Consumer-facing companies contributing to decarbonize the heavy-industry

How and to what extend demand of consumer-facing companies could incentivize a hydrogen-based decarbonization in heavy-industries

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Preface

'A rising global population and rising standards of living should continue to drive growth in demand for energy for decades to come.'

'At the same time, there is a transition under way to a lower-carbon energy system with increasing customer choice and potential price volatility.'

- Ben van Beurden, CEO Royal Dutch Shell

This master thesis is part of the graduation requirements of the master program Complex System Engineering & Management, part of the faculty of Technology, Policy & Management, at the Delft University of Technology (TU Delft). The hosting company was the Royal Dutch Shell, the oil & gas corporate who is at the edge of a large scale transition towards renewable energies. A full-time internship in the hydrogen strategy team was provided to ensure the full experience of the hosting company as well as knowledge sharing between the university and Shell. The strategy team was looking into future opportunities in the energy mix and identifies sectors where hydrogen may develop. For companies like Shell, long term strategies are of importance to keep up with developments and to act on-demand requirements to stay competitive while decreasing global footprint.

It was a great experience and honour to be working with many bright minds at Shell who actually want to initiate a change in the energy transition. In my perception, corporates like these should be the key players to transition rather than only focus on government initiatives. Though some might accuse that big evil corporations focus too much only on making money, the validity of the business case is a must as well. If not, these key players would run out of money and the possibility to contribute to the goal vanishes.

Transitions require those in power to stand up and show where the majority should be led towards.

Executive summary

Hydrogen can replace unsustainable raw materials in new applications where heating and chemical processes currently use fossil fuels. As prices of conventional techniques are often lower than hydrogen-based solutions, other forces should encourage hydrogen implementation. For the heavy industry to use hydrogen as a decarbonization technique, the downstream users of products might work as a driving force to implement hydrogen upstream. The research looked into (1) the past mechanisms used by consumer-facing companies (CFCs) to incentivize supply chains to decarbonize. (2) Supply chain analysis of hard-to-abate industries holding the highest potential to be decarbonized by hydrogen. To this end, the research question had been formulated as: *What probable impact can consumer-facing companies have on industry's hydrogen-based decarbonization?* The hypothesis was that the final consumer would be willing to pay more for a green product which drives CFCs to initiate decarbonization in the upstream value chain.

From the supply chain analysis, consumer-facing sectors could be identified which use the products and commodities from the upstream industry. These consumer-facing sectors were interviewed to gain an understanding in consumer's changing demands, which could be drivers for CFCs to use decarbonized, hydrogen-based, products. The combination of both the mechanism identification and value chain analysis resulted in the discussion of mechanism application on hydrogen-based decarbonization.

Results

Steel industries show the highest potential to implement hydrogen-based decarbonization, partly through a demand-pull incentive from CFC. Through a model, steel production prices are calculated for each production route. By using carbon-neutral steel, carbon emissions from an average vehicle could be reduced by 29% against a final price increase of 1%. Interviews with steel producers have shown that current CFCs are already demanding the steel industry to transition on the long term. To be ahead of the competition, CFCs could try to incentivize the steel industry to do so even earlier on and play an active role in their decarbonization. Still, not all interviewed CFCs show to be willing to do so, some perceive the carbon-neutrality of steel not to increase the value of the final product.

Ammonia production shows to be the most promising industry to be driven to convert its existing hydrogen demand into sustainable hydrogen. This industry is somewhat able to be influenced by a changing downstream product requirement. The main reason to drive transition is likely to be related to regulations within the farming industry. Individual farmers, the buyers of the fertilizer, do not experience much pressure to initiate change in their current production processes. The main pull could possibly come from larger cooperations of farmers, provided they jointly want to act on decarbonization of their fertilizers.

Refineries turned out not to be an attractive case for the hypothesis. The main issue is the relatively low achieved decarbonization (only 3% decrease) if the grey hydrogen would be replaced by green hydrogen. Hence, the final product would not adequately be differentiated. Besides, interviews have shown that past incentives have not indicated consumer's willingness to pay for a carbon-neutral product. Shell provided its consumers with the option to offset carbon emissions from gasoline bought by paying a premium for nature-based solutions. Rarely consumers would use this option.

Methanol could, like with steel and ammonia, considerably be decarbonized through sustainable hydrogen. The value chain analysis though shows that the application of methanol instead is in industrial processes where the commodity is used as raw material. The CFC-based hypothesis will not hold as methanol is only a fraction of the raw materials used in the final downstream product and does not allow for enough decarbonization of the consumer's product.

Implication of results

The main research question is answered through value chain analyses alongside a qualitative assessment of mechanisms that could potentially affect hydrogen-based decarbonization. Though transition will depend on much more factors, part of risks can and should be solved by the value chain. Business model innovation, industry & sector level collaboration, and industry & market standards are considered to have the highest potential among mechanisms to reduce risks in transitioning the upstream industry.

The combination of both the clean product wishes, as well as the mechanisms are given, provide opportunities for downstream and upstream to work together on solving the issue. The full costs of upstream price increase can not be bared through the CFCs on their own. Rather, part of the solution on how to decarbonize the heavy industry can come from CFCs participating in stimulating mechanisms. The three mechanisms holding the largest opportunity to initiate a hydrogen-based decarbonization approach the problem as a complex issue where stakeholders from different levels are involved. These mechanisms transform the business model by not solely relying on the stakeholder upstream to change production but rather look at how downstream acts as well and creates value by doing so. Instead, a differentiation of the final downstream product is a possibility to gain additional value to support and finance costs from decarbonization.

Contents

1 Research introduction **1**
1.1 Introduction to the energy problem . . . 1
1.1.1 Hydrogen, the energy carrier . . . 1
1.1.2 Uncertainty about a hydrogen future . . . 1
1.2 Literature research on hydrogen as energy carrier . . . 2
1.2.1 Technical aspect of hydrogen production . . . 3
1.2.2 Scoping down on continental boundaries and demand sectors . . . 4
1.3 Literature research towards hydrogen in the heavy industry . . . 4
1.3.1 Scientific research on mechanisms to decarbonize the heavy industry . . . 5
1.3.2 Green supply chains . . . 6
1.3.3 Conclusion on literature about incentivized supply chain decarbonization . . . 7
1.4 Knowledge gaps identified . . . 8
1.5 Research question . . . 9
1.6 Scope and research approach . . . 9
1.6.1 Scope . . . 9
1.6.2 Research question approach . . . 10
1.6.3 Research methods and sub-questions . . . 10
1.7 Research flow diagram . . . 12

2 Industries transitioning **14**
2.1 Scientific methods used to research mechanisms . . . 14
2.2 Consumer-facing companies reducing emissions in value chains . . . 15
2.2.1 Value chain initiative: Walmart . . . 15
2.2.2 Value chain initiative: Mars . . . 15
2.3 Consumer-facing companies pushing for green power purchasing in value chains . . . 16
2.3.1 IKEA: Suppliers Go Renewable project . . . 16
2.3.2 Apple: Supplier Clean Energy Program . . . 17
2.3.3 Other programs . . . 18
2.4 Consumer-facing companies changing product requirements in value chains . . . 18
2.4.1 Timber certification . . . 18
2.4.2 Renewable power Guarantee of Origin . . . 19
2.5 How to drive transition in a value chain . . . 19
2.6 Mechanism availability for consumer-facing companies to change the value chain . . . 20
2.6.1 Mechanisms . . . 20
2.6.2 Determining mechanism applicability . . . 21

3 Structure of sectoral analysis **23**
3.1 Value chains . . . 23
3.1.1 Technical analysis . . . 23
3.1.2 Stakeholder analysis . . . 23
3.2 Interviews . . . 25
3.2.1 Upstream interviews . . . 26
3.2.2 Downstream interviews . . . 26

4 Supply & demand **27**
4.1 Supply . . . 27
4.1.1 Grey hydrogen . . . 27
4.1.2 Blue hydrogen . . . 27
4.1.3 Green hydrogen . . . 27
4.1.4 Overview hydrogen supply . . . 28
4.2 Hydrogen within demand sectors . . . 28

4.3 Introducing hydrogen to the heavy industry 30

5 Hydrogen within heavy industry 31
5.1 Defining value applications for hydrogen 31
5.2 Iron and steel 32
5.2.1 Current state of the art production methods 32
5.2.2 Market trends in Iron & Steel 34
5.2.3 Hydrogen implementation 34
5.3 Oil refinery 35
5.3.1 Current state of the art production methods 35
5.3.2 Market trends in refinery markets 35
5.3.3 Hydrogen implementation 36
5.4 Chemicals - ammonia 36
5.4.1 Current state of the art production methods 36
5.4.2 Market trends in ammonia 37
5.4.3 Hydrogen implementation 37
5.5 Chemicals - methanol 38
5.5.1 Current production methods 38
5.5.2 Market trends in methanol 38
5.5.3 Hydrogen implementation 38
5.6 Introducing value chain analyses 39

6 Value-chain analysis Steel 40
6.1 The steel chain 40
6.1.1 Consumer-facing segment: construction 41
6.1.2 Consumer-facing segment: automotive and the importance of OEMs 41
6.2 Technical analysis 41
6.2.1 Price of carbon-neutral steel 41
6.2.2 Construction 42
6.2.3 Automotive 42
6.3 Output from upstream interviews 43
6.3.1 Changing requirements from consumer-facing companies 43
6.3.2 Hydrogen-based DRI prospects 44
6.4 Background into downstream companies 44
6.4.1 BAM Group 44
6.4.2 Boskalis 44
6.4.3 Fiat Chrysler Automobiles 44
6.5 Stakeholder analysis 45
6.6 Output from construction interviews 46
6.6.1 Steel differentiation 46
6.6.2 Valuation of green steel 46
6.7 Output from automotive interview 47
6.8 Industry sum up 48

7 Value-chain analysis Refineries 49
7.1 The refinery chain 49
7.1.1 B2B channels 50
7.1.2 B2C channels 50
7.2 Technical analysis 50
7.3 Background into Shell 50
7.4 Stakeholder analysis 51
7.5 Output from interviews 52
7.6 Industry sum up 53

8 Value-chain analysis Ammonia **54**
8.1 The Ammonia chain . . . 54
8.2 Technical analysis . . . 55
8.3 Output from upstream interviews . . . 55
8.4 Background into downstream companies . . . 57
8.4.1 Lantmännen . . . 57
8.5 Stakeholder analysis . . . 57
8.6 Output from fertilizer interviews . . . 57
8.7 Industry sum up . . . 58

9 Value-chain analysis Methanol **60**
9.1 The Methanol chain . . . 60
9.2 Output from upstream interview . . . 60
9.3 Stakeholder and technical analysis . . . 62
9.4 Output from downstream interview . . . 62
9.5 Industry sum up . . . 62

10 The drive of CFCs to decarbonize industries **63**

11 Applicability of mechanisms on a hydrogen-based decarbonization **65**
11.1 Requirements for CFC mechanisms to drive an EU hydrogen transition . . . 65
11.1.1 Traceability of hydrogen . . . 65
11.1.2 Standardization of scope 3 emission methods . . . 65
11.2 Mechanism applicability on a hydrogen transition . . . 66
11.2.1 Industry and market standards . . . 66
11.2.2 Collaborative innovation . . . 67
11.2.3 Supply chain optimization . . . 67
11.2.4 Business model innovation . . . 67
11.2.5 Performance standards and incentives . . . 67
11.2.6 Product design . . . 68
11.2.7 Industry and sector-level collaboration . . . 68
11.2.8 Supplier development and collaboration . . . 68
11.3 Conclusions on mechanisms . . . 69

12 The steel industry's decarbonization driven by mechanisms **70**
12.1 Motivation for CFCs to implement mechanisms . . . 70
12.1.1 Construction . . . 70
12.1.2 Automotive . . . 71
12.2 Driving the demanded transition through mechanisms . . . 72
12.2.1 Industry and market standards . . . 72
12.2.2 Business model innovation . . . 73
12.2.3 Industry and sector-level collaboration . . . 73
12.2.4 Performance standards . . . 74
12.3 Conclusion on drivers to decarbonize alongside mechanisms . . . 74

13 Discussion **75**
13.1 Scientific contribution . . . 75
13.2 Societal value . . . 76
13.3 Reflection on research method . . . 77
13.4 General shortcomings to the research . . . 78

14 Conclusion **80**
14.1 General recommendations 81
14.2 Recommendations towards Shell 82
14.3 Future research 82

15 Bibliography **84**
15.1 Appendix I - Hydrogen demand scenarios 93
15.2 Appendix II - Governmental policies to decarbonize industries 94
15.3 Appendix III - Examples of renewable power incentives 97
15.4 Appendix IV - Interview one-pager 98
15.5 Appendix V - Grey Hydrogen 99
15.6 Appendix VI - Competitiveness of Green Hydrogen 100
15.7 Appendix VII - Details on market trends 101
15.7.1 Iron & steel 101
15.7.2 Refineries 101
15.7.3 Ammonia 101
15.8 Appendix VIII - Outcome of the steel price model 103
15.9 Appendix IX - Backgrounds into companies 106
15.9.1 Detailed background into BAM 106
15.9.2 Detailed background into Boskalis 107
15.10Appendix X - CO2 impact of different scope 3 emission categories per industry . . . 108
15.11Appendix XII - Acknowledgements 109
15.12Appendix XIII - Research Paper 111

List of Figures

1 Global annual demand for hydrogen throughout the last decades (IEA, 2019a) . . . 2
2 Selected hydrogen production methods. (Acar et. al., 2014) 3
3 Fundamental types of renewable incentive mechanisms (Haas et al., 2011) 7
4 The graphical representation of the scope 10
5 Research Flow Diagram 13
6 CFCs deciding on suppliers through their disclosed carbon emission data (CDP, 2019) 15
7 Apple's targets for renewable energy commitments in its supply chain (Apple, 2020) 17
8 Prioritization of suppliers to collaborate with 20
9 The tools positioned against efficiency vs. transformation and supply chain vs. product offering. An adapted version of CDP report (CDP, 2017) (CDP, 2019). 22
10 Different scopes of including company's emissions (Protocol, 2013) 24
11 Hydrogen production options (Shell) 29
12 Energy intensity demands per sector (IEA, 2019a) 32
13 Graphical explanation of the BOF and EAF processes 33
14 Hydrogen-based DRI-EAF process 34
15 Developments in maturity, costs and readiness of different sustainable steel production methods (Berger, 2020) 35
16 Sulphur regulation trend against oil demand trend (IEA, 2019a) 36
17 The current production methods with hydrogen coming from SMR and the sustainable alternative 37
18 Simplified framework of the steel value chain with data from 2018 coming from Eurofer (EuroFER, 2019) 40
19 Trade-offs of using green steel in vehicle manufacturing 43
20 Some of the main stakeholders in the steel value chain 45
21 Identified research's refinery supply chain 49
22 Main identified refinery market players 51
23 Value chain of ammonia including data from Bicer's research (Bicer et al., 2016) . . 54
24 life cycle perspective of farming process from Lantmännen showing the impact of fertilizers on their supply chain's carbon footprint (Lantmännen, 2019) 57
25 Some of the main stakeholders in the ammonia business 58
26 The methanol supply chain based on Ragaert's research and IHS market analysis (Alvarado, 2017) (Ragaert et al., 2017) 60
27 Schematic picture of hydrogen GoO market 66
28 Steel incentives placed on their impact to hydrogen-based decarbonization of the heavy industry 69
29 A given example by Rijkswaterstaat with concrete related DuBoCalc calculation to get to an MKI level 71
30 ID.3 model, designed by Volkswagen (Volkswagen, 2019) 72
31 Sustainable H2 demand scenarios 93
32 CCfD mechanism explained (Sartor and Bataille, 2019) 94
33 Simplified graphic representation of the SMR process (Simpson and Lutz, 2007) . . . 99
34 Hydrogen production costs in USD/kg of different techniques (IEA, 2019a) 100
35 Margins of refineries (IEA, 2019a) 102
36 Model of steel costs through hydrogen DRI-EAF against BOF 103
37 Model calculations on BOF and scrap based EAF 103
38 Model calculations of EAF with DRI as raw material which is based either on natural gas or green hydrogen 104
39 Model calculations of DRI based on natural gas and green hydrogen 105
40 Screenshot of the Boskalis sustainability report (Boskalis, 2019) 107

41 Research by Farsan showing relative impact of different scope 3 aspects (Farsan et al., 2018) . . . 108

List of Tables

1 Hydrogen demand predictions made by the Hydrogen council (Hydrogencouncil, 2017) 4
2 CE Delft's Techno-economic SMR carbon-capturing overview (CEDelft, 2018a) . . . 27
3 Grey, blue and green hydrogen production (Nikolaidis and Poullikkas, 2017) 28
4 Research by the Danish Department of Energy into emissions from road transport (MI, 2018) . . . 38
5 Current prices of production methods for carbon-intense and carbon-neutral steel. The hydrogen-based DRI-EAF is a mixture of about 10% scrap steel and 90% DRI. 42
6 A table to sum up the qualitative results related to each sector with as end category the impact consumer-facing companies can have on sustainable hydrogen usage in the upstream industry. A '+' represents a favourable case to value chain decarbonization relatively to other industries . . . 64
7 Key takeaways integrated reports BAM 2013-2019 (BAM, 2019) . . . 106
8 Key takeaways annual reports (2017-2019) Boskalis (Boskalis, 2019) . . . 107

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Most importantly, I want to thank all interviewees. Though for some sectors it was difficult to find leads, the ones that were willing to provide knowledge on their expertise were very engaging and kept in touch during the process.

1 Research introduction

1.1 Introduction to the energy problem

The Paris Agreement has resulted in significant responsibilities for governments and nations to change energy usage in the near future. To this day, 189 member states are fighting together to tackle one of the biggest global problems and reduce global warming (UNFCCC, 2020). Energy usage will have to become more efficient and be more generated by an increasing amount of sustainable resources. There are four routes of decarbonizing technologies: capturing carbon emissions, using biomass as an energy source, electrification, and using hydrogen as a heat source or reducing agent (ETC, 2018b). This last pathway is one of the most promising and promoted energy carriers (Mazloomi and Gomes, 2012), as hydrogen can be used to decarbonize multiple different sectors and processes. Over the past decades, sustainable hydrogen has often been discussed to be of value, but uptake has not happened on a larger scale. With the rapid increase in renewable energy systems, along with the increasing awareness of environmental changes, hydrogen has yet another chance to gain interest and drastically decrease carbon emissions.

1.1.1 Hydrogen, the energy carrier

Hydrogen can be a valuable component as part of chemical processes in the industry, among other applications like a resource for power generation or fuel in transportation. Currently, hydrogen, produced from natural gas, coal and oil, is used for some industrial processes, and the usage is expanding over the past years (figure 1). About 75 million tonnes of hydrogen in pure form, and about 45 million tonnes in hydrogen-based fuels, is used each year (IEA, 2019b). This existing base demand for hydrogen could profit from the increase in renewables and lead to increasing sustainably produced hydrogen demand. Industries could scale-up the existing hydrogen demand using hydrogen in day-to-day operations and look into the diversification of the energy source to reduce their carbon footprint.

On top of that, hydrogen could replace unsustainable raw materials in new applications where heating and chemical processes currently use fossil fuels (IEA, 2019a). Examples of new applications where the hydrogen commodity can add value are, for example, aluminium, iron and steel heating and many hydrogen-based fuels like methanol (IEA, 2019a). In order to do so on a large scale, not only governments have to make this change, but the customers' valuation towards carbon emission-free materials has to change as well. A changed valuation from the consumers towards carbon-free 'clean' products could incentivize companies to produce them. There are many different stakeholders for each hydrogen demand sector, all with their own specific needs and requirements.

As the problem extends beyond solely a technical issue to produce hydrogen, the problem becomes a system with multiple components interacting with each other, which can be considered to be a complex issue. Complex System Engineering and Management (CoSEM) explores solutions in socio-technical settings where the problem requires a solution which exceeds technology and requires human behaviour, regulation and interests to be taken into account as well. Such an approach applies to decarbonizing hard-to-abate industries through hydrogen implementation as current technology developments will not be able to provide a profitable business case.

