving. The Swedish steel industry is currently putting a lot of effort into improving innovation through breakthrough technologies, and the innovative attitude channelled through the vision is a support to decision makers in the industry.[193]

> "The vision is reflected in the investment decision of the steel producers' top-level management. During moments of hesitation or difficulties in the decision-making process, people tend to turn to their pre-set visions and choose the alternative that goes most in line with this. We all want to be part of something meaningful, and having a clear vision of the future can be a great asset to the management."[194]

E.4. Benchmark: CEPI

According to de Galembert, CEPI has taken a clear stand as a driver of decarbonisation of the pulp and paper industry.

> "To us at CEPI, it is obvious that we have to decarbonise our industry if we want to survive. At the same time, there are very clear side benefits of decarbonisation, which create both positive as well as negative incentives for us to develop new breakthrough technology for decreasing production emissions."[195]

De Galembert explains that producing paper is an energy-intensive production process and the EU paper and pulp industry has a strong need to decrease its energy consumption.

> "The high price of energy is one of the things making the EU paper industry less competitive than the rest of the world, so by de-energising we will save money and do good at the same time."[196]

De Galembert describes improvement of public image as a one of the key incentives for conducting the industry's key decarbonisation initiative, the TTP[197]. The paper industry has been negatively perceived in terms of sustainability during the past decades, due to critics amongst other towards deforestation as well as the usage of chlorine in the bleaching process.

> "We ourselves know that we are making great improvements, but the public opinion does not want to see beyond the scandals. Because of our tree consumption we are often judged as 'bad guys', no matter our efforts. It came to a point when we realised that working with sustainability was not enough, but that we also needed to start working with better communicating what we do to a wider public, and launching decarbonisation initiatives such as the TTP became a great combination of both."

According to de Galembert, CEPI's member organisations show strong trust in CEPI today, and all members are currently being mainly supportive towards CEPI's suggested initiatives. Despite the many budget cuts required due to the current financial situation, the members are no longer afraid to support CEPI's decarbonisation initiatives also financially. Having a clear vision of how to tackle the challenges ahead has managed to create a culture where all members have a feeling of being in the same boat.

[193] Nilson (2015).
[194] Ibid.
[195] De Galembert (2015).
[196] Ibid.
[197] The TTP is one of CEPI's main initiatives for innovation of decarbonising activities, which is further described in chapter 7 and in Appendix F.

Appendix F – Compilation of interview answers regarding Research question 4 – *WHAT does the industry do, in terms of innovation?*

F.1. Current decarbonisation activities

The EU steel industry has been involved in several emission-mitigating projects during the past decade. End of pipe-solutions, such as CCS and CCU, are continuously researched as well as the initial steps towards steel production through hydrogen reduction. An example from the German steel industry is an initiative for cross-sectorial collaboration, which organises regular meetings between stakeholders aiming to increase efficiency in CO_2-mitigation along the value chain. The current discussion is also focusing on reduction of iron ores with H_2.[198]

Buttiens says that the steel industry currently utilises all technologies available to improve its decarbonisation efforts. Still, the margins for improvement with known technologies is small and insufficient, and there is a strong need for further development.

> "Some experts say that the steel industry is not yet using the current technology to the fullest. I do not agree – the industry is already using all technology available, but there is still not sufficient technology to control the current emissions. Efforts for mitigation of indirect emissions could to some extent be improved, but the industry especially needs to drive the innovation process and to develop new breakthrough technologies, for by example recruiting talents."[199]

Buttiens emphasises the difficulty of measuring innovation and progress, primarily regarding breakthrough technology. Comparing innovation capacity between two companies that both use blast furnaces can be easy, but obstacles occur when you have to compare blast furnace steelmaking with steelmaking through DRI. An internal benchmarking system would be needed, in order to compare and evaluate a company's innovation potential.[200]

Peters and Morvannou, as well as other respondents, describe ULCOS as the most important project on process innovation for decarbonisation and emphasises that it remains the currently best main technological solution to process innovation in the long run.

F.1.1. ULCOS

ULCOS[201] is a consortium of 48 companies and organisations from 15 European countries, aiming to develop technology for reducing CO_2 emissions from steel production by at least 50%. The initiative was launched in 2004, and the main negotiations between the participants of the project took place in 2009.[202] In the beginning of the new millennium, when prospects of sustainable steel production were bleak, the ULCOS initiative revitalised the development process and gave new hope to the development. Contrary to previous initiative, ULCOS contained an increased focus on CO_2-mitigation rather than the old time's purely economic incentives.[203] The ULCOS consortium initially invested in different technologies in order to diversify the investment and widen the technological focus. Four technologies have proven to be most successful and are currently focus for further development; Ulcored, HIsarna, Top gas

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198 Lüngen (2015).
199 Buttiens (2015).
200 Ibid.
201 ULCOS stands for *Ultra-Low Carbon dioxide Steelmaking*.
202 ULCOS (2015b).
203 Buttiens (2015).

recycling blast furnace and Ulcowin.[204] Some of the underlying technologies behind the ULCOS projects had existed during a long time, but this was the first time industry joined forces in order to improve process development of the industry as a whole. The project was highly successful until year 2010, when market conditions changed partly due to falling CO_2-prices and an increased Chinese influence on the steel market.[205]

F.2. How great is the technological challenge?

Steelmaking today requires steelmaking through primary steel production, large plant sites and 7-8 production steps before the final product is produced. To be viable at the market, you would need a production capacity of at least 4 million ton steel/year.[206] Fundamentally, steel can only be produced through reduction of iron ore to iron. The high quantity of steel produced in the world requires high rate of reaction in the reduction of iron ore in the iron making process, in order to avoid building enormous plants. Several alternative processes steel making are then not competitive, since they cannot meet the high rate of reaction in today's blast furnace.[207]

Since the 1960s', industry actors have been working on trying to make this production chain leaner and to find a comparable alternative to the blast furnace, but have not yet succeeded. A lot of research on process innovation has been conducted, mainly focusing on making steel production more economically viable by making the production processes cheaper. However, years of historic misfortunates and crisis have limited the steel industry's ability to develop new processes, and the alternatives available today are still far from optimal.[208] Respondent E emphasises the fact that different geographic regions have different level of challenges ahead.

An important improvement of steel production could be the possibility to produce steel in fewer production steps. There may also be other potential solutions that are not carbon-based.[209] Lüngen emphasises the need for carbon in steel. Carbon in steel is needed for the strength of the product. Another advantage is that production with carbon in the metal allows for a decrease in temperature; pure iron requires 1536°C, whereas a carbon content of 4.8% in the hot metal decreases the liquid phase temperature to 1150°C.[210]

According to Respondent E, it is difficult to determine whether sufficient technology is already available for decarbonisation of the steel industry. What currently lie ahead are a number of different paths to develop from semi-industrial scale to full commercial scale (see section F.5), in order to further decarbonise during the upcoming decades. By combining these production methods with CCS or CCU it could be possible to reach reductions of at least 50-80% kilogram CO_2 per kilogram of reduced metal, compared to the emission levels of today.[211]

Nilson argues that the technology required for fulfilling the emission goals until 2050 is already available today. The obstacle is rather connected to cost-efficient supply of commodities to the extent that the industry requires.

[204] The HIsarna ironmaking process (2015).
[205] Respondent B (2015).
[206] Buttiens (2015).
[207] Nilson (2015).
[208] Buttiens (2015).
[209] Ibid.
[210] Lüngen (2015).
[211] Respondent E (2015).

"In order to fulfil the goals, steel producers must have either access to cheap electricity or the possibility of building CCS or CCU facilities next to their plants."[212]

F.2.1. Blast furnace

EU plants are modern compared to the rest of the world, and a blast furnace can produce from 100 ton to 5,5 million tonnes hot metal.[213] A lot can be done to achieve CO_2-emission mitigations in the blast furnace. Respondent E lists three main alternatives for CO_2 mitigation are available with today's technology:

- Exchange some of the coal or coke for biomass.
- Enrich the H_2 off-gases, for usage in other processes.
- Clean the CO_2 off-gases, for usage in other processes. An example is the ULCOS project called Top gas recycling blast furnace (see section F.2.1.1).[214]

F.2.1.1. ULCOS: Top gas recycling blast furnace

Top-gas recycling is the name of a process where CO_2 off-gases in a blast furnace are cleaned and reused in the furnace. Respondent E explains that this technique already exists in semi-industrial scale, and would need to be upgraded to full industrial scale as a next step. During a short period of time, ArcelorMittal was running an ULCOS project on Top gas recycling blast furnace at the company's plant site in Florange (France). The objective was to learn more about the real costs of such a project, and on how to operate with CCS. However, the financing of the project did not work out, and the project was prematurely cancelled in 2012.[215]

F.2.2. Arc furnace

Smaller steel producers that run arch furnaces instead of blast furnaces are somewhat better positioned to accomplish emission mitigations. By switching to green electricity in the arc furnace (instead of for example carbon-based energy sources), some emissions can be directly reduced.[216]

F.2.2.1. Direct Reduced Iron

Through DRI steel production, natural gas[217] is used as the reducing agent, instead of coke. Natural gas and off-gases from the production process are chemically converted in a reactor, creating H_2 and CO, working as a reducing gas in the steelmaking process. In DRI steel production the iron is never melted, but has a solid form during the chemical reaction process.

There are currently no hydrogen-based steel plants available in the world. Through collaborations between the steel industry and the plastics and chemical industry, H_2-prodction could be made a competitive process in the future, but a lot of issues still remain. One of the main challenges ahead is to generate a competitive process for steel production through H_2 usage.[218]

According to Respondent E, a switch from blast furnace to DRI will decrease the specific CO_2 emissions with 50%. In combination with the usage of green electricity the CO_2-emission mitigation possibilities will become substantial.[219] To date, two natural gas based DRI technologies, MIDrex and HYL, have appeared to be promising alternatives to the BF-BOF route. The ULCOS project ULCORED is another example of a DRI technology.

[212] Nilson (2015), translated from Swedish.
[213] Lüngen (2015).
[214] Respondent E (2015).
[215] Buttiens (2015).
[216] Peters (2015).
[217] Natural gas primarily contains methane (CH_4).
[218] Lüngen (2015).
[219] Respondent E (2015).

Lüngen says that the alternative theoretically available for decarbonisation today would be to replace iron ore reduction with CO by H_2. This alternative is however today still theoretical. The main issue regarding steel production through iron ore reduction with H_2 in direct reduction plants is whether it is possible to assure sustainable supply of energy and hydrogen. Hydrogen does not occur naturally on Earth, and has therefore to be created. Hence, a sustainable steel production through DRI would require production of H_2 without CO_2 emissions.[220]

There are some methodological problems with hydrogen-based steel production. One example is that there is a critical temperature during fine ore reduction with H_2 in fluidized beds when fine ores tend to stick and glue on the wall of the vessel. Another aspect is when reducing lumpy iron ores (pellets and lump ores) with H_2 in a single step shaft furnace the generation of water steam during the process, which inhibits the reduction of the iron ores. A lot of research remains before steel production through this process will be possible in industrial scale.[221]

F.2.3. The ULCOS HIsarna

Several respondents, including Respondent D and Respondent E, describe the HIsarna as the most active ULCOS project and one of the current technologies with most potential.