1.1.2 Uncertainty about a hydrogen future

In order to become cost-efficient, large amounts of hydrogen have to be produced to obtain an economy of scale. This requires global participation (Gim and Yoon, 2012) (Hydrogencouncil, 2017). Determining how usage of hydrogen as an energy carrier will develop and if this economy of scale will be reached includes a lot of uncertainty (Sutherland, 2020) which slows down developments. Still, the European Commission has concluded in July of 2020, that the commodity is at a 'tipping-point' to become of sufficient scale with new investment plans announced by companies on a weekly basis

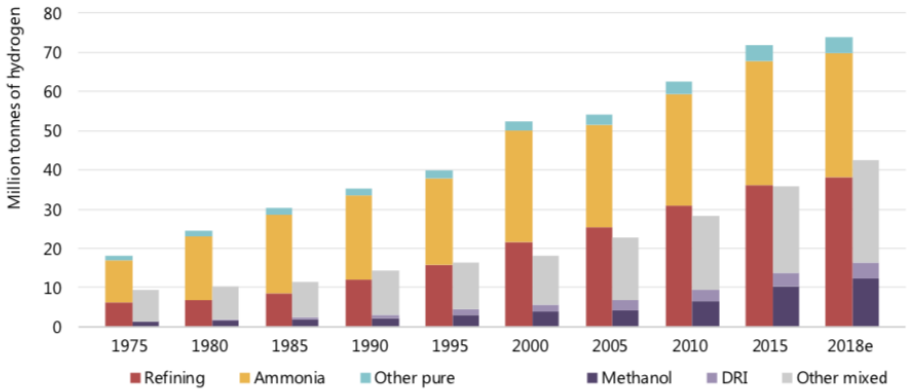

Figure 1: Global annual demand for hydrogen throughout the last decades (IEA, 2019a)

in different applications. For these companies, the uncertainty regarding hydrogen is still very high, and depends partly on how governments and private companies will position themselves towards this resource and what the timeline of implementation will look like. Most certainly, not all industries will use hydrogen to decarbonize; some will be easier decarbonized than others. The research institute CE Delft stated in 2018 that: *'At the back end of the energy chain the potential for use in industry (feedstock, process heat) and for power generation is relatively easy to roll out* ' (CEDelft, 2018b).

The overall problem identified is that in order for hydrogen to become globally used in considerable amounts, economic feasibility of the business case is required. As mentioned, the industry has a foothold in hydrogen demand and some processes are capable of using hydrogen instead of fossil fuels. Hence, the industry could play an essential role in progressing demand for hydrogen, which could influence the business case of other hydrogen applications positively. Once the possible substituted processes are distinguished, there still remain issues in cost-effective feasibility as a final barrier. A cohesive approach of stakeholders is required to, in some way, increase hydrogen demand globally and not leave it up to energy providers to do this on their own.

The next section addresses literature research into hydrogen implementation. From this literature research, a knowledge gap is identified in order to create the research question. Following the research question, correspondent sub-questions are deducted, as well as their research methods. The thesis proposal ends with a graphical representation of the method section in a research flow diagram.

1.2 Literature research on hydrogen as energy carrier

This chapter will try to find literature gaps in existing literature where additional knowledge is required to come to a solution to the problem. From these gaps, new research can be conducted to add knowledge to the problem situation to solve it. The main high-levelled concepts associated with problems of hydrogen implementation discussed are technical aspects of reducing costs or improving efficiencies and case studies about what value hydrogen can fulfil.

From a large number of papers, 20 general hydrogen related, and even more hydrogen in the industry related articles have been analyzed, to learn from previous research which relates to the problem description. These papers give a better view of the background knowledge of existing literature (Wee and Banister, 2016) and provide information to look further into the master thesis' added value of the topic. The articles selected for the review were found through the search machines Google Scholar and Scopus. The search input was matched within the article's title, keywords as well as the abstract. The first search input were the words Hydrogen AND Energy carrier AND Review and resulted in 554 articles through Scopus. A further refinement of adding energy as the focus was used to obtain 159 papers. More specific research input would be done through adding Heavy industry OR Supply chain aspects OR Decarbonization OR Business case to the already presented input string.

In the next sub-paragraphs, some papers will be discussed to analyze existing literature from which a research gap can be determined.

1.2.1 Technical aspect of hydrogen production

First of all, technical development was reviewed to see if developments on hydrogen's technical production side are still progressing. It is highly critical for industries to adapt to the technical aspect of hydrogen production, as well as consumption, as costs need to be reduced for hydrogen to become competitive with other energy carriers. The main issue discussed in this section of the literature review is the efficiency of hydrogen over other energy carriers. The question is whether it would make sense to use hydrogen as an energy carrier over other methods and if so, doubts that hydrogen will never be competitive can be rejected. Indeed Aziz et al. (2019), Crabtree (2017) and Di Profio et al. (2009) show that multiple kinds of hydrogen carriers like gaseous- and liquid hydrogen, methanol and ammonia can be considered to be technically promising for the future.

Multiple different kinds of research describe different production methods for hydrogen. For example, an extensive review of 17 different production methods are described in an *environmental, technical, financial, and social* assessment by (Dincer and Acar, 2015). Moreover, Acar and Dincer (2014) shows in figure 2 the resources for hydrogen where the research makes a high level distinction between fossil fuels, nuclear power and RES. Currently, about 9% of the hydrogen generated comes from either coal or natural gas (IRENA, 2019).

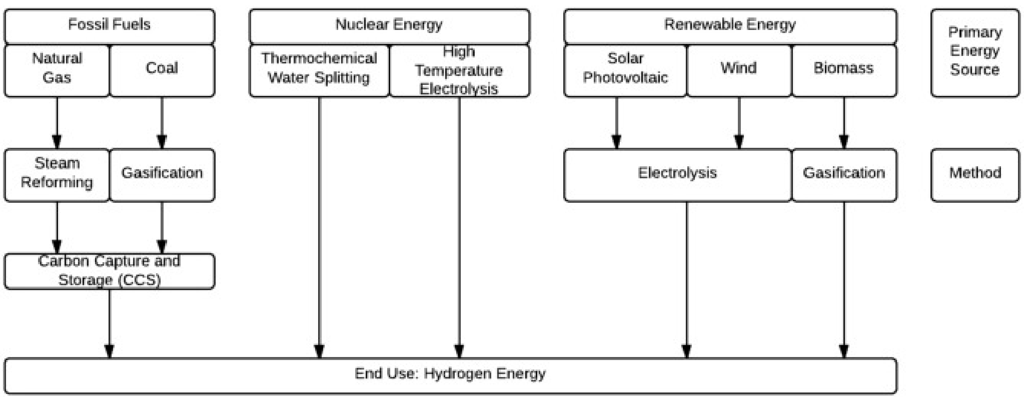

Figure 2: Selected hydrogen production methods. (Acar et. al., 2014)

The economic cost efficiency is in most researches discussed as well, specifically by Lund and Mathiesen (2009) and Abe et al. (2019) who state that hydrogen is 'a hopeful, ideal cost-efficient, clean and sustainable energy carrier.' (Abe et al., 2019). On top of that, it is attested through Aakko-Saksa et al. (2018) and Wang et al. (2016) that most of the papers include developments in the hydrogen technologies readily well described through multiple technical system possibilities, like Liquid Organic Hydrogen Carriers (LOHCs) and circular hydrogen carriers. Novel hydrogen production mechanisms are still being researched in new papers like Luo et al. (2018), by describing chemical loop reforming and chemical loop hydrogen production. At the current time, no knowledge gap for further research is found within this technical production field of hydrogen that applies to a CoSEM kind of research as it would become a sole technical issue rather than a complex system problem.

1.2.2 Scoping down on continental boundaries and demand sectors

Given that hydrogen will, according to the research mentioned above, mature close to the competitiveness of other energy carriers in the future, case studies can identify requirements, needs and outlooks on what is possible for a widespread hydrogen layout. Like Chapman et al. (2019) who analyzes the United Kingdom and the United States on hydrogen implementation and gives global demand predictions as well. Demand predictions can be highly fluctuating, as shown in appendix I, where a summary of multiple different scenarios is gathered to show the uncertainty about future hydrogen demands.

A roadmap previously made on a global scope by the Hydrogen Council was published in 2017 (Hydrogencouncil, 2017). The research concentrated on hydrogen demand by 2050 and included some predictions towards 2030. Within the research, a distinction is made between different sectors where demand for hydrogen is present and may develop even further. The differentiation of sector demand is an essential aspect of the research, as different sectors may require different incentives to increase demand and hence, can be seen as separate hydrogen demand entities. Currently, five sub-industries consume about two-thirds of the energy in the whole industry segment (Hydrogencouncil, 2017). These industries are *'aluminium; chemicals, petrochemicals, and refining; cement; iron and steel; and pulp and paper, all of which require large quantities of energy to run equipment such as boilers, steam generators, and furnaces.'* (Hydrogencouncil, 2017). The final energy consumption is expected to grow with 10 percent until 2050 driven by the economic growth in Southeast Asia (Hydrogencouncil, 2017). Delivering part of this energy growth through sustainably produced-hydrogen would have a significant impact on carbon emissions.

Future global hydrogen demands			
Sector	Supply/Demand	Hydrogen demand (TWh)	Year
All	Total hydrogen demand	2778	2020
All	Total hydrogen demand	3889	2030
Energy	Supply: energy sector to other sectors	250-300	2030
Industry	Demand: additional to current hydrogen demand in heating the industry sector	167	2030

Table 1: Hydrogen demand predictions made by the Hydrogen council (Hydrogencouncil, 2017)

1.3 Literature research towards hydrogen in the heavy industry

Previous literature research has not included any demand for sector-specific papers. To scale the broad global view down, a few sectors were introduced in previous studies where demand for hydrogen is present and possibly can grow. As the heavy industry holds a large share of current hydrogen demand, potential future demand (Hydrogencouncil, 2017) as well as being a massive source of global pollution (Dong et al., 2019), progression should be made in order to diminish carbon footprint. Following the definition of the hosting company Shell, the heavy industry can be deduced in the following six sub-sectors: (Petro)Chemical; Oil and Gas; Iron and Steel; Paper, Pulp and Print; Non-metallic Minerals and Non-ferrous Metals.

Hydrogen within the industry can be used as a reactant feedstock material in processes as well as a heating fuel. Sutherland describes the issue of high-grade heat needs being fulfilled through fossil fuels which are the most inexpensive resource (Sutherland, 2020). According to Sutherland's paper, hydrogen could be used for heating needs and decarbonize some parts of heavy industries once the issues of uncertainty and cost-effectiveness are taken care of (Sutherland, 2020).

The sub-sector iron and steel holds about 7% of global carbon emissions since it is highly dependent on fossil fuels like natural gas and coking coal (Ahmed, 2018). Otto uses a case study on the German steel industry to expose the potential that hydrogen has to reduce carbon emissions in this sub-sector of the heavy industry (Otto et al., 2017). Bhaskar takes the scope broader and presents through a python model that at a European level, the carbon emissions of iron and steel can be reduced by more than 35% utilizing hydrogen (Bhaskar et al., 2020). Most sub-sectors are not researched on their hydrogen applicability or do not hold considerable potentials for hydrogen implementation. Often, only a final demand that the potential hydrogen holds in the heavy industry is provided, and does not include any details on the relationship of the potential to the explicit sub-sectors.

The research of Friedman and the Center On Global Energy Policy concludes that industrial heat through hydrogen is an actionable start to decarbonize the industry but does increase wholesale production costs by 10 to 50% depending on the hydrogen origin (Friedmann et al., 2019). As such, research should determine in what ways these costs can be covered in order to enable the transition to scale-up. Part of the costs could potentially be covered by other parties then governments and the upstream industry. Hence, defining the willingness to pay from the consumer's perspective, and identifying drivers to increase this willingness could make the hydrogen demand applications more actionable. On top of that, once a willingness is identified, mechanisms could be implemented to decarbonize the industry.

Next sections will focus on scientific research covering mechanisms to decarbonize industries. From this can be explained in what way industries have been initiated to decarbonize themselves. Before that, the next paragraph looks into the effectiveness and efficiency of mechanisms, in order to understand if mechanisms are of use in promoting renewable options.

1.3.1 Scientific research on mechanisms to decarbonize the heavy industry

Main barriers for a decarbonized transition in the industry relate to costs and lifetimes of facilities which often are still useful to operate for many more years (Bataille et al., 2018). Also, the heterogeneity is mentioned as a difficulty for transitioning the industry, as facilities can be very different from one another and require case-specific solutions. Though some industries have managed to reduce their emissions to below 1990 level, further decarbonization will require radical measures (Bataille et al., 2018). A review paper by Bataille contains the most comprehensive research in terms of mechanisms and policies to decarbonize the heavy industry (Bataille et al., 2018). The main finding, as most research states, is the need for R&D development support in order to bring down costs and initiate carbon taxation to hold large scale emitting industries accountable for their footprint (Bataille et al., 2018).

The vast amount of research on mechanisms to reduce carbon emissions relate to governmental influences through: carbon pricing (Bataille et al., 2018) (Åhman et al., 2017), carbon contracts for Difference (CCfD) (Sartor and Bataille, 2019), EU carbon border constraints, quotas (Rahman, 2020), research and development support (Åhman et al., 2017) (Rissman et al., 2020), energy efficiency standards (Rissman et al., 2020) (Russell, 2015), data transparency (Rissman et al., 2020) and low-carbon product labelling (Russell, 2015) (Killip et al., 2019). Appendix II provides elaborate explanations on all of the concepts. Often, research conclude that it is possible to increase a product's value by decarbonizing, like Russell (2015), Killip et al. (2019) and Rissman et al. (2020).

The effectiveness of renewable promoting mechanisms was described by Mitchel et al., who compared the renewable obligation system in England against the feed-in system in Germany (Mitchell et al., 2006). The research's focus was on the degree of effectiveness the mechanisms were able to address to reduce the risks on the power generation side (upstream) and concludes that both mechanisms reduce risks, though feed-in tariffs are most effective. Another conclusion is that the risk reduction, which increases the efficiency of a support mechanism, needs to be investigated (Mitchell et al., 2006). Khazaei and Zhao (2018) shows that through mechanisms in a two-settlement power market, power generators achieve efficiency. Sovacool (2010) takes the research from Mitchell et al. even further and concludes that both effectiveness, as well as efficiency, are achieved through mechanisms with preferably the feed-in tariff.

All of these mechanisms are driven from a governmental implementation rather than a CFC mechanism. However, because the mechanisms provided above are related to governmental influence, the question is rather, to what degree a consumer-facing company can be of influence. Over the past decades, consumer-facing companies, from now on to be called 'CFCs', have modified value chains according to their needs and requirements. CFCs are businesses which deal directly with end consumers. These are often the well-known brands in consumer goods like, for example, food products, vehicles or home equipment. Downstream companies (CFCs) requesting their supply chain to adhere to specific needs and requirements related to product specifications is called demand-pull.

1.3.2 Green supply chains

Literature discusses reduction in supply chains as an extension of a traditional supply chain where activities are included to minimize environmental impacts of a product (Eltayeb et al., 2011). Incentives to make the supply chain 'greener' have not always shown to gain the outcomes hoped for (Eltayeb et al., 2011). In the past, value chain decarbonization exposed the organization's negative emission performances and those of its supply chain (Eltayeb et al., 2011). Data is more and more gathered through organizations like the Carbon Disclosure Project (CDP) and understanding of a company's carbon footprint is becoming increasingly transparent (CDP, 2017) (CDP, 2019), resulting in reduced risk of tackling carbon footprint as the data is becoming publicly known. After all, attacking supply chain emissions do not expose any new information about a company's carbon footprint as it is already known by now. Research by Eltayeb et al. (2011) shows that consumers do not differentiate between the CFC environmental performance and its suppliers. This means that in order for a CFC to be recognized as sustainable, also its suppliers should follow the same environmental development.

The most cited Green Supply Chain Management paper by Zhu and Sarkis (2004) showed that in the early 2000's, the expectations and beliefs was that the relation between a green supply chain and economic and environmental benefits seemed to be a significant win-win. The expectation was there that companies that try to make the value chain greener show that when they can accomplish this, their economic performance would also increase. Over time, Mathiyazhagan et al. (2013) showed that the expectations were indeed grounded as green supply chains not only reduce environmental impact, but also increase the economic performance of a company. Several studies have shown that environmental sustainable development of value chains and green production is related to a company's economic well-being and lead to organizational performance (Chen, 2008) (Prashar and Sunder M, 2020) (VenkatesaNarayanan et al., 2021) (Çankaya and Sezen, 2019). An important addition by Mathiyazhagan et al. (2013) was the requirement of financial incentive for a supplier to adhere to the initiator's sustainability wishes.

On the definition of what green supply chain initiatives are is a larger disagreement among literature research, as explained by Eltayeb et al. (2011). Eltayeb et al. (2011) regards this disagreement to be the result of green supply chain initiatives being an underdeveloped scientific area which allows for discussion. Following the paper by Eltayeb et al. (2011), there are 5 categories identified relevant to green supply chains:

- Customer environmental collaboration: activities where environmental performance is gained through a customer and a company pursuing joint projects (Grekova et al., 2016) (Pero et al., 2017).

- Eco-design and Eco-materials: collaboratively decarbonizing interactions between designers, stakeholders in the value chain and consumer (Cicconi, 2020) (Gheorghe and Ishii, 2007) (Ishii and Stevels, 2000) (Saroop and Allopi, 2016).
- Green purchasing: reducing presence of hazardous materials, increase energy efficiency and recycled content, and include green power. Also, green purchasing is the action of a CFC choosing what supplier to purchase from based on the effect a company has on environmental goal (Çankaya and Sezen, 2019) (Mathu, 2019) (Zhu et al., 2013) (Hassini et al., 2012) (Eltayeb et al., 2011).
- Supplier environmental collaboration: activities where environmental performance is gained through supply chain partners pursuing joint projects and share knowledge opportunities (Grekova et al., 2016) (Zhu et al., 2013) (Mathu, 2019).
- Reverse logistics: activities related to circular economies and reuse or recycling products by taking them back into the value chain (Jayaraman and Luo, 2007) (Mathu, 2019) (Eltayeb et al., 2011).

As literature research does not show a clear definition of value chain mechanisms, and scholars disagree on the definition and relative importance (Eltayeb et al., 2011), mechanisms will be further researched at a later stage. Chapters 2.2 till 2.4 show some examples of how well-known companies have changed their supply chains to adhere to their environmental goals and objectives. In this chapter, clearly defined mechanisms will be identified for further use in the thesis.

1.3.3 Conclusion on literature about incentivized supply chain decarbonization

Scientific literature research touches on the importance of supply chain mechanism from CFC: '*industrial decarbonization is more likely to succeed with solutions involving most if not all supply chain actors (e.g. government, basic materials producers, manufacturers, and retailers)* ' (Bataille et al., 2018). All of the above-described policy mechanisms can be organized according to the following classification by Haas et al. (figure 3) where most can be placed in the regulatory section being investment focused (Haas et al., 2011). Generation based focused incentives would mean that the upstream generation is promoted, which falls out of the research' scope. The closest to the supply chain mechanisms for CFCs to be used is the voluntary investment focused incentives.

		Direct		Indirect
		Price-driven	Quantity-driven	
Regulatory	Investment focused	Investment incentives Tax credits Low interest/soft loans	Tendering system for investment grant	Environmental taxes Simplification of authorisation procedures Connexion charges, balancing costs
	Generation based	(Fixed) Feed-in tariffs Fixed premium system	Tendering system for long term contracts Tradable green certificate system	
Voluntary	Investment focused	Shareholder programs Contribution programs		Voluntary agreements
	Generation based	Green tariffs		

Figure 3: Fundamental types of renewable incentive mechanisms (Haas et al., 2011)

Scientific research rather misses out on the influence of the downstream companies in the supply chain as a participating actor to stimulate upstream industry decarbonization through hydrogen. There is shown to be research into making small value chain suppliers greener through different kinds of efficiencies. Rather should large industrial producers be incentivized as well where the hard-to-abate sectors get more incentives from their customers. For a better understanding of the incentives, scientific research is not comprehensive enough. Instead, the research will look into company reports of supply chain incentives alongside market reports from the Carbon Disclosure Project (CDP). The CDP was mentioned by Rissman to be the foremost important stakeholder in value chain decarbonization (Rissman et al., 2020), to identify a more extensive package of mechanisms and incentives. More on CFC mechanisms to decarbonize upstream industries will be discussed in chapter 2.

1.4 Knowledge gaps identified

The foremost concern for sustainable hydrogen usage in the heavy industry is whether governments will transform the industry, or whether the industry will get the incentive from the demand side to change. CFCs demanding their supply chain to transition towards producing a particular product with specific requirements is called a pull-effect. The fact that consumers become more aware of sustainable products and demand them to be produced carbon-neutral does not mean that the industry will adapt to this behaviour as the industry itself is not consumer-facing. Since the heavy industry delivers to CFCs, they could incentivize the heavy industry to use carbon-neutral resources like sustainable hydrogen.

Identification of drivers in a sector's value chain would show upstream industries why hydrogen usage could be valuable in processes. As the heavy industry is often discussed as a potential hydrogen user, research must show that there is added value to do so. As CFCs are experiencing increasing demand for 'clean', sustainable products, the urge of sectors to transition should be examined to understand what sectors to focus on.

On top of that, research needs to determine to what extend mechanisms could be of use to incentivize industries to decarbonize. The above described drivers of CFCs could result in value chain mechanism implementation to force the industry to adhere to changing requirements.

As such, the two the primary literature gaps are identified for further research:

Through what mechanisms can consumer-facing companies influence their upstream value chain partners to produce decarbonized products?

There is a knowledge gap on through what mechanisms consumer-facing companies can influence the heavy industry to reduce emissions.

There is a lack of knowledge on how the demand for decarbonized products, from consumer-facing sectors, may influence the upstream industry to decarbonize.