The HIsarna pilot plant is located at Tata Steel's plant site in Ijmuiden (The Netherlands) and is today capable of producing around 8 tonne of hot metal per hour, which is equivalent to approximately one cubic metre of liquid metal per hour. The project is currently about to enter its fifth campaign, which is connected to proving robust process stability and plant availability. This is a necessary stepping-stone to de-risk further scale up towards demonstration scale and commercial scale.[222]

The HIsarna's main contribution to CO_2-reduction occurs mainly through improved efficiency in the blast furnace, with reduced energy consumption and less CO_2 emissions as a direct effect. Another benefit is that the exhaust gases are 'pure' and ready to store through CCS.[223] The HIsarna off-gases have a very high CO_2-concentration (95-98%), which means that these gases are suitable for CCS.[224]

The HIsarna also optimizes the steel-making route by allowing an increased flexibility in raw materials and a high possibility for recycling of secondary raw materials as well as scrap. Furthermore, the technology offers economical benefits, such as reduced costs of operation and maintenance, as well as smaller unit sizes and increased flexibility in production. In practice, this means that several intermediate steps in ordinary blast furnace production can be left out. HIsarna uses pure oxygen instead of air and the process gas flow rate is therefor much smaller than that of a blast furnace. Furthermore, HIsarna eliminates the use of coke, sinter and/or pellets. Hence, the footprint of a HIsarna steelmaking plant would be significantly smaller than that of a blast furnace plant.[225]

The HIsarna development still has a long way to go, and it is uncertain whether the upscaling phase will be successful.[226] It will mainly be profitable to implement the HIsarna technology in

[220] Lüngen (2015).
[221] Ibid.
[222] Respondent B (2015).
[223] Buttiens (2015).
[224] Lüngen (2015).
[225] Respondent B (2015).
[226] Buttiens (2015).

construction of new steel plants, due to obstacles in implementing breakthrough technology during restorations.[227] Respondent B says that the technological challenge of the HIsarna may be manageable, and that the challenge rather lies in financing an upscaling of the project.

F.2.4. Electrolysis

According to Respondent E, steel production through electrolysis is still a somewhat futuristic dream, however not unrealistic. There is progress in the development, but the technology still only exists in laboratory scale. Examples of a project using electrolysis for steel production is the ULCOS project called ULCOWIN (or ULCOLYSIS).[228]

The electrolysis technology is extraordinary, since it produces iron completely without usage of carbon. The character of this iron is a little different from the iron produced through classical methods, since it is very hard, less sensitive to humidity and does not rust in the same way.[229] If steel production through electrolysis would turn out to be a successful production method, the produced steel would still have to be carbonised in order to maintain the strength of the steel.[230]

The development of steelmaking through electrolysis is currently progressing well, but the technology has one major disadvantage; the production is limited by the amount of square meters available instead of depending on the volume of a reactor. Hence, a production plant would have to cover large areas, and the electrolysis would therefore be more suitable for small-scale projects instead. [231]

F.2.5. CCU and CCS

Some respondents emphasise the opportunity in developing CCU and creating new business models through industrial symbiosis. Closer collaboration between the EU steel industry and other industries would create beneficial market opportunities and improve the EU's transition to a circular economy.

Also CSS is described as a possible opportunity to the EU steel industry. According to Buttiens, the biggest hurdles to overcome in CCS development are connected to market mechanisms. The risk of market dominance is often not considered in the CCS debate. CO_2-gases are hard to transport and not popular to the public, which means that storage ownership has to be taken into account. If there is only one owner of a CO_2-storage, then this storage owner can set the market price. The system would have to guarantee a fixed price, low enough for the storage to be economically viable to use.[232]

> "From the steel industry's perspective, it seems unrealistic that the manufacturing industry would ever be able to pay for the development of CCS. Considering the value and necessity of steel to our society today, CCS could be a valuable technology to use as long as the pricing is sufficient."[233]

Using CCS could be a way for the steel industry to 'buy time' and to mitigate emissions during the upcoming decades, until sufficient breakthrough technologies have been developed. The problem is that CCS would be a temporary solution to the steel industry, and the financial incentives to invest time and money in CCS development are therefore weak. If sufficient CCS

[227] Nilson (2015).
[228] Respondent E (2015).
[229] Buttiens (2015).
[230] Lüngen (2015).
[231] Buttiens (2015).
[232] Ibid.
[233] Ibid.

technology would already be available, it is likely that the steel industry would gladly invest in it, but given today's development challenges in the field of CCS it is unlikely that the steel industry will take a driving role in the development process.[234]

According to Peters, great effort has already been put into developing CCS as the main revolutionary development to the EU steel industry. However, today the political legislations are changing and several countries have instead decided to vote against the storage option, among them Germany. It is very important for the competitiveness of the European steel industry to follow several paths towards a low-carbon metallurgy. For instance, CCU is another promising approach.[235]

One of the main difficulties with CCS is connected to transportation of the CO_2. Peters suggests 'CCTS' as a more correct phrasing than 'CCS', where T would mean transportation. There is currently no solution to the issue of choosing a location for the storage facility, as well as transporting the CO_2-gas to that location. One possibility would be to build pipelines transporting CO_2-gas. This would constitute large one-off investment. Pipelines are also likely become a national issue as well as unpopular in public opinion. Alternatively CO_2 would have to be transported with current means of transportation, such as via rail or road, which would result in high costs and negative environmental impact due to large volumes. In order to overcome the transportation issue, the optimal scenario would be to have a CCS facility in direct proximity to a steel production plant. That, however, would require steel plants to be located where the conditions for both steel production and CCS are ideal, as well as building CCS facilities by every steel plant. CCU, on the other hand, offers solutions that do not rely on material transportation over long distances, as the re-use of carbon takes place in a plant close to the steel plant. Low energy prises together with fair regulations increase the opportunity for steel plants to also be a carbon provider for high-value chemicals or fuels.[236]

F.3. Investing in innovation

Most of the respondents emphasise that the steel industry will need a large amount of financial resources in order to improve decarbonisation efforts.

F.3.1. Technology Readiness Level

According to Respondent A, the development of breakthrough technologies in the EU steel industry is currently experiencing the first valley of death. The ULCOS project has successfully finalised its levels of knowledge development and is currently stuck in the first valley of death (around TRL 4). Substantial funding will be needed before the project can finalise the levels of technological development, including phases of demonstration and upscaling (at TRL 5-7). The blue cross in Figure 12 (see section 7.4.1) indicates the current development of breakthrough technology in the EU steel industry. Respondent A suggests that several EU funding schemes can be utilised in order to overcome the first valley of death, for example FP7 and SPIRE. At a later stage the EU steel industry could utilise more advanced EU funding schemes, such as the Innovation fund or the EU ETS, in order to overcome the second valley of death. [237]

F.3.2. Need for investments in breakthrough technology development

The respondents agree that there is a strong need for investments in breakthrough technology development. Existing technologies have already been improved and developed near its' maximal

[234] Respondent B (2015).
[235] Peters (2015).
[236] Ibid.
[237] Respondent A (2015).

ability, which means that the industry is currently in need of radical rather than incremental innovation. In order to develop process innovation in a large scale you need major investments in innovation.[238]

Respondent A explains that the EU currently needs to retain a rate of investment on around 3% of GDP to innovation, in order to remain competitive. Currently, only a few EU countries are reaching this level, whereas the remaining countries are far behind. The average part of GDP invested in innovation in EU is approximately 2%, whereas for example South Korea and Japan are investing 4-5%. In practice, this means that the EU is not making any major investments in innovations that can give revenue in the future, but is instead only making incremental improvements. Increased investments are essential in order to have a competitive European steel industry in the future.[239]

Respondent A emphasises the importance of investing in innovation, if the EU steel industry wants to remain competitive towards the rest of the world in the future. Innovation and development of new breakthrough technologies is essential, both for emission mitigation and to maintain European growth. Several EU funding schemes are in place, for financing innovative initiatives, which could be (and to some extent are) utilised by the steel industry (see section F.3.3). [240]

Respondent E describes lack of financial resources as the main obstacle to further development, since process development of steel production is extremely costly. A new process is not perceived as commercially viable and will not gain further investments until the cost of the new investment is lower than the operational costs today, which is one of the reasons behind the current lack of development.[241]

Companies in the EU do not make enough profit in order to further develop process innovation, and one of the main difficulties to overcome is connected to the lack of financial resources. Long investment cycles are barriers to development of breakthrough technologies. EU steel producers have already made huge investments in their existing plants with capital tied up for decades ahead. In the EU, transition to new technology would lead to no return of previous investments, in comparison to better growing regions where it would be easier to adapt new process innovations by constructing a completely new plant without wasting resources.[242] Many EU blast furnaces operating today were built or relined 10 to 20 years ago, which means that major restorations are likely to occur during the upcoming years. Since technology optimal for decarbonisation is not yet available, any major implementation of CO_2-mitigating processes will therefore probably not be conducted until yet another couple of decades from now.[243]

Peters stresses the importance of continuous development as one of the main recommendations to the EU steel industry.[244]

> "If the producers in the EU steel industry wants to continue to earn money, which they have to do in order to survive, then they have to have a continuous improvement process. Development step by step might not generate breakthrough technologies overnight, but is still very important."[245]

238 Respondent D (2015).
239 Respondent A (2015).
240 Ibid.
241 Respondent E (2015).
242 Peters (2015).
243 Lüngen (2015).
244 Peters (2015).
245 Ibid.

Morvannou uses the current crisis in the UK steel industry as an example of what harm lack of investment can do to the industry. Lack of investments during the past 20-30 years has led to that the UK steel industry is completely non-competitive today, and is currently closing numerous steel production activities and plants.[246] Morvannou emphasises the crucial need of investment if the EU steel industry should be able to decarbonise until 2050.

> "At the moment there is no clear solution to the decarbonisation problem, because there is no money. The EU steel industry is a highly capitalised industry, and without large investment there will be no possible progress towards decarbonisation."[247]

Respondent G says that there is a need for access to capital in order to improve continuous R&D, but also need for upfront payments available to install new technologies, which might not pay back until decades later.

> "One concrete action would be that they would develop a framework for how they can invest in green technology, to ensure that they have budget for R&D and access to capital at the right moment etc. In that case, even the green NGOs could be willing to support them."[248]

Respondent B emphasises the importance of developing the ULCOS project further.

> "We need to focus on developing this technology here in the EU, or else some other country will pick up the idea and outrun us. It is often easier to build new steel plants than to renovate old ones, and if we develop a breakthrough technology in the EU it is possible that we can see this technology implemented not only in the EU but also in Asia and Africa in the future. This should be seen as a great market opportunity and a way to decarbonise the industry."[249]

F.3.3. Utilisation of current funding schemes and financial instruments

Enabling access to capital, but more importantly the continuity of funding, is a crucial issue for European companies. Many different industries agree that in order to meet the EU decarbonisation goals, the industrial actors need to be guaranteed not only temporary investments but also financial support during a longer time period of ten years or more. More continuity in the financial support would lower the risk of an investment, and hence make it easier to acquire further funding also from external investors. However, the current financial instruments do not guarantee any regularity in the funding schemes, which further deters the possibility of granting funding from external investors. Respondent B argues that the current EU funding schemes are disadvantageous for capital-intensive decarbonisation projects, whereas other countries such as Japan have a national strategy for guaranteeing continuous funding during several years to similar project. One underlying reason is the difference in the decision-making process between a nation and a large union of nations. As a result, the EU risks failing to remain a competitive developer of process innovation in capital-intensive industries towards the rest of the world.[250]

[246] Morvannou (2015).
[247] Ibid.
[248] Respondent G (2015).
[249] Respondent B (2015).
[250] Ibid.