The research will focus on whether a possibly perceived added value, of a hydrogen-based product, could drive a pull-effect in the value chain. Basically, the research will be split in two sections. On the one hand, the research will look into the first knowledge gap of what industries show the highest potential to experience pressure to decarbonize from CFCs. On the other hand, the research will identify CFC-initiated mechanisms which can be used to initiate decarbonization in a supply chain. Chapter 1.4 will show a graphical representation of how these two research strings play themselves out over the thesis, after which in a final chapter both will be discussed upon their influence on each other. Following the identified gap, the main research question is deducted.

1.5 Research question

The main research question, which follows from the overall design approach, is stated as follows:

What probable impact can consumer-facing companies have on the heavy industry's hydrogen-based decarbonization?

Corresponding sub-research questions developed should constructively build on each other, forming an answer to the research question. The sub-research questions are:

- *Through what mechanisms can consumer-facing companies influence hydrogen-based decarbonization upstream in the value chain?*
- *How to identify changes in demand for clean heavy industry products?*
- *What sub-sectors in the heavy industry are dependent on sustainable hydrogen to be decarbonized and what consumer-facing segments are in the downstream value chain of those sub-sectors?*
- *What industries have the highest chance, desire and capabilities to be influenced to decarbonize by consumer-facing segments to produce hydrogen-based products?*
- *What mechanisms hold the highest impact potential on hydrogen-based decarbonization?*
- *To what extend can CFC-initiated mechanisms support the request of hydrogen-based products from the heavy industry?*

1.6 Scope and research approach

1.6.1 Scope

This research has not set a time boundary to unlocking the value chain of the heavy industry in terms of hydrogen usage. Overall, a short-to-middle-term condition can be taken into account, for example, from the near future up to 2050. As the research will mostly be based on qualitative analyses, uncertainties related to this time-laps decrease as particularly quantitative aspects are hard to foresee.

The source of hydrogen can be from different roots and through different methods. Hence, the start of the thesis has to define the different kinds of sustainable hydrogen production processes to show that not all hydrogen produced will result in the satisfaction of demand requirements. It is required to understand where the supply might be coming from, what costs are related to it, and what it consists of (e.g. (some) carbon emissions or none). The supply of hydrogen is not included as the main focus of the research. It instead needs to be covered and recognized in order to analyze what the consequences of hydrogen in the heavy industry and corresponding value chain are.

The consequence of sectoring and studying the heavy industry is that some interrelations between increasing hydrogen demand in the heavy industry and the total hydrogen demand may be lost. Still, in order to give a well-grounded outcome of the research, a smaller scope is required. In the ongoing research, the scope will decrease depending on what sub-sectors are more important over others.

The geographical aspect of scoping has an impact on specifying boundaries from components (heavy industry demand groups) in a European value chain because the urge to change is more prominent in this continent than in many others. Value chains of the European Union can not be considered the same as other continents. As value chain identification and case studies focus on European boundaries, the assumption will be that the outcomes in other continents will be different. An important aspect will be to focus on the main developments on the European level and not look too much into country specifics as that much detail will cause an overload of research required.

A representation of the scope discussed so far is depicted in figure 3. More interestingly, the non-discussed components are presented, which still hold inter-linkages with the components within the scope. Towards the end of the research, a discussion of these relations will be included to bolster missed conclusions.

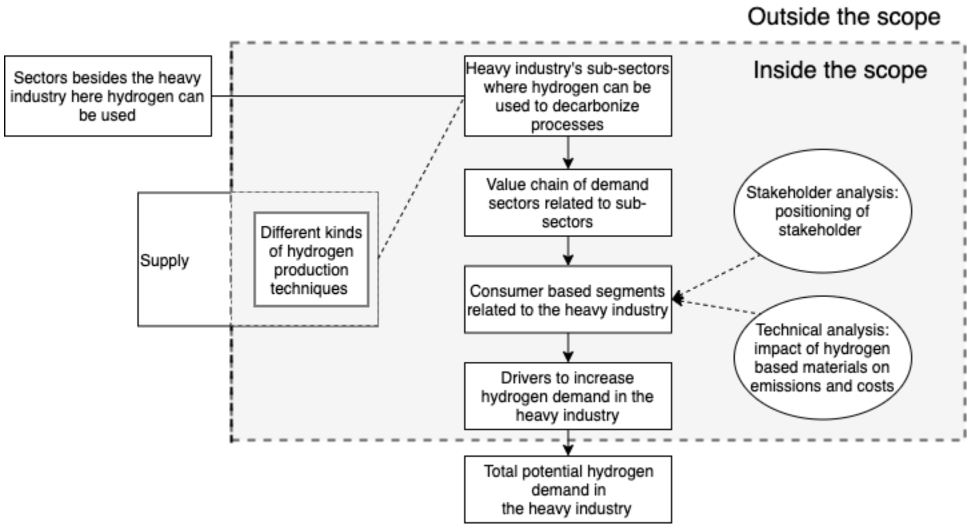

Figure 4: The graphical representation of the scope

1.6.2 Research question approach

The research will have to prove that CFCs have incentivized heavy industries to change towards more sustainable production in the past. From this, the potential hydrogen pull towards upstream can be researched. A table with pluses and minuses will show which consumer-facing sectors that require materials from the heavy industry are expecting their consumer's demand to change and have the ability to incentivize upstream production. The drivers and identification of which sectors are most applicable for incentivizing their upstream production are conducted through sector analysis and interviews of demand sectors. By applying interviews for specific sub-sectors, a final goal will be to use the *case study approach* to develop an understanding of how CFC are experiencing hydrogen-based products which could result in an increased demand for hydrogen in the heavy industry. The case study approach tries to fill the knowledge gap to *'gain an understanding of the issue in real-life settings and recommended to answer how and why'* (Harrison et al., 2017). This research will try to use quantitative aspects of impact on the value chain as well as qualitative identification of drivers not to give exact outlooks, but to show what can be accomplished and through what sub-sectors.

1.6.3 Research methods and sub-questions

This section will elaborate on how the sub-questions in the research will be addressed and what research methods and data gathering will be conducted. For each sub-question, the methods are discussed. The hypothesis is expected to have the final consumer being willing to pay more for a green product, which drives CFCs to initiate decarbonization in the upstream value chain. The sub-questions so see it this hypothesis is valid, and methods related to the hypothesis, are defined as follows:

1. *Through what mechanisms can consumer-facing companies influence hydrogen-based decarbonization upstream in the value chain?*
   This section will have to prove, through existing literature studies, that in the past, CFCs have incentivized stakeholders in the value chain to become more sustainable and responsible with resources. It will function as a proven theoretical framework that consumer-facing segments can incentivize upstream sectors to change processes. On top of that, a framework of value chain mechanisms will be identified following existing research into renewable power implementation and decarbonization methods. These mechanisms will, in turn, be discussed regarding their applicability to the hydrogen implementation in a later stage.

2. *How to identify changes in demand for clean heavy industry products?*
   This section will describe the theoretical framework to identify, in a structured way, how the demand requirements change for downstream CFCs. This question includes the boundary for heavy industry products among stakeholders, and how case studies on stakeholders will be interviewed at a later stage. Specifically what questions to focus on during interviews is of importance to be determined.

3. *What sub-sectors in the heavy industry are dependent on sustainable hydrogen to be decarbonized and what consumer-facing segments are in the downstream value chain of those sub-sectors?*
   This research method is based on a literature review as background knowledge in the heavy industry is researched. Sector details and scoping to relevant products is the most important outcome from this section. This section could look like standard market analysis, including figures on the market. Researching specifically in the demand section rather than focusing on the supply section provides a better view on opportunities where potentially hydrogen demand can develop. The hosting company (Shell) has much expertise in the technical capabilities of hydrogen and can be a source of valuable data on differences between heavy industry sectors that can use hydrogen. The heavy industry has some identified sub-sectors, and this section will also give these sub-sectors a deep dive in their downstream value chain. The consumer-facing demand segments of these sub-sectors will be identified.

4. *What industries have the highest chance, desire and capabilities to be influenced to decarbonize by consumer-facing segments to produce hydrogen-based products?*
   A table will be constructed with pluses and minuses to show the driving consumer-facing segments that want to change the upstream industry's materials. The segments having the highest willingness to change towards hydrogen-based materials will be used for potential mechanism application. Within the case studies, research down the value chain will be done like, for example, the needs of a car manufacturer who wants to reduce their carbon footprint. Requiring carbon-neutral cars means that in their value chain, the metals they use must become carbon-neutral as well. As a result, some demand in the iron & steel sub-sector of the heavy industry must need to change their production processes to adhere to demand. Case studies will consist of a stakeholder analysis through interviews, as well as a technical analysis where costs and emission reductions are calculated. Chapter 3 discusses the case studies in some more detail.

5. *What mechanisms hold the highest impact potential on hydrogen-based decarbonization?* The mechanisms identified in the first sub-question will be differentiated on potential applicability on a hydrogen-based decarbonization. A qualitative difference between the mechanisms will be explained to understand what mechanisms would work best for a CFC to transition an upstream process.

6. *To what extend can CFC-initiated mechanisms support the request of hydrogen-based products from the heavy industry?*
   Knowing what drives the consumer-facing businesses to use carbon-free materials allows one to reflect what this means for the upstream heavy industry. The in question 4 identified industry which holds the highest potential to see CFCs request carbon-neutral products will be used

as boundary to what qualitative end the mechanisms could support downstream requests. Preferably, some detailed examples related to the high-potential mechanisms from sub-question 5 will be presented.

1.7 Research flow diagram

A flow diagram of this research is constructed (figure 5) where all the six research questions are covered. It shows the necessity of finishing the research questions one after the other as some questions require input from another. The thesis' structure can be divided into three parts. Firstly, like with Sovacool's paper, the mechanisms need to be identified to decarbonize value chains. The second part is literature research on hydrogen and by which sectors within the heavy industry can use it. The heavy industry sectors where hydrogen is of great importance to decarbonize are identified. The third part, value chain analysis, identifies demand sectors (consumer-facing sectors) and gives an overview where heavy industry's products can be found. Nearing the end of the research, the mechanisms will be discussed on applicability of incentivizing hydrogen-based decarbonization.

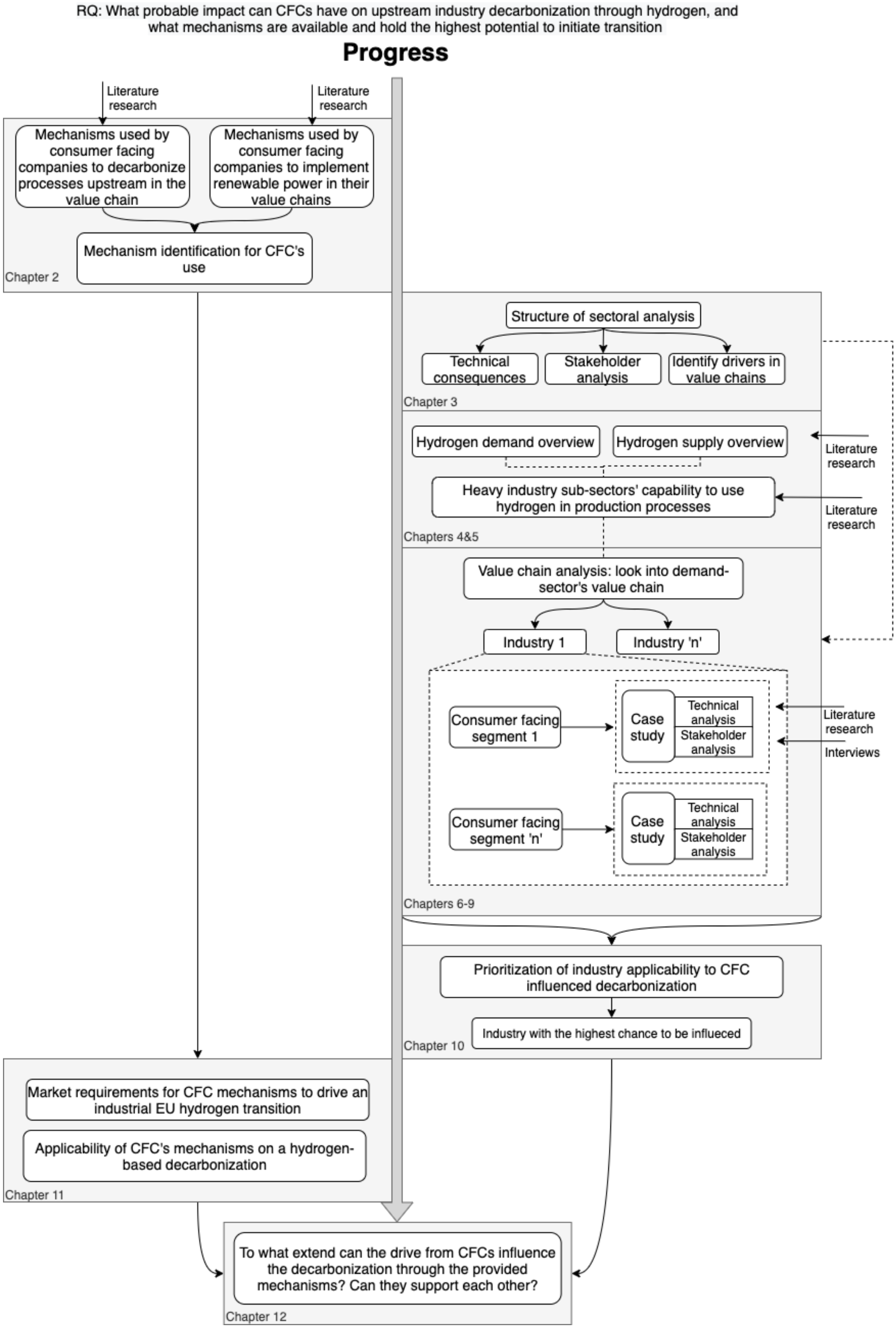

Figure 5: Research Flow Diagram

2 Industries transitioning

Because the scientific literature does not show to consent in clearly defined mechanism availability for CFCS, the research will discuss practical examples and look into non-peer reviewed research like the CDP. This approach will give a better defined mechanism availability instead of the rather generic definitions in science. In section 2.1, a scientific approach to research the mechanisms is introduced. The section will show that this research does not allow the same method used in previous research as the conditions are different. Section 2.2 will show CFCs reducing emissions in value chains. This is basically what can be achieved through hydrogen implementation. Section 2.3 gives examples of implementation of renewable power in value chains. The last examples in 2.4 show specifications in upstream products changed accordingly to fit certain consumer requirements. These three sub-chapters will be used as a proof of concept that heavy industries are decarbonizing and that in the past, CFCs have changed upstream industries following their requirements, more specifically, 'green' requirements. Chapter 2.5 describes a general framework for CFCs to incentivize decarbonization in their value chain. Finally, 2.6 provides an overview of mechanisms applicable for CFCs to decarbonize their value chain.

2.1 Scientific methods used to research mechanisms

Sovacool's research, discussed in chapter 1.3.1, follows a qualitative approach and uses expert interviews, along with academic peer-reviewed literature, as the primary sources. The qualitative research approach by Sovacool made a structure where the predefined mechanisms were addressed to industry experts (Sovacool, 2010). Following these interviews, the expert's opinions on mechanisms were discussed to understand what mechanisms work best in promoting renewable energy. Different stakeholders in the power industry were interviewed, for example, power generators, power suppliers, regulatory bodies and more (Sovacool, 2010). The semi-structured interviews allow for an open conversation and the possibility to follow up on interesting topics mentioned by industry experts. Upfront is an analytical framework composed of mechanisms to increase renewable power after which each mechanism is explained and discussed.

The interviews are the primary source of information to research the incentive of a mechanism to increase renewable power production. Research like this, with mechanisms predefined and industry interviews to understand incentives for an industry to become more sustainable, is the closest approach to what this research will use. Hence, chapter 3 will discuss the structure to interview value chains to understand downstream company drivers to incentivize the upstream industry to decarbonize. Interviews will be used in the identification of drivers for CFCs to decarbonize their supply chain. In figure 5, this is the right hand side of the research. The approach by Sovacool does not allow to say anything about the left-hand-side mechanism applicability on a hydrogen-based transition.

The main difference of this research with Sovacool's approach is that this research paper does not look into mechanisms which have been in use for years, and instead looks into what mechanisms could potentially influence the industry. As research is lacking knowledge on the relation of mechanisms to CFC requiring decarbonization, more specifically, to hydrogen-based decarbonization, the research will have to define its own research structure. As said, can the method of the CFC willingness partly be based on Sovacool's research approach using interviews. A difference to the paper by Sovacool is the goal of interviews in the research. This research will try to identify drivers for CFCs to change their value chain rather than present the correspondent a discussion on potential mechanisms. This chapter will provide a review on how to decarbonize the industry through mechanisms implemented by CFCs. First, different approaches on incentivizing the value chain will be shown. This shows that in the past, CFCs have changed upstream industries following their requirements, more specifically, 'green' requirements. Following this will mechanisms be presented on how this is done, and has the research to follow an approach of how to determine what mechanisms are best used to initiate a hydrogen-based transition.

2.2 Consumer-facing companies reducing emissions in value chains

This section is focused on decarbonizing the supply chain through whatever means. In the later section, the focus will alternatively shift on renewable power implementation throughout supply chains. Initiatives discussed are included as they are shown to be first of its kind or best practices of industries.

The CDP is a charity trying to enable companies to gather and disclose carbon footprint data. A group of participants, along with the CDP, committed in 2008 to incentivize their supply chain to increase knowledge on environmental information on their whole supply chains (CDP, 2019). With time, many large scale CFCs joining this initiative have increased the awareness to look into the carbon footprint in the value chain. 47 of the 115 major members have set value chain reduction goals, and they intend to incentivize to decarbonize (CDP, 2019). These prominent members establish many different sorts of programs, and some of those will be highlighted in the next paragraphs.

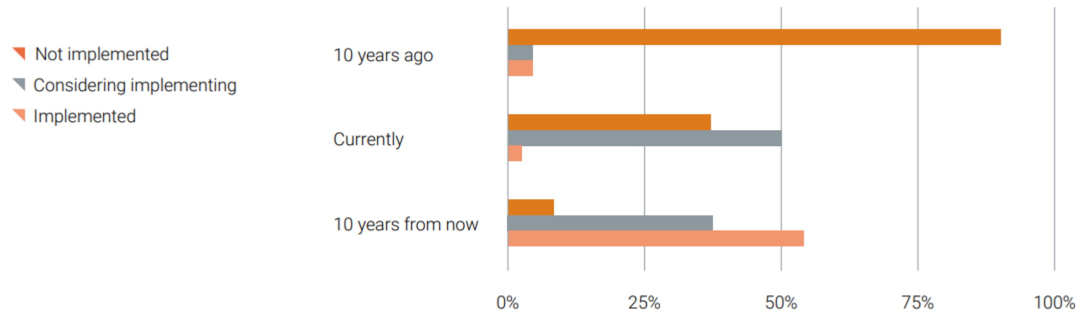

Figure 6: CFCs deciding on suppliers through their disclosed carbon emission data (CDP, 2019)

2.2.1 Value chain initiative: Walmart

Walmart's Gigaton Initiative is a project introduced in 2017 to reduce throughout its supply chain one gigaton of CO2 emissions by 2030 (Walmart, 2020). Together with over 1,000 of its suppliers, Walmart is searching to lower its emissions (Walmart, 2020). To show the size of impact: the project's carbon reduction, if accomplished, would be equal to Brazil's annual emissions (ACORE, 2018).

The matter of how difficult the goals are is up to the companies themselves. Walmart tries to encourage them by helping out in finding solutions rather than giving money to do so. Hence, a financial incentive is not given, rather the positioning of a supplier is increased with the Walmart concern, which gives them more security to operate on the longer term.

2.2.2 Value chain initiative: Mars

Mars Incorporated has given an interview to the ACORE about their intentions to decarbonize their supply chain. The overall Sustainable Generation Plan has $1 billion in the budget to ensure long term growth (Mars, 2019). The company has gotten strict vetting systems to ensure an impact on reductions while gaining returns on investments (ACORE, 2018). The company has committed to a target of reducing greenhouse gas emissions by 67% by 2050, including value chain emissions (ACORE, 2018). The corporate sustainability teams are trying to identify where the largest carbon footprint share is coming from to incentivize decarbonization through market mechanisms in renewable energy usage.

Mars is one of the early adopters of including the full value chain in its carbon footprint measurements and includes it as part of their operations. Current initiatives run by Mars to decarbonize the value chain's stakeholders often include deploying renewable energy. Through partnering with suppliers enables Mars the possibility to bid for larger renewable projects and sign PPAs of at least twice the size as they would do on their own (ACORE, 2018). These actions result in both direct emission reduction as well as indirect emission reduction with benefits from decreased prices by applying an economy of scale effect. This cohesive approach by including stakeholders is an exemplary example of how carbon reduction investment risk is spread over the supply chain while influencing the downstream product to the maximum. Most suppliers they partner with are well-known companies with which Mars has worked for several decades. This has given a bond of trust to work on projects for the future where more value may be created through sustainability. According to the Global Renewable Energy Program Manager, the main focus in choosing suppliers is the energy footprint they have, their relationship to Mars and risks to deliver.

2.3 Consumer-facing companies pushing for green power purchasing in value chains

Parallel market development with the current hydrogen development happened over a decade ago when renewable power came into the market. On the one hand, the conditions were very different as the infrastructure was better structured, and the traded commodity held the same function capabilities (hydrogen replacing conventional fuels can have consequences on processes). However, just like with the current situation, no economic business case was telling the companies to invest in renewable power, and they still did see the added value. Hence, this development of the renewable power market could be seen as the precursor of developments in the hydrogen market.

In 2018, over two-thirds of the Fortune 100 companies had committed their power supply to renewable electricity for their whole operation (ACORE, 2018). According to the American Council on Renewable Energy (ACORE), the multinational companies are at the forefront of enabling renewable energy in their strategy. The acknowledgement of the intrinsic value of sustainable assets and reducing emissions throughout their operations is for others an example to be followed. To add to this, these multinational companies are beginning to implement so-called 'business-to-business market incentives' throughout their value chain to incentivize upstream production, as well as midstream suppliers, to use renewable power (ACORE, 2018). This development is similar, but with lower barriers, to the hypothesis from this research. Some best practice cases discussed by the ACORE are shown in paragraph' *proof: consumer-facing companies changing the value chain*' to show the example of reducing emissions throughout the value chain. Before that, the next paragraph will discuss incentives CFC have taken to enable renewable power in their supply chain. From this, lessons for a hydrogen push in supply chains can be learned.

2.3.1 IKEA: Suppliers Go Renewable project

IKEA has stated to set its target to become climate positive by 2030 and was a first mover in incentivizing renewable power projects throughout a CFC's supply chain (RE100, 2017). The success of uptake was limited, IKEA was possibly too ahead of the situation as it was used throughout 2014 and 2015. Nevertheless, the company had stated by 2018 to relaunch the program with its updated sustainability strategy.

IKEA revealed a statement that it wants to invest 200 million in decarbonizing its value chain (IKEA, 2019). A larger part of this money is used to transform IKEA's supply chain into using renewable power (IKEA, 2019). '*Our ambition is to reduce more greenhouse gas emissions in absolute terms by 2030 than the entire IKEA value chain emits*' - Torbjörn Lööf, CEO (IKEA, 2019). Along the way, IKEA will search for new partnerships with unique perspectives and support them by scaling up (IKEA, 2018). On top of that, the company is ensuring an adequate income for suppliers, which means that in order to reach climate goals, premiums may be paid.

2.3.2 Apple: Supplier Clean Energy Program

Apple initiated a solely renewable power-focused project. Apple reached its own goal of becoming all-renewable near the end of 2018 but was not finished yet as it initiated a program to increase indirect renewable power demand. The company started the Supplier Clean Energy at the end of 2015 to show suppliers their belief of importance to implement renewable energy (Apple, 2019). Apple announced in April 2019 that a doubling of its suppliers has committed to the 100% renewable power target (GTM, 2019). These renewable power developments bring down Apple's value chain emissions as the manufacturing accounts for 74% of the total footprint, which primarily consists of electricity used (Apple, 2019). A total of 71 manufacturers and suppliers have committed to this target which means that the target of 4GW commitment 2020 was already overshot by 2019 (see figure 7) (Apple, 2020). This 4GW represents more than one-third of the electricity required over the whole chain (Apple, 2019). The program update in 2020 states a new company-wide target to transition its whole supply chain to 100% renewable power by 2030 (Apple, 2020).

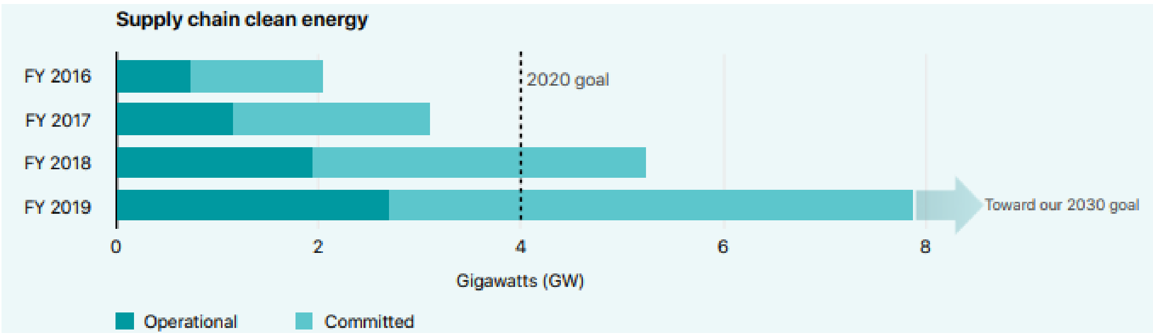

Figure 7: Apple's targets for renewable energy commitments in its supply chain (Apple, 2020)

The first step Apple takes with its suppliers is to look at energy efficiency measures at the 'super facilities' which then are transitioned to renewable energy. Besides that, Apple helps its suppliers by applying a 'Clean Energy Portal', which shows where to buy renewable solar and wind power. Through this portal, Apple is an intermediary to connect its suppliers to energy developers at the highest quality (Apple, 2019). Apple's program update states that they help out suppliers as well through financial support and overcoming regulatory barriers. An example in the emissions related to Apple's products can be shown through the iPhone 8, which has 83% fewer carbon emissions than the iPhone 6 (RE100, 2017). This reduction is mainly due to an increased supply chain purchase of recycled scrap aluminium.

On top of helping the supplier to transition, Apple considers itself to be responsible to take leadership to advocate for policy changes. The company spends millions between 2017 and 2018 to lobby for electricity policies (GTM, 2019). Colin Smith, who works as an analyst for Wood Mackenzie, sees companies pushing their affiliations to pursue renewable commitments. He stated '*We are now moving into a world where corporates are enabling their supply chain and their partners and customers* ' (GTM, 2019).

2.3.3 Other programs

Not only IKEA and Apple have started to decarbonize its supply chain through helping/requiring suppliers and manufacturers to use renewable energy. Some other examples are given in appendix III.

2.4 Consumer-facing companies changing product requirements in value chains

2.4.1 Timber certification

Rainforest deforestation has been a major global concern for decades and is continuing to do so as countries and companies are trying to gain wealth for their self-interest. For this reason, the United Nations Conference on Environment and Development (UNCED) had developed guidelines and principles in 1992 to maintain needs to combat this deforestation (Ghazali, 2020). This complex issue found part of its solution in the industry and trade of timber which turned out to be a 'key agent' (Ghazali, 2020).

In the beginning, many NGOs and global media targeted the international trade of timber to be the source of the problem. Gradually, overtime campaigns spearheaded from banning and boycotting timber towards CFCs and organizations trying to find a sustainably managed production of timber which would not be harmful instead. Hence, the sustainable forests providing timber came to life where this timber would be labelled or certificated following a system of global standards, to help differentiate between different kinds of timber. *'The aim was to use market-based incentives and voluntary compliance'* (Ghazali, 2020). Companies like IKEA, who use large amounts of wood, have worked for long times to promote and advocate for sustainable forest management (IKEA, 2019).

Timber certificate is a written statement that acknowledges the origin of the wood and is attached to a batch of wood. The certificate explains the quality and what farmer it comes from and is often validated by a third- and independent party. For timber companies, the certificates can be a validation of their managed practices, and they can be compared against standards designed by the international community. Through certification, transparency in the upstream timber production is enabled, which validates environmental claims made by producers which would traditionally not be able to confirm this, as information was not disclosed. The certificate includes two key components:

- Product certification: provides traceability of the timber for further phases in the supply chain. These further phases are included in the environmental footprint of the timber and could have a significant impact on the valuation (Ghazali, 2020).
- Certificate of sustainable forest management: forest inventory/planning, harvesting, silviculture and social impacts of timber production on the area (Ghazali, 2020).

This differentiation in consumer behaviour has, in turn, influenced producers to adhere to these market signals and offered the sustainable timber for a premium with enough economic margin to make the business case feasible (Ghazali, 2020).

For the certificate to be internationally recognized, an international standard is required alongside participation among countries and organizations. The approach of managing the forest is linked to ISO standards in the 14000 series standards which are related to environmental management tools and provide a measurement of a company's environmental practices (Ghazali, 2020). For both key components, a credible institution is required to identify and evaluate the process against the given standards to protect the integrity of the certificates. Objectivity and transparency have proven to be critical values for such a system to be implemented successfully. On top of that, for monitoring of transport, processing, secondary manufacturing and retail a log is required. With the certification of timber, it has become possible for CFC's to prove their willingness to buy responsibly. As such, one can see in annual reports from companies like BAM statements about timber purchases and recognition to the environment.

2.4.2 Renewable power Guarantee of Origin

A Guarantee of Origin (GoO) is a document which proves that the power bought is coming from renewable production. During the early 2000s, utility companies tried to sell renewable power on the business market as well as the household market but required the differentiation of generation to be acknowledged (Hamburger, 2019). As power is transported over a common grid, the traceability of power used is impossible (Gkarakis and Dagoumas, 2016). Hence, the GoO for renewable power producers enabled them to licence their capacity as a differentiated product to consumers. One GoO represents one generated MWh of power (Hamburger, 2019).

The European Energy Certificate System (EECS) is an instrument of the Association of Issuing Bodies (AIB) which also governs certificates of other sustainable products like heat for industrial processes obtained through renewable resources. Institutional bodies like these are essential for the certificates to be recognized in order to prevent fraudulent markets.

2.5 How to drive transition in a value chain

From the previous examples and analyses by the CDP, a framework can be made with all actions a CFC could take to implement transition in their value chain successfully. These steps should be communicated openly to suppliers and material providers for a CFC to gain the best support from their value chain. It is essential to understand that the CDP, who has been the leading resource of this approach, is a research institution which can not be considered to be top tier scientific research. Their interest is mainly in promoting value chains to decarbonize, and reports may be written with a subjective view. Knowing this, mechanisms should be looked upon critically and both the approach, as well as the conclusion, will not include any CDP remarks. Instead, the structure and availability of mechanisms in a CFC's reach will be used to provide the full set of mechanisms available for hydrogen implementation. The following sub-paragraphs will go into more detail wherein step 3, the full set of mechanisms is presented. At the end of the research, these mechanisms will be discussed upon hydrogen implementation.

Understanding
To build an effective supply chain program, CFCs need to know the footprint along their whole value chain to understand what impact their business has on environmental boundaries. To understand the degree of freedom a CFC has, it is needed to take the resilience of the business into account, to understand the level of playing field. This understanding is also essential for upstream production to see what opportunities can be gained without disrupting their operations too much.

Targeting
After analyzing and understanding the supply chain's opportunities and risks, plans can be developed to address progress. The vision and ambition of the CFC needs to be translated for supplier-specific applicability to what they are capable of adding. A strategic roadmap, including a timeline with actions, is to be developed in line with the objectives. The final goal of the roadmap is a reduction target either medium or long-term to show to internal business units, as well as the market what transition a company is committing to. Targets can contain different sub-targets, like a renewable power target besides the overall emission reduction target. For a CFC, it is important to help suppliers efficiently and prioritize whom to help the most. Figure 8 shows the prioritization strategy.

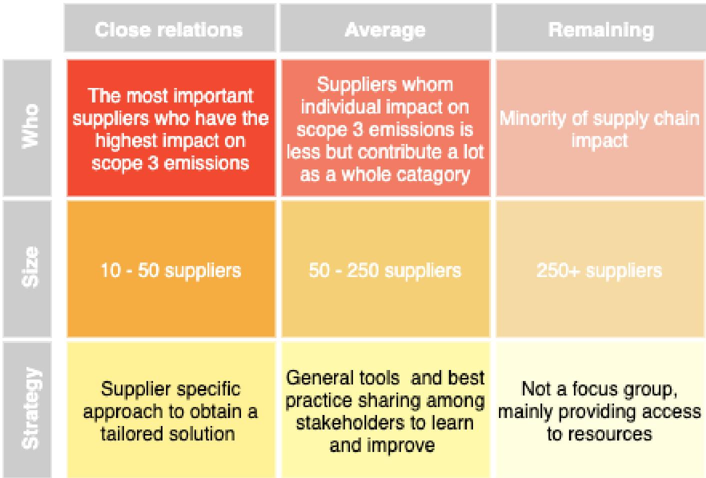

Figure 8: Prioritization of suppliers to collaborate with

Acting
With defined targets, the analysis can start on how to optimize processes and apply mechanisms to change supply chains. Often a mechanism entails that a CFCs should help their suppliers to share the risks. All of the projects by CFCs discussed above have tools for the supply chain to decarbonize, but in varying levels of participation and diverse resources to do so. The commonly used tools by the CDP and other programs are listed in chapter 2.6 (CDP, 2017) (CDP, 2019), which in turn can be discussed for hydrogen implementation usage at the end of the research.

Iteration
Continuous incremental improvements are required to keep the business becoming increasingly sustainable. A continuous learning process with iterations and data sharing from implementations will help businesses achieve this, and further decrease their carbon footprint. The ultimate goal of the CDP is to ensure a learning process for other companies and share best practices among participants.

2.6 Mechanism availability for consumer-facing companies to change the value chain

2.6.1 Mechanisms

The research's understanding of concepts will be explained in more detail for the later discussion on hydrogen-based transition. Any implications about what other organizations consider to be the meaning or value of these mechanisms will not be taken an interest in, and definitions of mechanisms will be given underneath (CDP, 2017) (CDP, 2019).

- **Industry and market standards**: Certification and traceability of products (e.g. timber certification). Industry-wide standards and regulations assure that a certificated product holds additional value and that standards have been met. This enables the differentiation of sustainable products against the traditional ones.

- **Performance standards and incentives**: Mechanisms for CFCs to give preferred supplier status recognition to those suppliers being best practices in sustainability. CFC providing public recognition of commitments made by their supplier enables these suppliers to improve their branding towards the public as well as potential customers.

- **Collaborative innovation**: Advising on what general 'off-the-shelf' high impact solutions to implement (e.g. energy audits to decide which renewable supplier to choose from). Past incentives have companies like British Telecom helping suppliers with cooperating agreements with renewable power suppliers like Npower.
- **Supply chain optimization**: The larger share of decarbonizing mechanisms in this area are related to data sharing platforms to increase (energy) efficiency. CFCs working together with their suppliers on lean management logistics like optimizing and reducing the required transportation of goods.
- **Business model innovation**: Creating downstream value by implementing circular businesses or changing the business model of suppliers. Working together on solutions and innovation like automotive companies working together to improve motor components to make the car become faster. Other examples of a shift in the business model are by increasing product lifespans and introducing product-service systems.
- **Product design**: This mechanism provides suppliers with a design guide to develop a circular product and how to express this sustainability in the design towards customers. The product design is more on how to make use of sustainable progress on the 'commercial and customer' level. Using small efficiency gains in the product design enables to present the product sustainably.
- **Industry and sector-level collaboration**: Collaboration through including multiple stakeholders from different industry chain levels and trying to solve complex matters from brainstorming sessions. Collaboration is more on the education side of transformation rather than acting on it through spending resources on transition together.
- **Supplier development and collaboration**: Online forums to train, support and assess existing suppliers in the supply chain. The main goal is to improve efficiency programs and energy usage of a supplier through knowledge from the CFC and other suppliers. Some cases implement financial tools to support investments (e.g. investments in supplier's renewable portfolio).

All incentives can be considered either to initiate higher efficiency in a value chain or to be a transformation mechanism. The difference between the two can be hard to comprehend as efficiencies can be part of a transformation. Efficiency methods are already used in many industries, and in order to decarbonize further, a transformation is required. Hence, the interpretation of transformation is radical changes in the processing technique, which have a high impact on decarbonization. Efficiency mechanisms represent smaller improvements with the processes remaining as they were used to be.

On top of that, there is a focus either on the supply chain versus product offering. Again a more in-depth explanation is required to understand the research's difference between the two. Supply chain mechanisms focus on the traditional supply chain changes where the moving of goods, or usage of energy, throughout the supply chain is changed or optimized. Supply chain improvements are well known under data gathering and supply chain optimization through these data which, consecutively, reduces emissions. Alternatively, in the product offering, a change is made through the product's design or valuation by industry and consumer. Figure 9 shows the focus areas with the corresponding mechanisms to it.

2.6.2 Determining mechanism applicability

All of these mechanisms will be used in chapter 11 to understand to what extent they could complement hydrogen-based decarbonization in the heavy industry. The discussion of what mechanisms might work the best mainly will be based on the amount of resource commitment required from the CFC and the impact it can have on succeeding hydrogen-based decarbonization. The discussion on

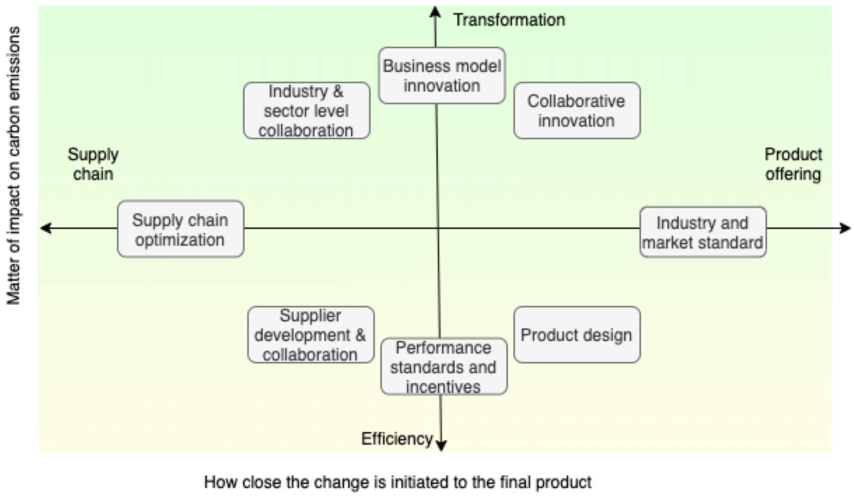

Figure 9: The tools positioned against efficiency vs. transformation and supply chain vs. product offering. An adapted version of CDP report (CDP, 2017) (CDP, 2019).

the applicability will be qualitative and based on the mechanism explanation alongside the process knowledge obtained in the ongoing research. Chapter 5 for example, describes to what extend hydrogen can decarbonize the heavy industry. This section will show the amount of change required in a process to implement hydrogen. If this required change in a process is very high, a mechanism like supply chain optimization is not likely to be most applicable as it looks most often into transport and lead time optimization. Still, the main usage of mechanisms is not the exact relative applicability of mechanisms, but rather in what way the CFC drive to decarbonize its supply chain can be supported by mechanisms. To do so, first, the research will have to examine if there is a driver for CFCs to use decarbonized, hydrogen-based, products. If there shows to be some driver for CFCs, the discussion on mechanism influences is considered to be just.

3 Structure of sectoral analysis

This chapter describes how value chain analyses are structured and what important aspects require research, to understand if CFCs have incentives to drive upstream industry to decarbonize.

3.1 Value chains

After the identification and explanation of the heavy industry's sub-sectors in chapter 5, the following chapters will go deeper into the corresponding value chains. These chapters include the interviews which are elaborated in section 3.2. The structure of the value chain chapters will be as follows: value chain mapping analysis, technical analysis, stakeholder positioning, and interviews with both upstream and downstream companies.

A definition of supply chains by Christopher is a "*. . . network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer*" (Christopher, 2005). Hence, in this sense, a supply chain consists of two or more stakeholders, each adding value to a specific commodity/product/flow. The supply chain includes all stakeholders related from production until the 'end consumer', so at the back end, the final target group who uses the end product should be incorporated as well (Stadtler, 2015). A value chain describes a wide range of activities involved to a product or service, and should not be envisioned as a tangible reality, but rather be used to simplify a framework of how this part of the world works (Mitchell et al., 2009).

3.1.1 Technical analysis

Though the research will mostly focus on qualitative aspects to stakeholder engagement, some quantitative aspects related to the feasibility and consequences will be explored as well. The case study has set a scoped boundary where an end product is identified. Following this boundary, consequences of the hydrogen usage upstream in the process can be calculated. For example; a case study on the automotive industry will include the percentage of cost increase given sustainable hydrogen is used for steel production. This increase, in turn, can be matched with driving forces in the stakeholder analysis to reason whether the price increase would fall within the willingness to pay.

Other quantitative aspects related to the demand sector can be researched on top of the qualitative willingness to pay (e.g. how much the company is trying to reduce carbon emissions over the past years, which trend could be increased by using green hydrogen-based steel). All of these quantitative aspects help to understand how strong drivers must be in order for the industry to adapt to sustainable processes and to increase hydrogen demand. Through interviews with the CFCs, their view on the additional cost can be understood. The discussion on the willingness to pay a premium will not be an exact outcome. Instead, the interview will try to understand to what extent some additional premium might be paid. If a premium is likely to be paid, one could argue that a value chain incentive may be of significant influence to drive transition in the upstream industry.

3.1.2 Stakeholder analysis

Stakeholders in the chosen demand sector have to be identified, and correlations between them and the sub-industry are explained. A stakeholder analysis will include a graph with some stakeholders, positioning themselves relatively among different variables, and distinguishes the innovative stakeholders from the traditional ones. On top of that, the willingness to change throughout a market needs to be identified, alongside which stakeholders are most willing to drive the potential transition. The stakeholder graph will include on the Y-axis a companies relative willingness to look into/change to hydrogen-based products. The x-axis will show the positioning of the stakeholder in the value chain, going from upstream production to downstream consumer-facing companies.