Respondent G emphasises the impact policy makers have in driving process innovation for decarbonisation. The steel industry needs 'green investments'[251] in order to reach the decarbonisation goals. Therefore, Respondent G says, public finance has to step in and earmark money for sustainable innovation.

A counterargument against the use of financial instruments as drivers of innovation is that companies without money are not able to innovate. Buttiens argues that the current system is starting in the wrong end, by initially making companies pay (for example through EU ETS) and then give them money back if they agree to do research (through for example NER300).

> "Research is something that wealthy companies are doing, not poor ones."[252]

NER300

Respondent D describes that the NER300 financing instrument was not optimally utilised, due to the lack of CCS technology available in the industry. To be able to benefit from this funding, the steel producer would need to have a project involving CCS. The obstacle was that since the market actors did not have the money or technology to develop running CCS-projects, the steel producers did not benefit from NER300 because they did not meet the requirements. Theoretically there was NER300 money available for the industry to innovate, but in practice no one could use it.[253]

The research fund for coal and steel (RFCS)

The RFCS is a fund created and owned by the industries to support research, and the fund is very well utilised by the industry.[254] A report evaluating ten years of RFCS, states that each euro initially invested in the fund created an accumulated benefit of fourteen euros in return.[255] However, the RFCS only contains approximately 50 million euro per year, which is not a lot of money in the context of process innovation.[256]

RFCS may not generate enough financial support to foster breakthrough technologies, but is an important asset in order to keep performance levels continuously high.[257]

The Investment plan and EFSI

Respondent D is positive to the potential of the EU Investment plan, which includes the European Fund for Strategic Investments (EFSI), and says that it could be very beneficial to the industry if the steel producers do their best to utilise it. An example is the Italian steel producer Arvedi, who received money from the Investment plan for their Modernisation programme.[258]

The EU ETS

The EU ETS is a financial instrument which is currently in it's 3rd phase, lasting from 2013 to 2020. In the past years, the industry has taken a clear advantage of the EU ETS allowances, Respondent D explains.

> "During the past years, the steel industry has produced less than it did during its' pre-crisis prime years. Still, the industry has been using data from the productive years to receive allowances for high emission-levels, even when they in fact produced much

251 The term 'green investments' refers to socially responsible investments in environmentally conscious business practices.
252 Buttiens (2015).
253 Respondent D (2015).
254 RFCS (2015).
255 Schneider, W. (2015).
256 Respondent D (2015).
257 Peters (2015).
258 The Investment Plan for Europe (2015), pp. 2.

> less. It has therefore been possible for steel producers to make a profit on selling CO_2-allowances, without any real contribution to decarbonisation. In the next phase, the EU ETS will have been developed with more accurate production levels, and it will hence be harder for the industry to abuse it."[259]

One key recommendation to the EU steel industry is to start considering the EU ETS as an opportunity, not as a threat. Respondent A suggests that in ten to fifteen years from now, there will be a system or several systems for carbon pricing all over the world. China is expected to launch a Chinese carbon pricing system during year 2016, and in the future it will be common practice to cut CO_2 emissions everywhere possible. If the EU steel industry decides to be a forerunner in the process they will have the opportunity to gain ten years of experience ahead of their competitors in other parts of the world, in terms of understanding how a carbon pricing system affects production patterns, specialisations and affects incentives to invest etc.[260]

> "The European Commission has made a study on EU ETS' effects on investments, showing that EU ETS so far has helped companies finding out where it is feasible to invest. According to the study, companies have also been able to use EU ETS as a tool for development of their own internal processes."[261]

The steel producers often argue that they do not have the resources available for innovation. As a response to this, Respondent A says that if a company of the magnitude as the main EU steel producers really wants to invest, they will find a way to invest even with limited resources. According to Morvannou, one of the main recommendations that has been directed to the EU steel industry during the past decade has been to implement an obligation to reinvest profit gained from sold emission allowances into decarbonising activities.

> "The steel industry is currently experiencing the biggest crisis in the industry since the end of the Second World War. Yet, today the industry can sell emission allowances and earn money ends up in the stakeholders' pockets, instead of being reinvested in decarbonisation activities."[262]

Issues with the EU ETS

From the perspective of steel producers, the EU ETS is developed in an unfavourable way for manufacturing industries. The emission allowances are adjusted towards energy production, where decarbonisation is far more concrete than in the field of materials production. Also, the EU ETS measures direct emission, whereas indirect emissions also can have a significant effect on the overall environmental impact. The four main manufacturing industries affected by this directive are the ones with the largest quantity of final goods produced per year; cement, steel, wood and plastics. The objective of these materials is mainly to provide food, shelter and mobility, which are areas that are likely to see an increased worldwide demand during the upcoming decades.[263]

F.4. Benchmark: The Two Team Project

In this section, some lessons learned from CEPI's initiatives for innovation through breakthrough decarbonisation technologies are described.