Within companies changing to become carbon-neutral, the research's focus should be to what extent they include their emissions from the supply chain as well. The supply chain emission consideration is a vital aspect of the research as some companies are currently not taking any emissions, related to their products bought, into account. There are three different scopes of emissions a company is responsible for:

1. Direct emissions from the company which are fully within their control. Examples are on-site power production, process emissions or fleet vehicles.

2. Indirect emissions related to energy purchased from outside the company but used within the company. For example, electricity and heat which is used in processes.

3. The indirect emissions outside the organization, and out of the organization's control. Indirect emissions often are the larger share of carbon footprint represented in a product (Protocol, 2013).

Figure 10 shows these different scopes with examples what is included in which scope. For this research it is of importance that CFCs include scope 3 emissions because the hypothesis is that: *CFCs could demand emission reduction in the materials bought from the industry, for them to differentiate their consumer product against other CFCs.* If no company would even consider including scope 3 in explaining their carbon footprint, no demand requirement change would take place. Most companies only account scope 1 and 2 in their sustainability targets though the average size of scope 3 accounts for about 70% of the total emissions (ACORE, 2018).

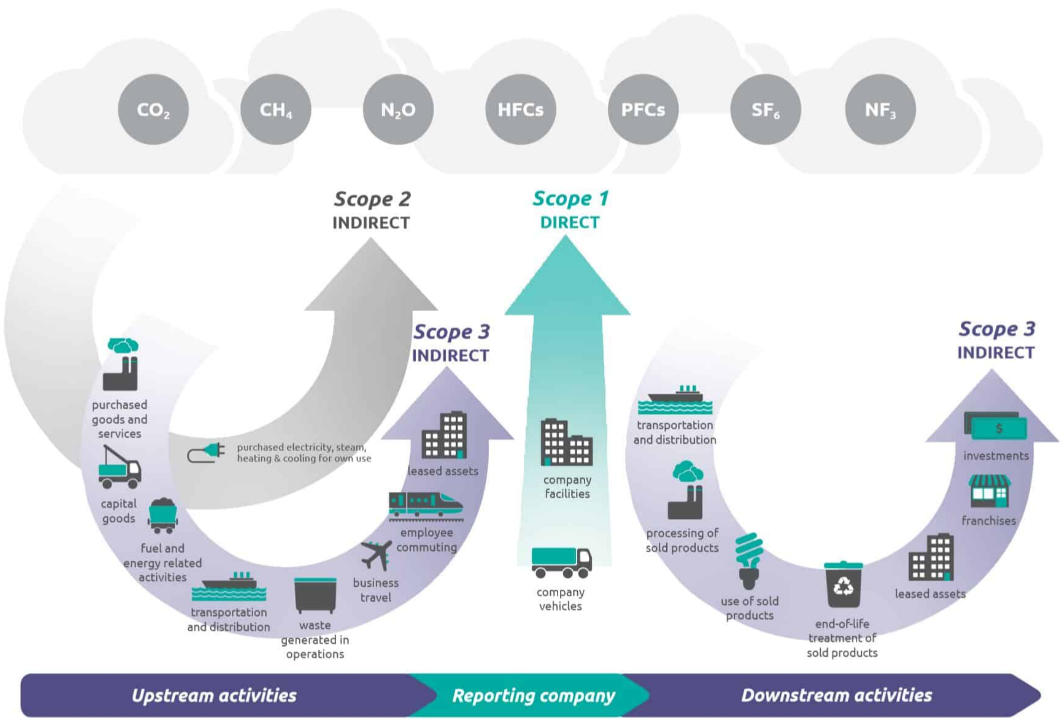

Figure 10: Different scopes of including company's emissions (Protocol, 2013)

3.2 Interviews

Interviews are part of the case study to verify: the positioning of stakeholders in the stakeholder analysis, understand what drives stakeholders towards carbon-neutral products, understand differentiation possibilities of carbon-neutral products and reflect with them on technical consequences. The most important interviews will be the ones related to the case studies, as these represent the tendency to change to hydrogen-based products for a whole business segment. There are different groups of interviewees to be discussed, and the following groups are identified related to hydrogen consumption in the heavy industry:

- *Hydrogen producers (e.g. Air Products, Air Liquide or Linde)*
- *B2B suppliers of hydrogen (e.g. Shell)*
- *Heavy industry sub-sectors (e.g. Iron & Steel or Ammonia*
- *Consumer-facing sectors (e.g. Automotive, Construction or Mechanical Engineering)*
- *Enabling players/consortiums (e.g. HYBRIT, H2FUTURE)*

The group 'consumer-facing sectors' will be interviewed extensively, as the case studies are performed on them. Heavy industry sub-sectors represent the companies which could implement hydrogen in their processes, hence, are of importance to interview as well. The other three groups are included to cover the scope of hydrogen implementation. These do not represent too much importance to the research, as they are mostly on the hydrogen supply side, which is out of scope. Hence, these interviews will, besides Shell as refinery owner, not be conducted. Interviews will be held in a semi-structured way where a one-pager with questions is presented upfront (appendix IV). Along the way, some interviews may take deviations. This can be the case with semi-structured interviews and will be encouraged, as long as there is an added value to the research. Interviewees can be contacted through the researcher-, Shell- or TU Delft's network.

From these interviews, alongside industry-specific scientific research, a table will be constructed to show which sectors have the potential to initiate decarbonization mechanisms. The variables used to assess the applicability of the hypothesis will be:

- Upstream willingness to change
- Downstream willingness to change
- Downstream willingness to include scope 3 emissions
- Upstream product cost increase
- Downstream product cost increase
- Impact on product's carbon footprint
- Overall score, sector to change

These variables take both technical restrictions to adapt, like cost increase, as well as willingness and motivation of sectors to change, into account. The third addition, besides these two groups of variables, is the impact on a final product's carbon footprint because the reduction in upstream production should ideally be of such influence so that the final product could be differentiated against the traditional product.

3.2.1 Upstream interviews

In the upstream interviews, the goal is to identify some recognition to the matter of the topic, and if they already experience deadlines by CFCs to decarbonize. Possibly, their view on hydrogen as a decarbonization method may be far reached, and they potentially prefer other techniques being implemented. Hence, it is of importance to enter the interview with an open mind towards decarbonization methods to the answers given by them, and not steer the interviewees into a particular direction where hydrogen comes out as the (sole) solution. From these interviews, the main points of concern to use hydrogen in processes could be acknowledged, and drivers to transition are identified. The primary outcome may be the requirements for the specific industry to produce a (close to) carbon-neutral product and how they would like to spread out the risks related to investments among stakeholders.

3.2.2 Downstream interviews

The downstream company interviews are of importance to learn whether they already evaluate 'green' upstream products differently and whether this valuation is expected to change. To add to this valuation, the research needs to understand to what extent the final consumer's product increases in value, as this could drive the CFC to initiate incentives throughout their supply chain. Customers, following the hypothesis, should be willing to pay more for a decarbonized product and hence, downstream interviews could provide some insight in whether it is valid for a specific sub-sector.

4 Supply & demand

The research will have to define in 4.1 the general basics of hydrogen production to understand current trends (e.g. production price) and consequences (e.g. emissions) of different hydrogen production methods. After this supply definition, the general demand sectors where hydrogen could be used in are mapped out in section 4.2.

4.1 Supply

4.1.1 Grey hydrogen

Currently, by far the larger share of all industrially produced hydrogen comes from natural gas through the steam methane reforming (SMR) process (Simpson and Lutz, 2007) (Sanusi et al., 2017). This method, alongside hydrogen production through coal, is called 'grey' hydrogen production. This process is a filthy and carbon-emitting technique. It should not be confused with the sustainable image that hydrogen has over the general public. More on the processing technique is given in appendix V, where a detailed description is given.

4.1.2 Blue hydrogen

Hydrogen is highly praised for becoming a more sustainable resource than fossil fuels. As such carbon emissions, which are currently a by-product of the process, should be reduced as much as possible. Blue hydrogen uses the same SMR process but includes a new process step for emissions to be captured and stored. The additional process, called Carbon Capture & Storage (CCS), captures CO2 from the process and transports the gas through pipelines or boats to be stored underground (CEDelft, 2018a) or in ocean floors (Nikolaidis and Poullikkas, 2017). Current markets use little volumes of blue hydrogen because the CCS technology is still advancing and is currently mainly used as feedstock in ongoing chemical processes (CEDelft, 2018a). In order for this production/storage combination to grow, a more viable business case must occur where large scale CO2 can be stored against low costs. Research from CE Delft on CCS in SMR facilities is shown in table 2 where CCS shows not to capture all CO2 emissions.

	CO2 capture	CO2 capture levelled cost H2 (EUR/m3)	CO2 avoidance cost (EUR/kg CO2)
SMR (without capture flue glass)	50 - 70%	0.135 - 0.146	0.037 - 0.060
SMR (with capture from flue gas or H2 as fuel)	85 - 90%	0.154 - 0.165	0.049 - 0.070

Table 2: CE Delft's Techno-economic SMR carbon-capturing overview (CEDelft, 2018a)

4.1.3 Green hydrogen

The hydrogen most praised in media and science to be 'the energy source of the future' is the so-called 'green hydrogen'. With the RES increase all over Northern Europe, projects are emerging to use solar and wind power for electrolysis to split water into hydrogen and oxygen (equation 1). Electrolysis is a well-known and mature approach to split water through an endothermic process (hence using electricity to start the reaction) (Nikolaidis and Poullikkas, 2017). The alkaline based electrolyzer is the oldest method but has low power densities compared to newer technologies. The Proton Exchange Membrane (PEM) show the highest potential. Where current efficiencies lie between just 65 and 80%, future expectations are that this will increase to 85% (IEA, 2015). Any renewably generated power can be used as raw material like solar thermal, solar PV, wind and nuclear.

$$2H_2O + power \longrightarrow O_2 + 2H_2 \tag{1}$$

Local hydrogen production through electrolysis, like at fuel stations, is seen as potentially cost-effective in the future (Acar and Dincer, 2014). Electrolyzers can currently, on a commercial scale, produce up to 3,000 ton H2 (20MW) annually (McPhy, 2020). Large scale, like 100 or more of MW capacities will not be economically competitive any time soon without governmental support.

Electrolysis is not the only method where future green hydrogen production originates from. Biomass, which are plant and animal material based raw materials (like wood, crops and industrial residues), are considered carbon-neutral as well and can result in hydrogen production through a thermochemical process. Though carbon dioxide is released upon reaction, the amount of absorbed emissions during the feedstock's lifetime is considered equal to the emissions emitted afterwards (Nikolaidis and Poullikkas, 2017). This method of non-electrolysis hydrogen production is less likely to reach scale and is not discussed among reports by the IEA (IEA, 2019b) (IEA, 2020).

4.1.4 Overview hydrogen supply

To conclude the subparagraph of hydrogen supply, table 3 shows a summary of Nikolaidis' research with the principal (dis)advantages of production techniques listed. In order for CCS to be used from a supply perspective, either the ETS CO2 price needs to be at a level to make CO2 capturing economically feasible, or down the supply chain drivers must develop to make the willingness to pay to reach the required amount.

Method	energy efficiency (%)	Advantages	Disadvantages
Blue	74–85	Mature technology with existing infrastructure, transition technology towards green hydrogen	Dependence on fossil fuels
Green	40–60	No CO2 using RES, proven technology, existing infrastructure, abundant feedstock, O2 as byproduct, contributes to RES integration as electricity storage	Low efficiency, high (capital) costs

Table 3: Grey, blue and green hydrogen production (Nikolaidis and Poullikkas, 2017)

Appendix V describes in more detail some of the literature research on what is required for green hydrogen to become competitive against the other production techniques. Nevertheless, the research's hypothesis holds that there is an added value, or 'premium', for the green production methods and as such, does not require the production processes to become break-even with each other.

4.2 Hydrogen within demand sectors

Future energy demand for hydrogen will likely develop in many different sectors. Most sectors will implement electrification where possible and where not, often use sustainable alternatives. Hydrogen has potential in specific sectors, and hence, this section will define sectors and scope into the industry's sub-sectors to identify processes applicable for hydrogen usage. The four highest-level energy demand sectors identified (by Shell) where hydrogen could fulfil energy demands are: Transportation, Building, Light Industry and Heavy Industry.

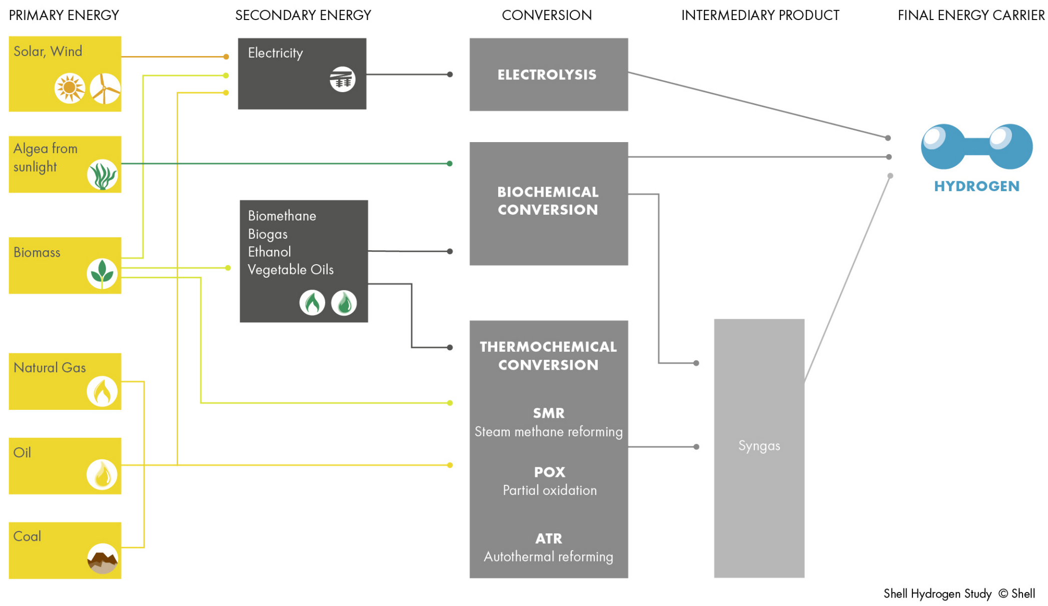

Figure 11: Hydrogen production options (Shell)

Most researches consider transport to encounter the highest percentage growth in the near future and should return the highest revenues (IEA, 2019a) (Emonts et al., 2019). Within transport, a sub-sector distinction can be made in Air, Shipping and Road & Rail. The main priority for hydrogen vehicles is for the fuel cell costs to go down, as well as hydrogen storage costs. If so, hydrogen fuel cell electric vehicles (FCEVs) could become competitive with electric battery based cars on long distances (IEA, 2019a). Most of the current FCEVs are found in Europe, California (US) and Japan. Though the amount of FCEVs doubled within a year, the total pales in comparison to the entire car industry. Hence, until 2020 it could barely be called baby steps of progress made among FCEVs. Car manufacturers taking the lead in FCEVs are Toyota and Hyundai whom both have expressed their intention to grow substantially in FCEV production (Toyota, 2020) (IEA, 2019a).

Currently, most heavy-duty vehicles running on hydrogen are forklifts and a few thousands busses and trucks (for demonstration purposes) on global basis (IEA, 2019a). China has taken the lead using hydrogen-based vehicles in heavy-duty transport by using thousands of hydrogen trucks from 2019 on-wards (IEA, 2019a). Since shipping and aviation have only a few other fuel options available, hydrogen, has a high potential to become the low-carbon option if policy supports push these transportation sectors to decarbonize. Still, only a few ships have hydrogen as a fuel, though expectations are that hydrogen and hydrogen-based fuels can grow someday (IEA, 2019a).

Building heat is the second high-level sector to increase demand for hydrogen potentially. The building sector accounts for 30% of the total energy usage and 28% of CO2 emissions globally, mostly through heating and hot water cooking (IEA, 2019a). Using low-carbon fuels for heat demand depends on many factors like building structure, energy prices & efficiency, who owns the building and so on. Multiple different scenarios exist where hydrogen can play a role in decarbonizing buildings. For example, blending hydrogen into the existing gas infrastructure as a transition fuel can reduce the carbon footprint, but not reduce it to carbon-neutral yet.

The light industry consists of the sub-sectors: Wood (products), Food & Tobacco, Textile &

Leather, Agriculture & Forestry, Mining & Quarrying and Machinery & Transport Equipment. The companies within these sectors vary largely in size and are often small business owners. Often, materials from the heavy industry are going into the light industry to be processed further. As the fragmentation is extensive, and hydrogen does "not yet hold too much-praised input" in this sector, further consideration of the light industry is not given.

4.3 Introducing hydrogen to the heavy industry

The final sector where hydrogen is valuable is to decarbonize is the heavy industry which, with 8.5 GtCO2, accounted for 24% of the global emissions in 2017 (IEA, 2019b). Expectations from the IEA are that the carbon emissions peak will be reached before 2025, after which a steadily decrease in carbon emissions will be initiated while production of goods will steadily keep on growing (IEA, 2019b). The main drivers for this emission decrease, while growing in production, according to the IEA, is related to energy efficiency projects, renewable fuels and the implementation of low-carbon processes. Highlighted as critical requirements are hydrogen-based production and CCS mechanisms implemented in the heavy industry, where the primary drive should come from governmental innovation funding and CO2 reducing policies. This governmental intervening was at the beginning of this research stated as one of the two ways to implement hydrogen implementation in the heavy industry. This research will continue to gain knowledge in how the demand side of the heavy industry can force upstream industries to transition as well. First, the sub-sectors will have to be identified to see where in the heavy industry, hydrogen-based products can be made.

5 Hydrogen within heavy industry

This section introduces opportunities hydrogen has in the heavy industry. Hydrogen value applications are introduced in 5.1. It includes all industries where hydrogen could be valuable, and which industries are taken into account for further research. Following this, 5.2 to 5.5 will describe different industry sectors where sustainable hydrogen can be used to decarbonize current processes. At first, the current production processes will be addressed. Secondly, macro-economical developments of these markets will be discussed to see if there could be a need to differentiate or innovate in order to increase competitiveness. To finalize, for each sub-sector, possibilities of hydrogen application in processes will be described. This section describes how the hydrogen-based sustainable process technique will differ from the conventional ones and gives some insight into the transformation required.

5.1 Defining value applications for hydrogen

Hydrogen used in the heavy industry can be used for different kinds of value-adding applications. There are two main categories: energy-related and non-energy related applications. A smaller third application could be identified as well, which uses the two different applications as a combination. This smaller section consists of the production of sustainable hydrogen-related fuels, which in turn can be used for transportation like aviation or sea shipping (Jörg Gigler, 2018). Here, hydrogen is used as a raw material (non-energy related) in the production of the fuel, with the final usage being a fuel in a process (energy-related). Another combination of possible application is natural gas-based liquid fuels where hydrogen can be mixed with the carbon monoxide into a syngas (Jörg Gigler, 2018). However, for the heavy industry, the most value could be gained from within the first two applications, and elaboration, where this can play out, is given underneath.

The more sector widespread application for hydrogen in the industry is as a source of heat. This relates to the energy-related application of hydrogen and can be used in low, medium and high heat applications. Although low heat applications in the industry could be fulfilled by hydrogen, electrification is the most obvious choice in these cases. However, sometimes temperatures have to be reached where commercial availability of electrification does not fit that well, as it has an upper limit of (only) about 400 degrees Celsius (N&M, 2018) (Occo Roelofsen and Witteveen, 2020). For processes where higher heat requirements are demanded, electrification has its limits. Here, other fuels will be required, and hydrogen could be a good fit, especially because high heat processes can run on hydrogen without large scale adaptions to the equipment (IEA, 2019a). This is a clear advantage. Like for example, aluminium recycling which uses natural gas furnaces or cement (currently) running on waste-derived fuels. (IEA, 2019a).

The non-energy related part of hydrogen usage is the application where hydrogen is used as a raw material in production processes. This application includes hydrogen usage as a reducing agent and as process gas for material treatments (Jörg Gigler, 2018). For a long time, hydrogen has been used in the production of ammonia. Another existing non-energy application of hydrogen is the usage in oil refineries where (bio)fuels and heavy oils are (re)processed.

Any sector of the heavy industry has some energy needs which hydrogen can fill, as every sector requires sources of heat in medium or high-temperature processes (figure 12). The IEA states that up to 2030, no hydrogen will get a foothold in the high-grade heating applications, as long as no broad policy support will be implemented (IEA, 2019a). From the market perspective, most likely by 2050, hydrogen will find itself of more value to the industry given the prices of hydrogen have dropped (IEA, 2019a). The same report continues with figure 12, which shows energy demands per heat category per sector. Following this figure, sectors like aluminium and cement show considerable high-grade heat demands. These can not be fulfilled by electricity.