259 Respondent D (2015).
260 Respondent A (2015).
261 Ibid.
262 Morvannou (2015).
263 Buttiens (2015).

F.4.1. Achieving the goals for 2050

According to de Galembert, the mitigation goals for 2050 are challenging to meet, but CEPI remains optimistic and considers the goals achievable. In their own roadmap, CEPI has made a double commitment of not only mitigating emissions but also increase delivered value. The aim is to achieve this by combined efforts, such as producing paper differently, making paper a solution rather than just a product and by developing the paper mill. CEPI's strategy for decarbonisation is based on three pillars, each of them summarised in a document:

- *The roadmap for 2050*, developing the goals and sets the ambition level.
- *The Two Team Project Report*, focusing on 80% CO_2 mitigation.
- The innovation brochure *"The age of fibre",* focusing on how to increase value with 50%.[264]

The Two Team Project in short

When the EC roadmap was announced, CEPI was facing a choice between trying to lobby against the goals or to embrace the extensive changes it suggested. They chose the latter, and instead of awaiting further directives CEPI decided to step forward and initiate their own roadmap with goals even more ambitions than the ones suggested in by the EC. In 2012 CEPI launched the roadmap for decarbonisation of the paper and pulp industry, stating that the paper and pulp industry has to achieve CO_2 emission reductions with 80% until year 2050, while at the same time creating 50% more value. It also concludes that breakthrough technology has to play a key role in achieving such progress. Due to long setup times in the industry, the roadmap argues that these breakthrough technologies need to be available already by 2030.[265]

"To implement the Roadmap and deploy new technologies, the sector has 10 years to think (research), 10 years to test, 10 years to build and 10 years to run and optimise the new technologies. Breakthrough technologies therefore have to become available by 2030 if they are to be online for 2050."[266]

In order to identify such breakthrough technologies, CEPI launched a project in form of a challenge, where two teams of experts were set to compete against each other in developing the best concept for improving paper- and pulp production. Part of the challenge was an open innovation challenge (crowdsourcing) to which the public was invited to submit ideas, but the main part of the project were the seven team meetings, held in an inspirational environment to foster creative discussions and concept development. Each team contained approximately 15 persons participating on voluntary basis from completely different fields, from academia as well as from different industries, with or without any deeper knowledge in pulp- and paper production.[267]

The project was launched in December 2012, and the teams presented their final reports in September 2013, listing eight new concepts for breakthrough technologies. There was no real reward for the winning team, and the real winner of the competition is said to be the pulp and paper industry in itself. Several of the technologies are currently under development as a direct outcome of the project.[268]

An idea initially met with scepticism

First and foremost, CEPI saw the TTP as an opportunity to reduce costs, explore new markets and reduce CO_2 emissions. Like most industry organisations CEPI has no decision-making

[264] De Galembert (2015).
[265] The Two Team Project (2013), pp. 2.
[266] The Two Team Project (2013), pp. 9.
[267] The Two Team Project (2013), pp. 14.
[268] The Two Team Project (2013), pp. 11.

power of its own, and the underlying idea of the TTP was developed by CEPI and presented to CEPI's board for approval. The board is composed of CEO's and chairmen of the member organisations, and the proposal was initially met with scepticism. However, the board accepted the initiative on the condition that it would not require any large financial contributions and that the ordinary agenda of CEPI would not be disturbed.[269]

De Galembert describes this initial scepticism as a result of not having had any clear long-term commitment to innovation at the time. The paper industry had implemented several minor incremental improvements during the past decades, but before TTP the last breakthrough technology in the industry occurred around 20 years ago, with the introduction of the shoe press.

> "The weak enthusiasm of the board was 'a stone in the shoe', giving us an incentive to deliver great results. Later, the attitude among the board changed completely when we presented the outcome of the TTP, and today they demonstrate great trust in CEPI and are highly supportive towards our decarbonisation initiatives."

Process

The TTP teams had seven meetings at different locations across the EU, which were all related to sustainability, but not necessarily to pulp- or paper production. Both innovation and applicability was considered during the development process, and two milestones were used – year 2030 and year 2050.[270]

Technological outcome of the TTP project

Out of the eight developed TTP concepts, five has now led to emergency patents, since these concepts were considered to be so disruptive in their nature that they needed to get a patent. During the first year, CEPI was licencing the concepts to members, in order to make the development available exclusively to CEPI members before it was released also to external actors. CEPI has hosted several partnering events, in order to support the members in forming consortia or applying for funding from the EU. The concept *Superheated Steam Drying* is an example of a TTP concept that has resulted in a consortium.[271]

Political outcome of the TTP project

According to de Galembert, the TTP did not only result in actual technologies but also had a positive side effect of more political nature. The TTP increased CEPI's possibility to lobby towards EU policy makers, and also created awareness of CEPI's sustainability work among external stakeholders. Since the TTP, the relations between CEPI and the EU policy makers have been strengthened, and de Galembert emphasises the value of working together with rather than against political decision makers, since it can have several important side benefits affecting also other relevant issues.

Implementation of TTP breakthrough technologies

De Galembert says that the implementation of the TTP projects indeed will be very costly – in comparison, a paper machine costs about half a billion euro. It is clear that in order to implement the new breakthrough technologies, massive investments will be needed. However, de Galembert emphasises that current emissions also do have a cost, which means that by saving energy and decreasing emissions there will be a financial gain in the end, even though the initial phase might be perceived as the more costly alternative.

[269] De Galembert (2015).
[270] The Two Team Project (2013), pp. 14.
[271] De Galembert (2015).

F.4.2. Key success factors of the TTP

De Galembert believes that the TTP concept can be applied also within other industries, among them the steel industry. De Galembert emphasises that the TTP was the first project of it's kind, which makes it hard to measure the key outcomes in comparison to other initiatives. However, some of the key success factors are listed below.

Stakeholder involvement

According to de Galembert, one crucial takeaway from the project was to bring in competences from outside the natural network sphere and involve them in the process. Involving people from outside the inner circle of CEPI, such as chemical industry, mineral suppliers, universities and technical suppliers, was a clear success factor and provided input that would otherwise not have been accessible. Involving committed people who were willing to think outside the box was a key success factor during the process. All team members participated on voluntary basis, motivated by the notion that they would benefit from the project in terms of knowledge, inspiration or by developing their network.[272]

Mixed groups are the most prosperous

De Galembert says that an important lesson learned was the prosperity in not creating regional working groups, but to instead mix people from all across the EU and make them work together. In order to foster regional diversity, the participants were teamed up with people from other regions, putting them outside their comfort zone and forced to work in a new context. All meetings took place at locations that were outside the participants' everyday environment, in order to inspire them to think outside the box, de Galembert explains.

Long-term work more beneficial

A lot of initial discussions could have been avoided if CEPI would have had the members onboard already from the start. In the long run, sustainable innovation projects such as the TTP can have a more friction-free start if the members are well prepared on the scope of the project, for example through long-term commitment to decarbonisation.[273]

Mindset is everything

The TTP report suggests that the largest breakthroughs happen in our minds.

> *"The teams' discussions gave rise to a vision on how the sector will need to adapt to benefit from the breakthrough concepts. But the adaptations entail not so much a series of technological breakthroughs as a breakthrough in mindset."*[274]

De Galembert suggests willingness as one of the core ingredients of a successful project. Having endorsement from all stakeholders (both CEPI's members and the project team members), and making sure in advance that all persons involved are aware of the rules, are key success factors for any such project, de Galembert explains.

Innovation does not have to be costly

The final cost for the Two Team Project was approximately €200 000. Around one third of the total cost was allocated to development of legal documents such as licences and non-disclosure agreements, de Galembert explains. The actual meetings and innovative sessions did not require significant amount of financial assets, and all team members participated on a voluntary basis.[275] According to de Galembert, the team members all felt that they would get benefits through their

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[272] De Galembert (2015).
[273] Ibid.
[274] The Two Team Project (2013), pp. 14.
[275] De Galembert (2015).

participation, in terms of knowledge, inspiration and networks, and that was incentive enough for them to join the team.

Remember that people count

De Galembert emphasises that all innovation origins from human beings.

> "Innovation is nothing abstract, but in fact the result of people's wishes and ideas. You need an enabling environment for your staff or stakeholders to promote innovation within your organisation."[276]

F.5. Forecast and improvements

In this section, the respondents' thoughts on forecasts and possible improvements in the EU steel industry are described.

F.5.1. Year 2015 and the lack of predictability

The EU steel industry is currently undergoing a phase of heavy political uncertainty, which makes it difficult for industrial decision makers to plan ahead and make major investment decisions. The EU institutions are currently making amendments to the proposal on the new EU ETS, and hence the industry has no predictability of how much they will have to pay for emission allowances after year 2020. The details of several funding schemes, such as the Innovation fund, NER400 and the Modernisation fund, require a couple of more years before all details have been established by the EU institutions, which further increases the uncertainty for the industry with regards to access to funding. Since it is a matter of billions of dollars at stake, the impact these decisions will have on the industry cannot be neglected.[277]

The EU is expecting a future lower demand at the home market than other regions are, since has EU is already developed railroads and buildings. Hence, future demand is likely to come from outside the EU and foreign trade will play an essential role to the industry.[278] The development of Chinese steel production is currently hard to predict, and will have a substantial effect on the development of the EU steel industry's future market share. The Chinese market can be expected to develop drastically during the upcoming five to ten years, but the direction remains unclear, as is the introduction of a Chinese emission trading system.[279] Respondent B explains that the unpredictable CO_2-pricing and taxation makes circumstances hard for steel producers. The respondent suggests that policy makers should focus not only on making more money available to process innovation initiatives, but especially on creating better conditions for steel producers to wisely spend their money, for example through improving the speed of decision making.[280]

The key limitation for development of breakthrough technology is risk. All actors are waiting for someone else to take the first step, so the others can follow and learn, but nobody is willing to take the risk. These high-risk process innovation projects, such as the ULCOS projects, must be supported in order to balance risk so that the benefits outweigh the risks.[281]

F.5.2. Are the goals for 2050 possible to achieve?

The steel industry is one of the EU industries where progress in decarbonisation efforts could have a substantial effect on the environment. At the same time, it will be a substantial challenge

[276] De Galembert (2015).
[277] Respondent D (2015).
[278] Respondent A (2015).
[279] Morvannou (2015).
[280] Respondent B (2015).
[281] Respondent B (2015).

for the EU steel industry to look into meaningful emission reductions. Morvannou says that decarbonisation of the EU steel industry is a very challenging task, and that the industry would need either huge investments or completely new breakthrough technology in order to significantly improve the emission levels. Respondent G says that in order to further develop, the steel industry needs to look into potential improvements within three main areas; **technological** development, **innovation** and the ability to **finance** actions for decarbonisation. There is not yet any confidence in the sector that such solutions will be available to them any time soon.[282]

The steel industry is already working on solving issues such as 'what technology is available today?' and 'what technology will be available in the future?'. However, the very nature of steelmaking as we know it today involves producing CO_2, due to the chemical reactions in the process. The industry has therefore chosen to focus mainly on the step in the production process where most emissions occur – in the blast furnace, where iron oxide is reduced to iron. Respondent D believes it is a good priority to focus on this part of the process since this is where there is a lot of room for emission mitigations, but also says that unfortunately improvements only in the blast furnace will not be enough in order to reach the current goals for 2050.

> "The steel industry has already done almost everything that could be done with current technologies, and it could therefore be a good priority for the industry to focus on developing the HIsarna at this moment. The problem is that in order to be commercially viable the HIsarna would need another 20 years of development, and the industry would therefore not be ready to meet the goals until 2050."[283]

At best, Respondent D believes in emission reductions of 30-40% until 2050.