Although these sectors' energy demands are large volumes, and hydrogen could indeed be of significance, this research leaves these sectors out. The reason is the possibility of other techniques to decarbonize these industries. In IEA, Hydrogen council and other rapports, it is stated that for aluminium and cement industries, it is unclear which solutions should be used to decarbonize (IEA, 2019a) (IEA, 2020) (HydrogenCouncil, 2020). To including high-grade heat of all sectors as an application would not be feasible to research, as the research would not be able to construct the downstream value chain because of the too-broad scope. Although the research leaves cement industries aside, lessons could be learned if compared to the steel industry, as both supply downstream construction companies.

Iron & steel and (petro-)chemical industries show the best potentials for large scale sustainable hydrogen implementation (IEA, 2020) (HydrogenCouncil, 2020). Only the specific sectors where sustainable hydrogen is a critical component to decarbonize are taken into account. The iron & steel, as well as the (petro-)chemical industry, holds high potentials for sustainable hydrogen usage and will be discussed on-wards.

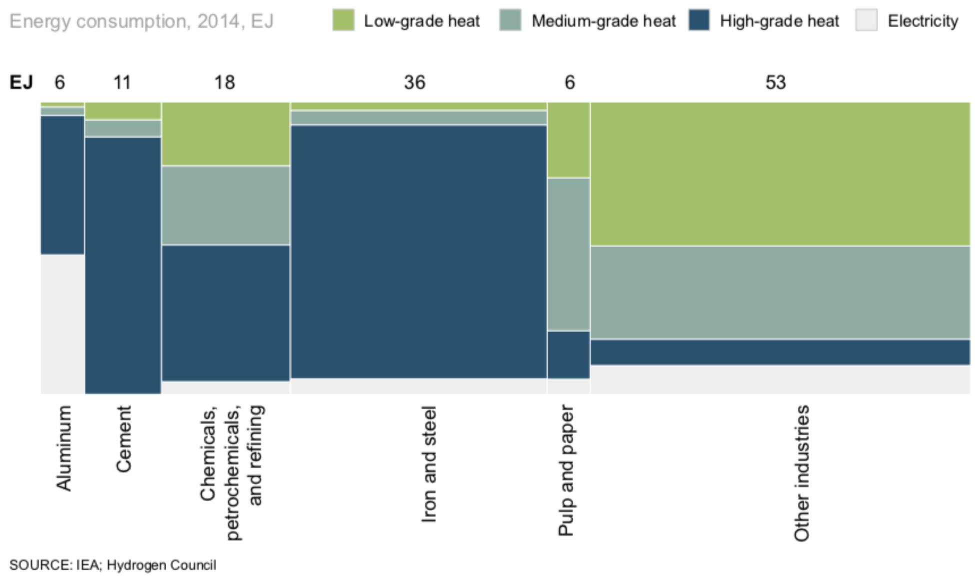

Figure 12: Energy intensity demands per sector (IEA, 2019a)

5.2 Iron and steel

The first sub-sector of the heavy industry described is iron & steel. The following paragraphs will discuss background into this sub-sector to understand market developments and how the market is structured. Hydrogen application in the non-energy, as well as energy-related applications, are addressed.

5.2.1 Current state of the art production methods

There are generally two different production routes to produce steel: primary and secondary steel production. Primary production uses iron ore as raw material, and secondary production uses recycled scrap steel.

The most used production method of steel is through the integrated iron and steel or Basic Oxygen Furnace (BOF) (see figure 13). The BOF method is the largest used process in Europe, with 58% of the total steel production in 2018 (EuroFER, 2019). BOF is the traditional production process and is known for the large share of emissions released to it because of the amount of required coke to make pig iron (Berger, 2020). As the process is well known, efficiencies and carbon emission reductions have been implemented over the past decades with methods like optimizing pellet ratios, top gas recovery turbines and coke dry quenching (Berger, 2020). Still, the process remains highly polluting, and hence, Europe's steel industry is responsible for 4% of the continental's carbon emissions (EuroFER, 2019). BOF's energy input is generally coming 89% from coal, 7% from electricity and 4% from natural gas & other gasses (WSA, 2019a). Though part of the coal demand can be replaced by natural gas or even hydrogen, carbon-neutrality will not be reached through the BOF steel process (Berger, 2020). Following a report from the Steel Institute VDEh the technical efficiency limit of resources in the reducing agent's consumption is reached (Ghenda, 2019). As EU producers reached the limit of thermodynamic processes, the industry should look at alternatives if it wants further to decarbonize (Ghenda, 2019).

The second production method of steel is through 'Electric Arc Furnace' (EAF), which can reform recycled steel, is less energy-intensive, and has about 2.5 times less CO2 emissions per tonne steel compared to BOF (IEA, 2019b) (Mandova et al., 2019). The average EAF plant is currently also far from carbon-neutral and uses 50% electricity, 11% coal, 38% natural gas and 1% of energy from other sources (WSA, 2019a). Still, energy efficiencies are to be gained in this relatively newer process, and it holds potential to run on almost solely (renewable) electricity. Besides using recycled steel, EAF can also use Direct Reduced Iron (DRI) as raw material and turn this into steel using the same process. In this sense, EAF can be considered as primary steel production, just like the BOF process.

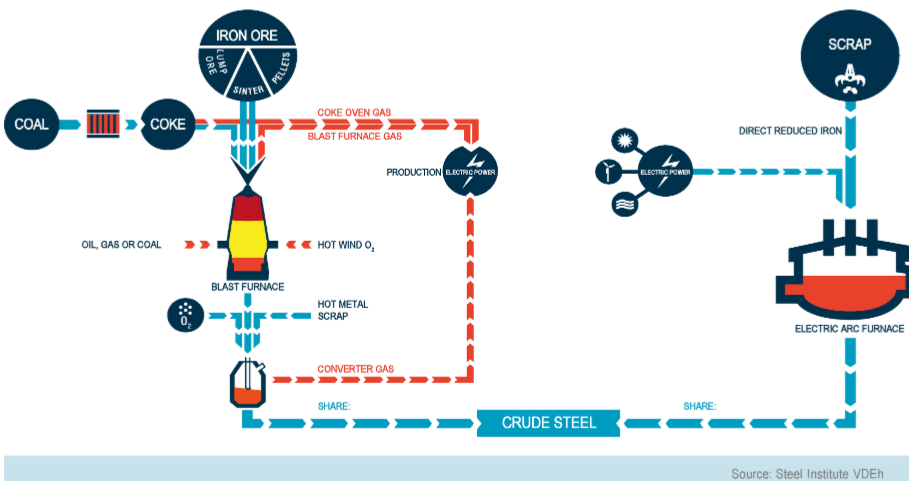

Figure 13: Graphical explanation of the BOF and EAF processes

Future expectations are that more EAF methods will be used as the carbon emissions, capital- and operational expenses are lower (WSA, 2019a). According to Mandova et al., scrap steel is not capable of delivering the necessary demand increase to replace BOF. Hence BOF is expected to dominate the European Union at least until 2050. (Mandova et al., 2019). However, a possible solution is that DRI could fulfil this shortage of scrap steel. The feedstock fuels in DRI production often come from natural gas or coal, and reducing agents currently use fossil fuels as well.

5.2.2 Market trends in Iron & Steel

Before looking into what hydrogen can do for the steel industry, an understanding of what drives the market is explained. Competition within iron & steel is driven by economies of scale, which has led to overcapacity of production (NERA, 2016). Fulfilling capacity is in the steel industry most important as factories cannot be shut down on short notice. Consequent price pressure has resulted in an enormous need to reduce costs. To show how much the overproduction is: Europe's production in 2014 was around 166 million tonnes; China's overproduction 379 million tonnes (NERA, 2016). Hence, Europe could easily see its steel production be replaced by global competition. This means that prices are kept low, and strategy is based on keeping the utilization rate as high as possible to spread the high fixed costs over the units sold. More on the market trends of Iron & Steel is given in appendix VII.

5.2.3 Hydrogen implementation

Nonetheless, what can hydrogen contribute to the steel process? It is often recognized that cleaner materials and energy carriers can be used within steel production. First of all, is the question of whether an entire 100% carbon-free industry is technically possible? Partly this depends on whether the process is capable of operating under hydrogen or electricity. Research from many different papers (Hasanbeigi et al., 2014) (Fischedick et al., 2014) (Berger, 2020) shows that the DRI production combined with renewable EAF processes can potentially be a carbon-neutral product provided sustainable hydrogen is used. Da's research in 2013 shows this hydrogen-based DRI and EAF is emitting 84% fewer carbon emissions compared to the most efficient BOF production method (Da Costa et al., 2013). Underneath is a figure that shows a graphical representation of the hydrogen-based DRI-EAF production.

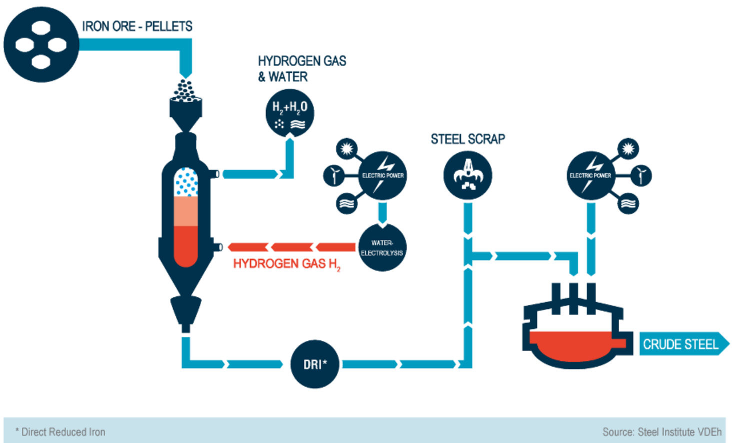

Figure 14: Hydrogen-based DRI-EAF process

$$Fe_2O_3 + 3H_2 \longrightarrow 2Fe + 3H_2O \tag{2}$$

Hydrogen can be used as a reducing agent in the Direct Iron ore Reduction (DRI). Hence, allowing hydrogen to be of great importance. DRI is the product from a process where iron ore pellets are cleaned by a reducing agent by which the oxygen in the iron ore is removed (Da Costa et al., 2013). The product is the same DRI bespoken in section 5.2.1 above and is capable to the treated by the EAF steelmaking process. Hydrogen usage in the DRI process is already demonstrated through HYBRIT and H2FUTURE projects in Austria and Sweden (Mandova et al., 2019). Figure 15 shows the results from a Roland Berger research where all innovations in the steel sector are rated. The hydrogen-based DRI-shaft furnace is shown to be the most cost-effective, most ready to use, and can be implemented within the shortest time frame.

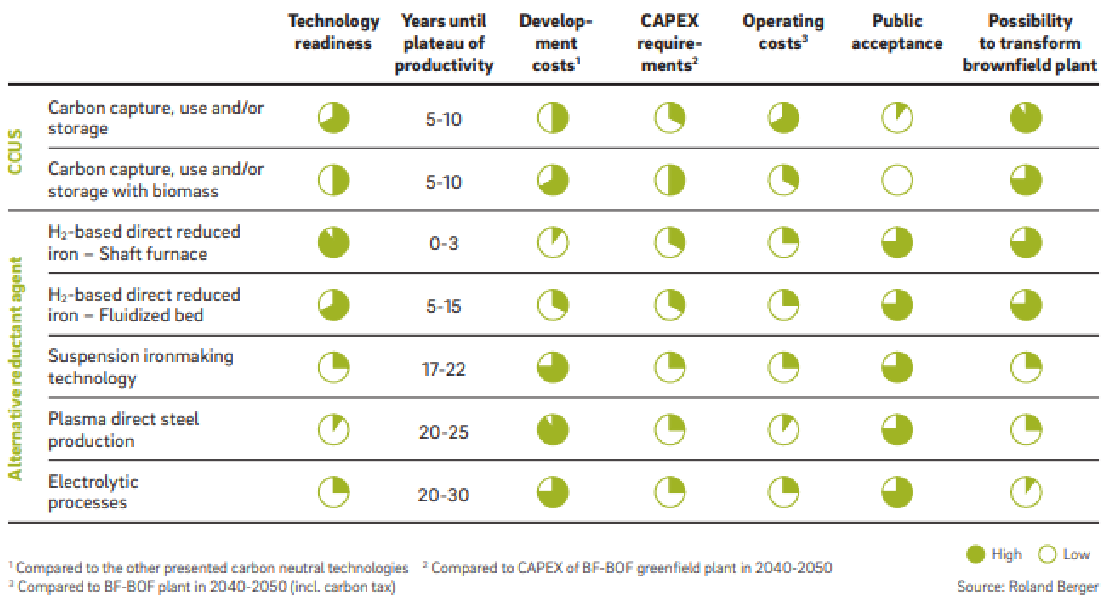

Figure 15: Developments in maturity, costs and readiness of different sustainable steel production methods (Berger, 2020)

5.3 Oil refinery

5.3.1 Current state of the art production methods

Oil refining uses 33% of the total current hydrogen demand in its process (IEA, 2019a). Oil refineries purify crude oil for end-users like transportation or as feedstock for the petrochemical industry. Most of the hydrogen used in refineries is produced on-site at own facilities, and this hydrogen represents about 20% of the direct emissions a refinery emits (IEA, 2019a).

There are two main functions which hydrogen fulfils in current refinery processes. The first function of hydrogen is in hydrogenation where heavy oil is cracked into a lighter product. This process is not used for all crude oil processes and is depending on the end product. With hydrogen cracking, the larger hydrocarbon molecules are broken into smaller molecules by reaction with hydrogen to obtain a higher valued product (Orkestra, 2018). The cracking can be done without hydrogen as well when catalytic or thermal methods are used (Orkestra, 2018). The second function of hydrogen is to remove sulphur out of the crude oil in a process which is called hydrodesulfurization (HDS) (see equation 3). HDS is a requirement for petrol, kerosene, diesel or other fuel oils as SO2 would become a by-product at later fuel combustion (Yamaguchi, 2003). On a smaller scale does hydrodenitrogenation take place as well where ammonia is obtained as a by-product.

$$C_2H_5SH + H_2 \longrightarrow C_2H_6 + H_2S \tag{3}$$

5.3.2 Market trends in refinery markets

Refinery output has slightly decreased by almost 1% in 2019, which is seen across all global regions. Expectations are that oil demand will decrease from 2030 towards 2050 but, under tighter environmental regulations, hydrogen usage will increase. (IEA, 2019a). This trend of growing regulations is often related to the sulphur content that is required to go down over the coming years. Figure 16 shows the ongoing developments of, on the one hand, the increase in oil demand on the short term and on the other hand, the decreasing sulphur allowances. Both developments increase hydrogen usage in this heavy industry's sub-sector.

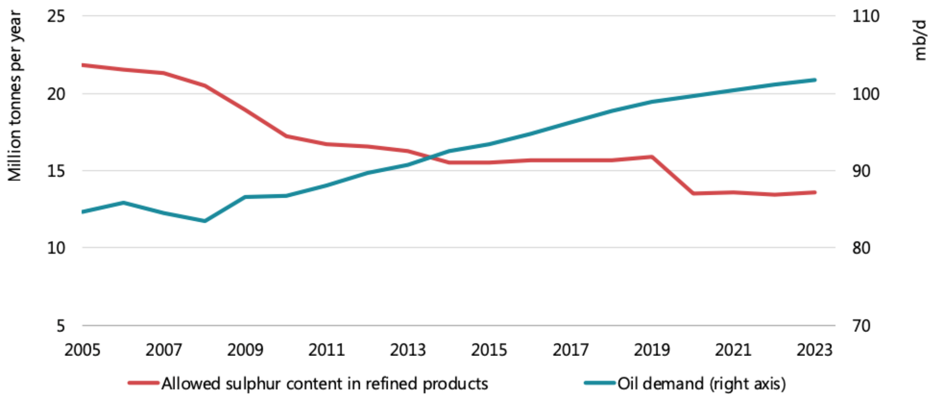

Figure 16: Sulphur regulation trend against oil demand trend (IEA, 2019a)

Europe's refineries have a combined throughput capacity that is capable of supplying the continent's own demand (Michiel Nivard, 2017). The product demand specifics differ among country, region and end applicability which makes refineries very different from each other. Hence, global trade in the refinery's products emerges to balance out these product requirements and mismatches in production. This results, just like for the steel sector, in that global competition emerges to produce on the lowest possible costs. Research from the Clingendael International Energy Programme (CIEP) shows that many of Central Europe's refineries are resilient to this competition. There are numerous different reasons for this strong competitiveness. (Michiel Nivard, 2017). Knowing that competition is not impacting European refineries too much, enables them to have an open attitude to potential product quality improvements.

As said, hydrogen over the past has been an increasingly important feedstock in refineries for the purification process. A vital remark to this is that the hydrogen being used is not produced sustainably and mostly using natural gas without CCS (IEA, 2019a). This means that there are decarbonizing leaps to be gained using 'green' or 'blue' hydrogen.

5.3.3 Hydrogen implementation

In comparison to the Iron & Steel sector is the implementation of green hydrogen in refineries much more straightforward as there is an existing hydrogen demand which only needs to be replaced by sustainable hydrogen. On the other hand, the research needs to look into how much reduction in emissions will be obtained by using green hydrogen. This will be discussed in chapter 7, where, through interviews, the value proposition of using green hydrogen will be identified.

5.4 Chemicals - ammonia

5.4.1 Current state of the art production methods

The production process of ammonia is considered to be a two-part process. First is the gas supply where the two raw materials for the second reaction step are obtained. The second step is the ammonia synthesis which consists of reacting gaseous nitrogen with gaseous hydrogen (Frattini et al., 2016). The hydrogen gas used is generally made through coal or natural gas gasification. Coal gasification is a process no longer present in Europe and replaced by steam reforming to produce the hydrogen. As the process uses grey hydrogen through mostly SMR, emissions reach close to 2.5 tons of carbon dioxide to produce 1-ton ammonia (HydrogenCouncil, 2020). The nitrogen used for the process is easily obtained as it is highly present in the air and only needs to be separated (Frattini et al., 2016). Once hydrogen and nitrogen are obtained, the ammonia synthesis happens following the so-called 'Haber process' (equation 4) (Kyriakou et al., 2020). The Harber process technique dominates the production of ammonia globally and makes it the most produced chemical worldwide (Frattini et al., 2016). However, ammonia production requires a large amount of energy. As such worldwide ammonia production accounts between 1-2% of global energy consumption and is responsible for about 1% of global emissions (Kyriakou et al., 2020) (Bicer et al., 2016). The main reason for this energy requirement is the hydrogen production in SMR reactors at high degree temperatures (Kyriakou et al., 2020).

$$3H_2 + N_2 \longrightarrow 2NH_3 \tag{4}$$

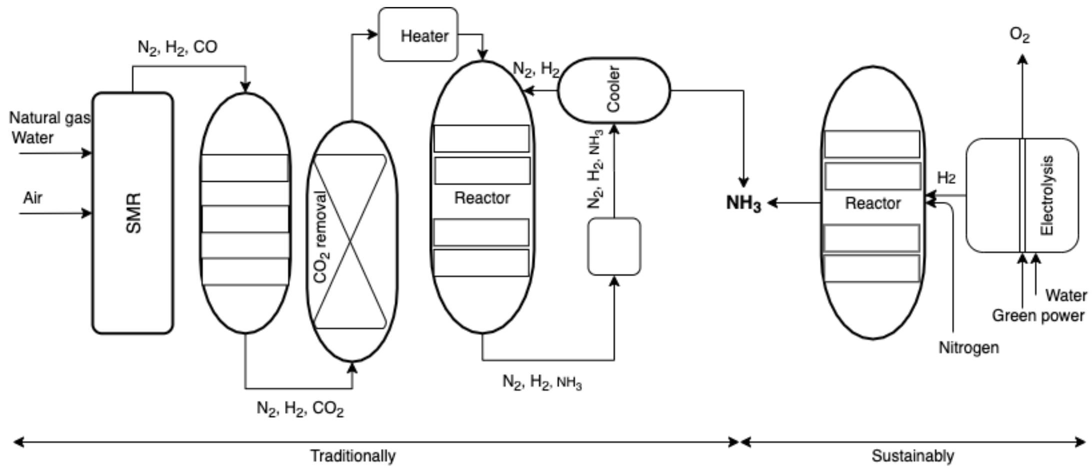

Figure 17: The current production methods with hydrogen coming from SMR and the sustainable alternative

5.4.2 Market trends in ammonia

About 14% of all ammonia is produced globally on Europe's production account, which means that it holds a large amount of competition from other continents. Especially Asia, like with the steel industry, holds over half of the global capacity and produces on lower costs compared to European companies. One of the reasons why Asia holds such a high capacity is because of the growing population and the need for increased food production. To support this much high amount of fertilizers need to be produced (Rafiqul et al., 2005). Additional market trends and applications of ammonia are explained in appendix VII.