Respondent A estimates that a realistic estimation would be at least 40-65% emission reductions until year 2050. The industry often states that without CCS the opportunities to decarbonise are very limited, but Respondent A estimates that the implementation of any kind of breakthrough technology would be likely decrease CO_2 emissions with around 17%. Respondent A describes the EU steel industry as 'pessimistic' regarding the timeframe, since the industry often claims that 2050 is too soon to allow any major changes. Meanwhile, research at the *Institute for Energy and Transport, Joint Research Centre in Petten (Netherlands)*, suggests that the breakthrough technology needed for decarbonisation could arrive up to twenty years earlier than suggested by EUROFER. The research also suggests, the expected implementation of these breakthrough technologies could be implemented twenty to thirty years earlier than suggested. One suggested explanation to this could be that EUROFER's roadmap is not bold enough to be progressive, and that EUROFER has been using early research for justification of its arguments in the decarbonisation debate.[284]

Nilson is positive that there will be a solution to the current decarbonisation issues, and says that it is just a matter of time until someone comes up with a new solution. However, Nilson argues that the goals could only be reached until year 2050 either through access to a large amount of cheap electricity for H_2 production and thereafter steel production through DRI, or the possibility to build CCS/CCU. Here, Nilson sees a strong need for political support, in order to enable such development.

Respondent E argues that it will be hard to reach the goals of 80% emission mitigation, since that would require a substantial need of improvements in terms of process development, material replacements etc. Yet, Respondent E remains positive and expresses a wish to work towards reaching the goal, but is not completely convinced. It is possible that several new processes will

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282 Respondent G (2015).
283 Respondent D (2015).
284 Respondent A (2015).

be developed until 2050, which could have a great impact on emission mitigations when they have been implemented. If some of the technologies currently investigated could be combined with CCU/CCS, CO_2-emission reductions of 50-80% [kg CO_2/kg reduced metal] could be possible.[285]

Lüngen describes a total emission reduction of 80% until year 2050 by the steel industry as absolutely impossible. There is no credible indication of how long time it would take to develop sufficient processes, and it would therefore be useless to make forecasts or promises that the industry will not be able to keep. Lüngen also emphasises the fact that it is impossible to make steel production completely free from CO_2 emissions. However, Lüngen stresses that the industry is currently working in full force on CO_2-mitigation efforts and that the past years' research has generated substantial progress in the field of decarbonisation.[286]

Buttiens believes that the steel industry will eventually be decarbonised, but emphasises that technological development, rather than financial instruments, will be playing a key role in the development process.[287]

For fulfilling the emission goals until 2050, Buttiens, among other respondents, describes ULCOS as the most credible breakthrough initiative today. The obstacle is that the timeframe is highly dependent on the development of CCS. It is still unclear whether CCS will ever become economically viable, and in if it in that case will be developed and deployed on time to meet the goals.[288]

F.5.3. The role of scrap in the future

Today, the arc furnace can produce steel made from 100% scrap as feedstock.[289] Respondent E believes it is important to initiate a discussion within the industry about the future role of scrap in steel production. 85-90% of available scrap is already being reused, but as of today there is not enough metal circulating to meet the world demand for steel. Scrap currently accounts for around 30% of the worldwide steel production.[290]

European buildings made from steel have a lifetime or around 40 years, which means that it takes approximately 40 years to circulate scrap back to production. The demand for iron ore can therefore be expected to peak in some decades from now, and will thereafter decline when more scrap is available on the market. Year 2090 the world is expected to have filled its demand of iron ore-based steel production, and be completely available to close the loop.[291]

Nilson urges EU steel producers to seize the opportunity of steel production from scrap. During the upcoming decades an extensive development of steel-based infrastructure can be expected in India and large regions of Africa. European steel producers are competitive in producing steel with high scrap content, whereas Chinese production is around 90% based on iron ore. Here, EU steel producers have a chance to develop a closed-loop economy through the usage of scrap.[292]

One proposed solution to the difficulty of decarbonisation has been to phase out blast furnace and only produce steel from scrap in arc furnace. This would lead to significant CO_2-mitigations,

[285] Respondent E (2015).
[286] Lüngen (2015).
[287] Buttiens (2015).
[288] Ibid.
[289] Respondent B (2015).
[290] Respondent E (2015).
[291] Nilson (2015).
[292] Ibid.

but has limitations both in terms of quantity, as there is not enough steel scrap available, and in terms of quality of the produced steel. With today's technology, steel produced from old scrap products can be used in for example buildings, but smaller steel slips with high quality requirements cannot be produced from scrap, based on the current level of knowledge and technological capabilities.[293]

F.5.4. Steel as an enabler of emission mitigations

There are several positive side effects from decarbonisation of steel products. Improved efficiency and quality of steel products can lead to reduced emissions further down the value chain. Hence, there might not be a direct emission reduction in the steel production process, but the overall emission throughout the product lifecycle may be improved.[294] Respondent E, as well as other respondents, emphasises the fact that improvements in the steel industry have a secondary effect on the environment through emission mitigating effects. Decreased weight of vehicles could reduce emissions with 20%, which would have the same effect as cancelling every fifth trip. In the end, it adds up to a significant amount of CO_2 saved, Respondent E says.

F.5.5. Quality of raw material

An important aspect of steel production is the access to high-quality raw materials. In order to assure a high quality steel product, the right resources need to be available.[295] Nilson suggests an improvement of the value chain, moving the responsibility upstream in the value chain from the steel producers to the iron mining company. The more oxygen the iron ore contains, the more coal (or other reducing agent) is needed. Hence, one could argue that a change in the value chain could add value to the process. The reason for this is that the downstream steel customer is not willing to pay for an upstream refinement, and the steel producer might hence be less inclined to improve the efficiency of the reduction process.[296]

> "Imagine that the mining companies instead refined the iron ore, before selling it to the steel producer. The mining company would then sell a refined product with added value for the customers, and could hence require a higher price for the product. In this case, it would be in the interest of the mining company to improve production efficiency and let the customer pay part of the cost of emission mitigation. In the current system however, the steel producer does not earn any money on an actual emission reduction and is thus less inclined to improve decarbonisation efforts."[297]

293 Morvannou (2015).
294 Respondent B (2015).
295 Respondent D (2015).
296 Nilson (2015).
297 Nilson (2015), translated from Swedish.