5.4.3 Hydrogen implementation

Like the section on refineries, the same holds for ammonia in that the existing hydrogen could be replaced by green hydrogen to make the product decarbonized. Scaling of green hydrogen is quite essential as considerable amounts of hydrogen are used in an ammonia plant. For example, an ammonia plant that produces 1 Mt needs 200 kilotons of hydrogen (HydrogenCouncil, 2020). In 2018, the global consumption of hydrogen in ammonia processes was estimated to be 31 Mt per year (IEA, 2019a). With the expected increase in ammonia comes the urge to deliver this demand sustainably.

5.5 Chemicals - methanol

5.5.1 Current production methods

Methanol is an industrial chemical compound used in a wide variety of day-to-day products like plastics and cosmetics. On top of that, methanol is used in the production of methanol-to-gasoline, which is valuable in regions where gas is abundant, but oil supplies are lacking (IEA, 2019a). Methanol is the most known shipped chemical product in the world, which shows that infrastructure is well developed (MI, 2018). Methanol is normally in its liquid phase and could technically be produced through many different approaches from a wide range of raw material feedstock.

The current methanol production is these days produced in 99% of cases from fossil fuels with almost always natural gas being the feedstock (Kauw et al., 2015). Over the past 15 years have coal-to-methanol gained market shares over natural gas as a feedstock since Asia has not included carbon emissions in its consideration and used to produce at the lowest costs (Alvarado, 2017). The current methanol production holds hydrogen as a central compound in processes whether it is from coal or natural gas, using 12 Mt hydrogen per year (IEA, 2019a). Hydrogen as a raw material in chemical production is expected to increase by 30% towards 2030, mainly in its existing applications (IEA, 2019a).

5.5.2 Market trends in methanol

Various problems arise with the increase in hydrogen production, for example: how should it be stored in large amounts? One of the solutions is by chemically storing it in methanol (Grinberg Dana et al., 2016). As such is methanol upcoming to be a transportation fuel. The case for using methanol as a transportation fuel is strong, and results are given in table 4.

Fuel	Current CO2 emissions (g/km)	Green alternative CO2 emissions (g/km)
Gasoline	176	123
Diesel	132	100
Hybrid	142	80
Hydrogen	178	3
EV	98	2
Methanol	83	2

Table 4: Research by the Danish Department of Energy into emissions from road transport (MI, 2018)

5.5.3 Hydrogen implementation

Renewable methanol is synthesizing the two key components: hydrogen and carbon dioxide, which has for some years been done in Iceland (Kauw et al., 2015)) (HydrogenCouncil, 2020). Renewable methanol can cut carbon dioxide emissions by 95% and nitrogen oxide by 80% in comparison to current production methods (MI, 2018). The method applied is following the Lurgi reaction, which is shown in equation 5. Carbon dioxide can be captured either from the atmosphere or from other industrial processes. Capturing the CO2 enables industrial players to make efficient use of the by-product and to avoid carbon taxation. Hence, with carbon tax likely to increase in the future, the business case for renewable methanol could become more advantageous.

$$CO_2 + 3H_2 \longrightarrow CH_3OH + H_2O \tag{5}$$

5.6 Introducing value chain analyses

This chapter has shown production techniques of different industry sectors and and in what way hydrogen implementation can be of use. The implementation of sustainable hydrogen is sometimes obtained through replacing the existing grey hydrogen (ammonia, methanol and refineries), and sometimes a matter of radically changing the production process (like for steel). Next four sections will look into the value chains of the industries to identify downstream drivers for upstream production to be transitioned.

6 Value-chain analysis Steel

6.1 The steel chain

After the production in an EAF or BOF process, steel often is not immediately ready to be used in the final consumer products. Many steel fabricators have a 'middleman' function where additions to the product are made in order to adhere to the CFC's end demand requirements. These middleman players are called Original Equipment Manufacturers (OEM) and produce only part of the final product. Hence, as the face-to-face customer of a steel producer is not the consumer-facing company, product requirements often come from this OEM. The OEM can consist of multiple players all operating in between the steel producer and the final product assembler. For the sake of convenience, and not including too many factors, OEMs are considered as one entity. Ongoing the research will be discussed whether the demand requirements in steel can be passed through these OEMs to change the steel produced.

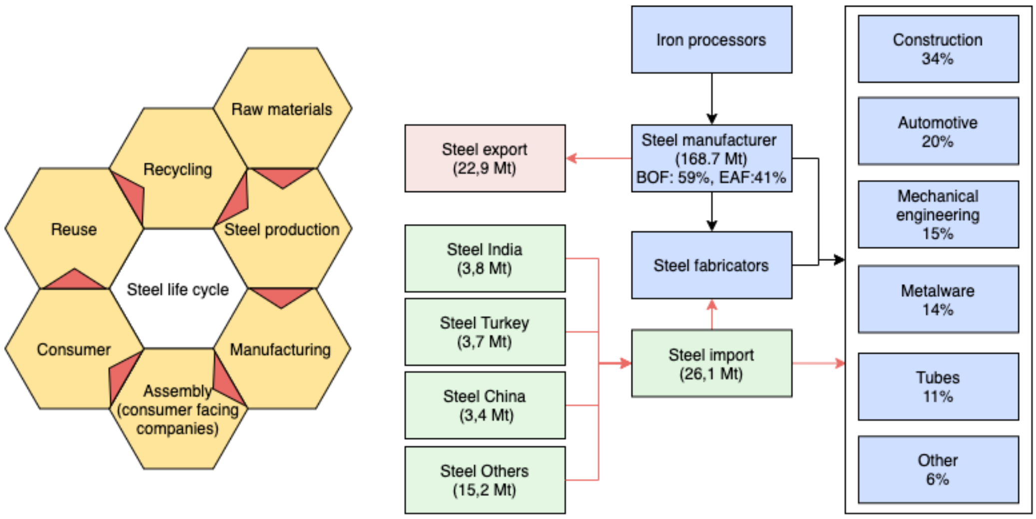

Figure 18: Simplified framework of the steel value chain with data from 2018 coming from Eurofer (EuroFER, 2019)

Eurofer is the European Steel Association who represents the EU steel production. Following their report, data is used to identify the steel value chain of Europe, which is graphically shown in figure 18. According to Eurofer, Europe is leading in implementing sustainability and innovations in the global steel industry. The export from Europe, about 13.5% of total production, equals about the import coming from a large number of different countries. The final steel usage sectors are shown in the graph from which construction is the most prominent application of steel. Tubes and mechanical engineering are not considered to be mostly consumer-facing products and represent not enough value to be continued by this research. Still, the impact of these sectors to the steel industry is of great significance and taking it not into account does not mean that no demand for hydrogen-based products may develop. The consumer-facing drive is just not as high as for automotive. Metalware has an extensive range of CFCs. As such, it is hard to look deeply into how the demand will change as companies are very fragmented and hold minimal amounts of market shares. Thus, for simplicity of the research, interviews will not include this demand sector.

6.1.1 Consumer-facing segment: construction

With construction being such a large share of steel demand, naturally, interviews have to be done to understand what their motivation could be to use green steel. All downstream construction companies use OEMs and steel traders for their supply of metal products. The reason for not buying directly from the steel producers is not dependant on the quality of the steel or whether it must be upgraded or changed in between. The main reason is the variation and seasonality in demand from construction. As said in the steel market chapter, steel producers are trying to keep production at a constant level to keep costs down as much as possible. While production plants keep on running, some constant demand is required, and this is where these OEMs and trading houses come into play. They store the commodity themselves for some time. Hence, OEMs and trading houses act as a customer with a constant demand who in turn sell it to construction at a premium.

6.1.2 Consumer-facing segment: automotive and the importance of OEMs

With 20% of all steel in Europe going into the automotive segment, this industry has a considerable buying power. If such an industry collectively plays into the ongoing trends of decarbonization, upstream steel production will hold no other choice than to adhere to these requirements. The CFCs have outsourced much of their operation to the OEMs with JIT (just in time) supply chains, reducing the complexity of their processes. OEMs, therefore, buy in large amounts of steel to process into more valuable products following the strict requirements from these final manufacturers (CFCs) and are usually bound with multi-year contracts. OEMs are highly present in, for example, welding, forming and coating of the parts. As said, the focus will not go into too much detail in these OEMs and consider the buying power of car manufacturers high enough for them to decarbonize along through the value chain. In short, car manufacturer dictates (or can dictate) what has to happen.

6.2 Technical analysis

Following the model (see Appendix VIII), the price of steel is highly influenced by hydrogen. The most important observation is that the steel price of hydrogen-DRI based steel, produced in the traditional situation by natural gas as feedstock, is not competitive with a BOF process. The model shows that the production costs of hydrogen-DRI based steel are between 69 to 124% more expensive than BOF steel depending on the price of renewable hydrogen. The model was presented to experts from steel companies who acknowledge the situation but added to this that variations among geographical areas are significant. Scrap steel prices, power, gas and carbon taxation, are all aspects for a detailed business case to be updated. For this research, the model will give an idea of how different processes are related to each other in costs. Area-specific details are not taken into account. Various researches have shown that a doubling of steel prices will result in end-use costs of cars, buildings and machinery to increase between 1-5% (Bataille et al., 2018).

6.2.1 Price of carbon-neutral steel

A small calculation is made on how the current business case is holding up. CO2 emissions per ton steel are taken from previous research by Hasan who found that German steel holds 1.708 kg CO2/ton crude steel (Hasanbeigi et al., 2016). Interviews with steel producers show that this data point can be correct, but that quite often a higher average is measured. In order not to make a case for hydrogen-based steel too favourable, this best practice of 1.708 kg CO2/tonne crude steel is used. Taking into account that traditional plants, if they would currently emit more CO2 per tonne steel, could reach the same data point through efficiency measures, we stick to the 1.708 kg data point. For hydrogen calculations is the low case price at 3.1 EUR/kg, and the high case price at 6.5 EUR/kg (ICIS, 2020). At this emission level with the current ETS system (of about 30$/ton CO2 taxation), the steel price would increase by 13.6%.

Since companies tend to show their willingness to decarbonize by 2039 (see upstream interview), all carbon-neutral steel options will be calculated. Nature-Based Solutions (NBS) is the scientific definition for planting trees to offset carbon emissions. For 1 ton of CO2 are NBS costs between 10 and 150 dollars (Richards and Stokes, 2004). As such, like with the hydrogen costs, a low case and high case is taken. Costs of CCS in Germany would account for 113 \$/ton CO2 (Irlam, 2017).

Steel	Costs low case (\$/ton)	Costs high case (\$/ton)
Traditional + NBS	429	668
Traditional + CCS	605	n.a.
Hydrogen-DRI-EAF	696	925
Traditional BOF	412	n.a.
Scrap EAF	401	n.a.

Table 5: Current prices of production methods for carbon-intense and carbon-neutral steel. The hydrogen-based DRI-EAF is a mixture of about 10% scrap steel and 90% DRI.

The table shows that although hydrogen-based steel is more expensive than other carbon-neutral options. Future developments with hydrogen prices going down could make the case more favourable as a larger part of the costs is related to hydrogen prices. For a better understanding: hydrogen is a considerable cost factor for steel. It represents 34% of the total costs (in the low case) and represents 54% of the total costs in the high case scenario. Hence, achieved reductions in the hydrogen prices, which is likely to happen in the future, would have considerable impacts on the final steel cost price. Though the NBS show to be relatively low costs, other barriers like: uncertain climate effectiveness, limited and uncertain property rights, and governance issues among others prevent this solution to be long term and large scaled (St-Laurent et al., 2017). In terms of being competitive with the current production methods, there still is a long way to go for sustainable DRI-EAF. If carbon taxation were the provide a break-even point between the two production processes, the taxation price would have to be at 166\$/ton CO2.

6.2.2 Construction

Steel in construction applications represents, on average about 4 to 5% of the total costs according to interviews with BAM and Boskalis. In steel-intensive construction projects, in the highest case scenario, total costs of the project consist of maximum 20% steel buy-in. However, on average, the low share of steel costs will apply over the total project cost. As such, the average cost of a project would increase between 2.8 to 6.2% using hydrogen-based steel depending on the final price of the steel model. The price for green steel could be afforded provided sustainability factors are of importance for such projects. Nevertheless, in the current situation of hydrogen-based steel being up to twice as expensive (following the model), makes the case still more difficult. Discussion on what this price calculation means for tendering is further discussed in paragraph 11.1.1 where a potential driver for the construction is discussed to use carbon-neutral steel.

6.2.3 Automotive

According to the World Steel Association (WSA), the average diesel car contains about 742kg of steel (WSA, 2019b) (Rootzén and Johnsson, 2016). Considering that an average car weighs around 1240 kg (Rootzén and Johnsson, 2016), means that a substantial share of the vehicle weight comes from steel (about 60%). 34% of the steel is used in the body structure, 23% in gears and engine, 12% in the suspension and the rest in wheels, tanks, steering and brake systems (WSA, 2019b). Many of these parts do not have immediate substitutes which means that steel will remain an essential material for vehicle manufacturers. If the current scenario of low hydrogen production cost is taken as a certainty, the price increase for a vehicle can be calculated.

Figure 19: Trade-offs of using green steel in vehicle manufacturing

This steel price increase would come down to a total price increase of a car of $210. Given an average diesel car price is about $20.000 (Rootzén and Johnsson, 2016) means that green steel would give a price increase of about 1,05%. This is entirely in line with research from the ETC who estimates that production costs of hydrogen-based steel impact a car price by 1% (ETC, 2018b). In terms of emission reduction of the final product is the decrease highly dependent on the kind of car. The carbon footprint of a car can differ substantially. About 5,6 tonnes of CO2 emissions are considered to be the average production carbon footprint of a gasoline vehicle (LowCvp, 2015). The emissions avoided from steel production are 1,64 tonnes of CO2, which represents 29% of the total emissions related to the production of an average car.

6.3 Output from upstream interviews

6.3.1 Changing requirements from consumer-facing companies

According to interviews, the upstream steel industry is experiencing pressure from companies to decarbonize as their clients are demanding carbon-neutral steel. This demand requirement is a long term strategy as consumers realize transition in this industry is a slow process with capital intensive investments required. Hence, demand for carbon-neutral products is often stated to be a must by the year 2039 in order for these companies to claim they use carbon-neutral purchasing in 2040. An easy way to make quick gains in decarbonization is recognized to be through recycling of steel. The EAF process, as said before, can make quick wins in reducing CO2 emissions and is often considered by steel consumers to be the future of steel production. A second reason for CFCs to demand recycled steel is that it misses out on the mining process, which is in their eyes an outdated and filthy business. What these CFCs miss out on though, is a market requirement around recycled steel. EAF production based on recycled steel could bring high tensions around the production technique and potentially makes investments high risked.

Current steel availability for a circular economy is only about 35% of the total steel demand. As such, large under-capacities might develop if a larger amount of CFCs would demand their steel to come from recycled sources. This under-capacity means that there will still be a need for primary steel, either through sustainable or through conventional processes. From a quality perspective, the need for primary steel is a must since the quality of recycled steel has too many impurities for applications like the automotive industry. High quality flat and long steel needs a clean iron as raw material instead of the scrap material, where residual metals like copper are in some degree present. An over-proportional EAF's recycled steel demand growth may lead to prices skyrocketing if driven by overwhelming decarbonization demands and reduced utilization of mining. Still, if customers are implying they will be willing to pay for this, there would not be such a problem. Nevertheless, the risks involved in investing in EAF plants will increase with the outlook on increased scrap material prices, and customers might look for substitutes once recycled steel prices skyrocket.

6.3.2 Hydrogen-based DRI prospects

Though some smaller parts of a BOF process could be heated with hydrogen to gain quick wins in reducing carbon emissions, the main potential of the energy carrier to transition the steel industry is through DRI production. As Europe does not have many EAF plants, the transition requires investments in EAF before any business case for hydrogen-based DRI will be considered. A gradual transition adding DRI with the scrap materials could be introduced to fill the gap of under-capacity in scrap steel. With the scrap material expected to rise in costs, the business case for hydrogen-based DRI is becoming more favourable. Moreover, in terms of steel quality, a mixture of scrap steel with DRI will provide more favourable product quality than using scrap materials solely.

To adhere to the request of decarbonized and recycled steel from CFCs, and the under-capacity of scrap steel, alongside the quality requirements, the development of hydrogen-based DRI is likely to be upcoming.

6.4 Background into downstream companies

6.4.1 BAM Group

BAM is an over 150 years old construction company with its headquarter based in the Netherlands. From the second world war on, it started to grow rapidly and now represents a large share of the construction market in the Netherlands and operates throughout the whole of Europe. Hence, they have a good overview of how the construction market develops and how demand for hydrogen-based steel might grow. BAM's integrated report 2019 shows in the key figures three different segments: profit, people & planet (BAM, 2019). Within this planet segment, a list of different statistics is given like the total carbon emissions in kilo tonnes, as well as tonnes per EUR revenue, obtained. Appendix IX shows the most important takeaways from the integrated reports over the last years and some more detail on the sustainable background of BAM. The emissions per revenue are the most interesting statistic as it shows the emissions made by the company, including a correction from change activity. This statistic decreased by 39% from 2013 to 2019, which means that some serious approach has been taken to reduce emissions over the years consistently (BAM, 2019). The CDP awarded BAM with an A on climate change approach (BAM, 2019).

6.4.2 Boskalis

Boskalis started mentioning emissions in its 2017 annual report, which is relatively late compared to competitors. The main findings are presented in appendix IX, alongside more company information. Only scope 1 and 2 emissions are currently taken into account for Boskalis. This means that all incentives to reduce emissions are currently related to the company's direct carbon footprint. The emissions per revenue do show a decreasing trend and thus shows that the company is also taking incentives to reduce them. Still, the indirect emissions are not fully incorporated, which makes the impact of upstream emission reduction questionably valuated. Following this, it seems that, besides technical properties, the low cost of raw materials is considered the main driver for Boskalis to decide its supplier on. Like BAM, Boskalis reports to CDP on their climate change approach. The report of 2019 was in contrary to BAM disclosed for public viewers and got scored a D by the CDP (Boskalis, 2019).

6.4.3 Fiat Chrysler Automobiles

Fiat Chrysler Automobiles (FCA) Group is responsible for the design, manufacturing, distribution and selling of Abarth, Alfa Romeo, Chrysler, Dodge, Fiat, Maserati, Fiat Professional, Jeep, Lancia and Ram brands and the SRT vehicles in over 40 countries. The larger share of the cars is sold on the mass-market and centrally organized, which makes it easier to implement new decisions over the global spread of facilities. Following their CDP report of 2019 is the score on attacking the climate change awarded with an A- (FCA, 2019). Following the same approach as done for identifying BAM's emissions per scope in Appendix IX, the scope 3 emissions for FCA represent about 88% of the entire carbon footprint. Over 72% of emissions are coming from purchased materials in upstream industries (FCA, 2019).

6.5 Stakeholder analysis

Figure 20 shows a few of the most important stakeholders involved in both the upstream as well as the downstream side of the steel market. The positioning of companies is based on the interviews and annual reports of affiliated companies. For example, SSAB and Voestalpine are acknowledged among steel experts to be early adopters to implement technologies for becoming carbon-neutral with projects like the HYBRIT plant and H2FUTURE pilot plant. Companies like ArcelorMittal do intend to transition over time but hold on to conventional methods and instead depend on governmental influences to transition. Ilva, an Italian steel producer, is identified to be one of the most polluting steel producers in Europe and is known to be under governmental pressure to reduce their pollution in the area.

BAM and Boskalis' position is relatively different as BAM has shown to decarbonize both in absolute terms as well as relative terms in reports (see chapter 6.5) and committed to scope 3 emission reductions. On top of that, CDP reports show BAM to be considered more sustainable by scoring an A against the D of Boskalis (see paragraph 6.4). Volkswagen and Mercedes-Benz are, contrary to FCA, publicly working on becoming carbon-neutral rather sooner than later. As such, these stakeholders are well developed in the understanding of the need for decarbonized products. OEMs, in comparison to the trading houses, are on better terms with both sides of the value chain and hence would enable a transition relatively easier.

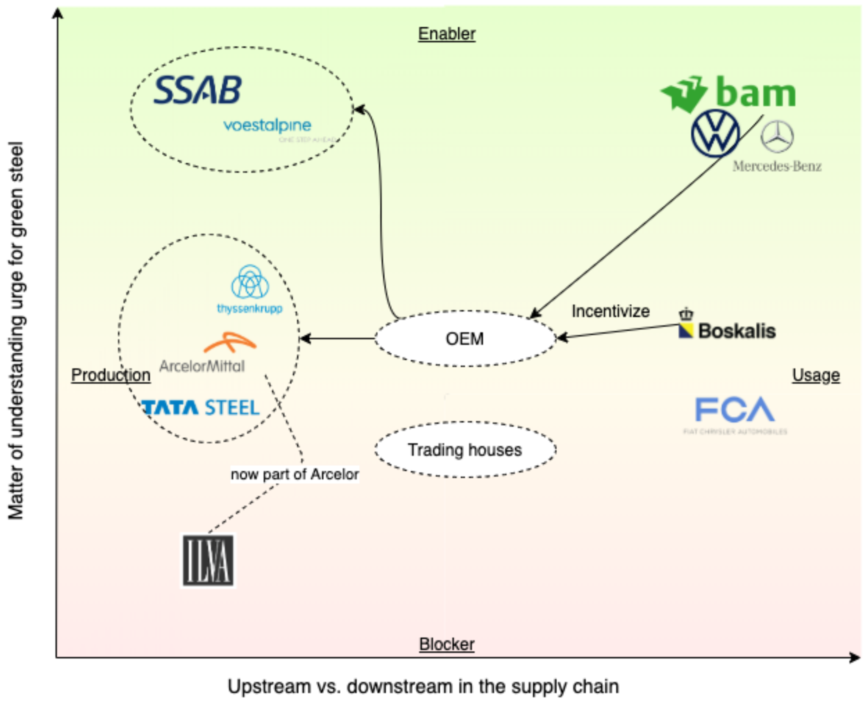

Figure 20: Some of the main stakeholders in the steel value chain

6.6 Output from construction interviews

6.6.1 Steel differentiation

The interview with the representative of BAM is a category manager steel, in the steel business for over 30 years. The 2 hours during interview started following the given question list (see Appendix IV) and resulted in a wide-spread background knowledge into the steel industry and how steel is procured at BAM.

Material procurement as a whole is often not even a fifth of the total project costs with cement being of most importance. In the Netherlands, relatively high importance is given to cement as material costs, with about 2 to 3 times higher total costs than steel. For Europe as a whole, this ratio of importance is about equal between steel and cement. Within BAM, the importance of cement over steel is not only visible in the material cost associated with projects, but also in internal knowledge where six cement product-specific researchers are employed while there are none for steel research. Some employees are well aware of the developments concerning steel, but no effort from the company itself has been made to change upstream production.

BAM, just like all other construction companies, do not make any differentiation from which producer the steel is bought from. To be more specific, only quality, like strength, is considered as a requirement. This could make it hard for an upstream company to differentiate its product. Europe still is the quality leader in terms of strength, while Asia is expected to catch up soon. Steel bought is following figure 20, where only a small part of the total steel bought is directly from the producer itself. Because of the fluctuating demand, a company like BAM hardly makes any direct deals with a steel producer. With the OEMs and trading houses being the primary source of steel sold downstream, knowledge about the steel origin is mostly lost. As these stakeholders do not specify what the source and production method of the steel is, it is difficult for construction to understand which type of steel was bought and what the emissions related to the product are. If green steel were to be produced, the current market structure would not be able to distinguish that green steel from other steel ones. Hence, for a downstream company to reduce its scope 3 emissions, this kind of material knowledge is required.

One of the leading environmental topics inside BAM is the heavy-duty transport impact related to steel. For cement, the emissions of transportation are relatively low as the cement dries up within one to one-and-a-half hours from the distribution centre. Hence cement is delivered from nearby, and thus the impact of transport is limited. However, this does not hold for steel which is shipped from all over the world. Large vessels carrying the steel are shipped over long distances and emits considerable amounts of CO2. These are all included in scope 3. For a company like BAM to commit to reducing scope 3 emissions, it would be worthwhile to work on reductions. Hence, an easier way for more upstream hydrogen usage (or a hydrogen carrier like ammonia) would be to use it for shipping purposes.

6.6.2 Valuation of green steel

The interview with Boskalis is a one-and-a-half-hour during interview with a lead in the sustainability team. The reason why an interview with someone from this department was chosen is to get a view from a carbon footprint perspective. The interview with BAM was with a steel focused employee who gave interest in using decarbonized products but did not see the added value given to the company's value proposition itself besides reducing its footprint. The interview with Boskalis would leave out most steel aspects, focus on project differentiation and how the end consumer shows the added value perceived.

With about 70% of all projects in the Netherlands, Rijkswaterstaat - a body of the Duch government - is the largest consumer and mainly focused on projects other than housing construction. Hence, the tendering process they use is analyzed to understand the demand requirements. There are two different emission-related ways for construction companies to win the tenders. First of all, a carbon ladder is introduced where companies score a tier 1 to 5 in terms of awareness and tackling emissions from a corporate perspective. Since almost all large constructors have the highest score, the differentiation with cleaner materials is of no use in this sense. The second measurement is where the projected emissions related to a specific tender come into play. EMVI (Economisch Meest Voordelige Inschrijving) is a concept by which a score is given to different companies trying to win a tender. EMVI means that different metrics are used in order for a tender not to be won only on the lowest price. With EMVI, the contracting authority asks for an action plan in which a construction company indicates how it is going to approach a particular project. The result of this analysis is a sustainability score, which is weighted together with the offered price. The stakeholder with the best price-quality ratio wins the tender. Duurzaam Bouwen Calculator (DuBoCalc) is a calculation method in which the EMVI is nowadays calculated. To be more exact, DuBoCalc was included in 17% of all tenders in 2018. One year after, this share already increased to become 53% of all tenders, and now has become the standard in every tender from Rijkswaterstaat. Also, other institutions started using this same method.

6.7 Output from automotive interview

The interview was with an experienced metals expert from Fiat Chrysler Automobiles (FCA). Current developments with hydrogen-based steel, or any other decarbonized steel, have not been tested or discussed yet. Most emission reduction programs are still on the scope of direct emissions rather than the indirect purchased materials. Which steel is purchased is based on three different variables: quality, cost and location. The location is mostly related to the security of supply and in smaller amounts because of carbon footprint. Quality though is an essential aspect to the purchase process. As such, FCA has over 20 leading steel suppliers in order to satisfy its steel needs. This large amount of steel suppliers shows that the automotive market is very competitive for steel producers and does not present a single winner to supply automotive with all of their needs.

As far as the interviewee knows, FCA has not considered an incentive to ask their supply chain to provide them decarbonized steel any time soon. In contrary to interviews with upstream steel producers, who have had demands to provide decarbonized products to automotive customers, FCA has no viable business case to add value to the vehicle through green steel. In their view, the hydrogen-based steel needs to be tested first on its quality before any further considerations can be made. On top of that, it is not likely in the interviewee's opinion that the consumer will be willing to pay more for a decarbonized produced vehicle. Hence, in this sense, the hypothesis for the automotive industry is not proven to be acknowledged by the representative of FCA.

The main reason, according to the interviewee, why FCA would incentivize their supply chain to decarbonize, is because of governments requiring the CFCs to use a percentage of recycled steel (like they do for plastics). This would incentivize them to use EAF based steel which is (at least for some part) based on scrap steel. On the other hand, some primary iron (like DRI) should be added to the EAF process in order to decrease impurities to meet the vehicle's body quality specs. It is imperative that quality testing is being done before any remarks can be made whether a hydrogen-DRI with scrap steel mixture would qualify to the needs and requirements. Because FCA has not had hands on any of this green steel, no answer could be given to this question.

To the question, if aluminium could become a substitute once steel becomes too expensive, the answer is no. Large scale aluminium applications are solely used for the high premium brands to make them faster. Steel is generally about three times stronger than aluminium and holds some technical preferences over aluminium treatment. The bulk-vehicles segment will remain highly dependent on steel in the future, both in consideration of cost as well as the vehicle's strength. Though a company like FCA does not see the added value of green steel yet, some CFCs like Volkswagen do play on carbon-neutral production and even have been broadcasting commercials of them active. Though some automotive do not valuate the hypothesis to be true yet, some other companies are already showing to spend resources to do so (see chapter 11.1.2).

6.8 Industry sum up

The first industry of the total of four taken into account has been analysed on its drivers to change. The chapter shows that upstream steel production is currently getting transition signal requirements from its downstream customers. On top of that, in order to adhere to carbon-neutral steel demand requests, EAF with a primary iron supply of DRI will be able to adhere to these demand requests while retaining quality aspects. Through a model are steel production prices calculated for each production route. The model shows that the costs related to avoided emissions in final consumer product are not of too significant size. For example, by using carbon-neutral steel, carbon emissions from an average vehicle could be reduced by 29% against a final price increase of 1%. Interviews have shown that current CFCs are already demanding the steel industry to transition in the long term. In order to be ahead of the competition, CFCs could try to incentivize the steel industry to do so even earlier on and play an active role in their decarbonization. Still, not all interviewed CFCs show to be willing to do so, as they perceive the price increase of steel not to the increasing value of their final product. The analysis also shows that for now, downstream companies will not be able to pay for the full amount of transition costs. Hence, requiring the government to add a stake to the problem as well. Next section will discuss the second industry, refineries.

7 Value-chain analysis Refineries

7.1 The refinery chain

Europe can be considered as the 'cradle of modern-day refining' and has a long-existing history with the oldest refinery dating from 1854 built-in Poland (Michiel Nivard, 2017). There are, following to CIEP, four different kinds of refinery categories:

1. International Oil Companies (IOC)
2. National Oil Companies (NOC)
3. Merchants
4. Joint Ventures (JVs)

Most of the companies in the European refinery business are IOCs concentrated in industrial areas. Merchant refineries try to be flexible with their activities to benefit from opportunities alongside their existing oil trading. A trend is that NOC's are mostly exiting from the European market. To some extent, they retain some presence in JV's with IOCs or merchants (Michiel Nivard, 2017). Refineries are in the oil & gas value chain considered to be one of the downstream activities. In this sense, upstream is the searching, exploration and production of oil and gas. The upstream segment is considered to be the highest risk and capital intensive segment, where profit margins can be impacted by external forces like international conflicts and agreements. The future promises less volatile margins as the operators become more flexible due to the decreased investment cycles (Orkestra, 2018). For example, price signals are better reacted on as lead times nowadays take up to a year at most while this used to be around ten years in the past (Orkestra, 2018). Following the original value chain of oil, the midstream segment consists of storage and transportation of the commodity. So these two segments are upstream from the refinery stage. They entail by far the larger share of emissions. The original upstream and midstream activities will be left out of the research' scope. Refineries are now considered as the upstream to reduce the complexity of the situation. Figure 21 shows the considered supply chain with the refineries as the upstream going on to downstream consumer supply. Still, for the impact consideration of green hydrogen, the original upstream steps should be taken into account as the impact of green hydrogen on the full supply chain could be relatively small.

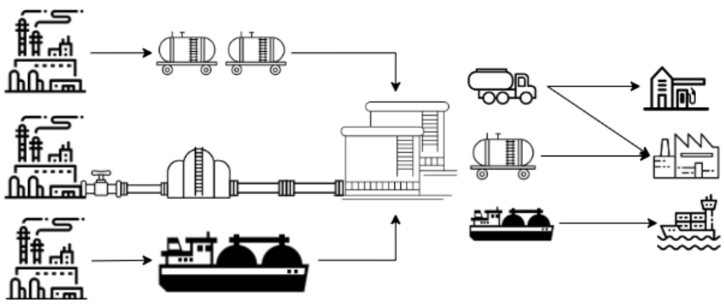

Figure 21: Identified research's refinery supply chain

Capgemini published research about optimizing value chain initiatives for refineries. In this, they discussed the collaboration inside the value chain concerning different business groups within each oil company. Capgemini concluded that the businesses are somewhat fragmented, which results in different business targets, worse decision making and reduced margins (Iqbal Latheef and Apicella, 2017). The reason for this fragmentation is the culture of 'point solutions' where issues and tools are used for specific departments and not through an entire supply chain. For the valuation of green hydrogen used products to become of meaning, a full supply chain recognition is required.

7.1.1 B2B channels

The fuels and specialty products, produced by refineries, are after transportation sold through B2B channels to industries and B2C service stations. For B2B, the variety of segments is so extensive, that it makes it too broad to identify demand change over the whole of the segments. Hence, no further consideration is given to the B2B segments besides that it can be said that most industries will try to use resources from the cleanest possible production processes unless it has a costs impact. Whether they can, in turn, pay more for these resources depends on their end market. Its willingness to pay a (small) premium or not.

7.1.2 B2C channels

Within the B2C channel, the downstream side is more transparent in terms of the final customers (imagine the service station). This customer base nowadays does not see any differentiation in the product based upon its production process. The purchased product is based on specifications and restrictions in terms of standards which each supplier is bound by. Following BCG research, future demand requirements will be heavily influenced by the customer. On top of that has the research concluded that: *'As consumer behaviour may vary over the coming years, often spurred on by environmental and GHG emission policies and their attached social benefits, the refining and marketing processes will also gradually have to be adapted'* (Orkestra, 2018). These two drivers are promising for the valuation of renewables.

7.2 Technical analysis

Hydrogen Europe analyzed the emissions refineries could reduce by implementing sustainable hydrogen. Though some of the hydrogen used comes from the process itself, where crude oil is cracked, and this hydrogen is re-injected, the greater amount is coming from SMR. Green hydrogen usage, instead of SMR-based grey hydrogen, could reduce upstream hydrogen-related carbon dioxide emissions by 91% (HydrogenEurope, 2020). This only represents the emissions related to hydrogen production, not to other processes. On the EU level as a whole, this would result in a 20 million ton reduction of CO2 annually (HydrogenEurope, 2020). The research equals the potential reduction in Germany and France to be equal to 650.000 BEV/FCEV cars replacing conventional vehicles (Vanhoudt et al., 2016) (HydrogenEurope, 2020).

The impact described above has quite some impact on the total emissions of refineries and hence could show to be an exciting investment. The reality, however, shows more problematic issues in terms of differentiating the final product through green hydrogen usage. From interviews at Shell, which will be described in more detail underneath, the conclusion arises that the end-to-end emission reduction of the product like diesel is reduced by only 2-3% through switching towards green hydrogen. The emission grade of conventional diesel treated by grey hydrogen is at 94 gCO2/MJ while green hydrogen usage would decrease this to 92 gCO2/MJ. The market is so large that this decrease shows a considerable amount of reduction, which could be considered worthy of investing in. Nevertheless, the reality shows that for end consumers, this reduction is too small to make a differentiation against conventional diesel production (see chapter 7.5).

7.3 Background into Shell

Shell is a large scale hydrogen consumer with its production site alongside the refinery at Pernis (Netherlands). Shell itself is known to be one of the largest traditional oil companies in the world. They are transitioning their operations into more sustainable directions and divest away from conventional oil. The Net Carbon Footprint ambition of Shell entails a greenhouse gas emission reduction of products sold with 20% and 50% by 2035 and 2050 respectively (Shell, 2019). Shell aims to '*thrive* *in the energy transition by responding to society's desire for more and cleaner, convenient and competitive energy* ' (Shell, 2019). Shell aims to provide other upstream applications (like discussed in the research) with green hydrogen rather than solely its upstream use in its refineries. Being the seller of the refinery product to the end consumer Shell is integrated into various parts of the supply chain. This gives, on the one hand, an unusual insight into the relation of upstream and downstream green product valuation. On the other hand, it reduces complexity to push changes upstream as no stakeholders besides the internal strategy are involved.

7.4 Stakeholder analysis

McKinsey's energy insides provide an online list of all refineries and corresponding owners in Europe. From this, the main stakeholders are chosen in terms of distillation capacity to determine which upstream stakeholders hold the highest impact on the entire sub-sector. It can be concluded that the larger share of refinery holders are using their own B2C retail stations, many being well-known gasoline providers. Hence, many of the market players fall within production and usage as they can be considered active in both markets. The Y-axis, with the understanding of the need to change, is a qualitative assessment based on market knowledge from interviews and publications of sustainable investments. On top of that, annual reports were read to understand mission statements and future strategies. For example, Exxon Mobil refuses to commit to being carbon-neutral by 2050 (Meyer, 2020). Neste is considered the best of class within the refinery segment as they are widely known to produce sustainable bio-fuels and provide Shell with carbon-emission offset credit compensation.

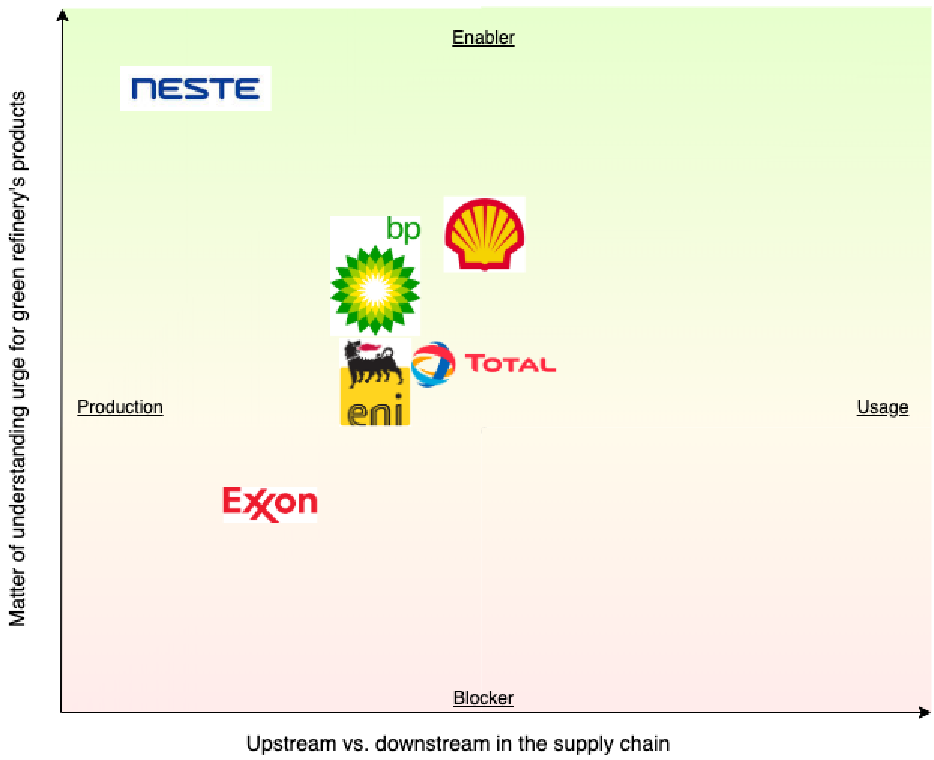

Figure 22: Main identified refinery market players

7.5 Output from interviews

Various interviews were held throughout the company with high ranked renewable investment seniors and experienced strategy analysts. In terms of investing in green hydrogen, Shell is at the level of a pilot-scale, an experienced player in green hydrogen and starting to build one of the first large scale electrolyzers in Rotterdam. The Shell Rhineland refinery has since three years a pilot running with a 10 MW electrolyzer supplying about 1% of the hydrogen demand. Currently, the plan is to build a 200 MW, first of its kind, electrolyzer near the refinery at the port of Rotterdam to supply about 15% of the refinery's total hydrogen demand. With over 70 different sub-plants at Pernis, many products can be switched to green hydrogen use. However, the reason why Shell decided to apply for this has to do with regulations rather than a market developing for green hydrogen-based fuels. The regulation responsible for this change is better known as RED II.

Renewable Energy Directive (RED) II is a European wide target set by the European Commission to increase RES consumption to 32% of the total energy demand (EC, 2018). Part of this proposal excluded transport from the overall goal. It has set sector-specific targets for member states to require their transportation fuel suppliers to produce a minimum of 14% coming from renewable energy (EC, 2018). This target is binding for suppliers and leaves no incentive or obligation for the demand side to adhere to. Transport is the sector where refineries are of importance as they clean the transport fuels with either dirty or clean hydrogen. Hence, the main initiative to use green hydrogen for companies like Shell comes from this RED II target. Assuming that a member state would reach the given target, company by company itself will see differences in reaching this requirement. If a company does not adhere to the 14% renewable fuel target, credits would have to be bought from cleaner companies like Shell does from Neste. In order for not having to buy these credits, and adhering to the RED II regulation, the business case to use green hydrogen over grey would therefore become feasible.

A caveat to this is that the European Commission has set this policy target for its member states on a higher level with the states to implement this policy on its own initiative. Hence, regional differences in details what falls under what category may appear as nations implement the directive. For multinationals, this will be of great importance to know what fuel falls under what category as a bio-fuel is known to have 30 gCO2/MJ or less. As implementing green hydrogen will not reduce emissions significantly, the question is if it may fall under the Renewable fuel of Non-Biological origin. Future judgements by the Europeans Commission and its member states will have to show if a by green hydrogen refined diesel is somewhat renewable or not.

In terms of this research, the hypothesis of the business case to use green hydrogen less fortunate. As the technical section points out, is the carbon footprint reduction over the end-to-end supply chain only a gain of 2-3% which is, following interviews, too low to differentiate the product with a premium against conventional production by competition. In terms of the B2C customers had a project been launched for consumers to be given a carbon-neutral product choice by optionally planting a tree to compensate for the emissions related to the diesel bought. Rarely customers would call for this option as the price increase was not accepted. As such, the conclusion has been made that the small emissions decrease through green hydrogen usage would not be significant enough to differentiate. Though the process indeed becomes greener, the actual footprint is very dependent on all steps before entering the refinery, which can not be resolved by using sustainable hydrogen. A bit more promising chances for product differentiation could come from the B2B sphere. With the aviation showing interest in decarbonized kerosene and jet fuels could smaller reductions be sufficient for product differentiation. Shell knowledge shows that about 10% carbon footprint reduction would be sufficient to have product differentiation within the aviation sector.

7.6 Industry sum up

The second industry of the total of four industries taken into account has been analysed on its drivers to change. The chapter shows that refineries are traditionally not mentioned as upstream but rather take part in the downstream process. As the research considers refineries to be upstream, the downstream entities consists of B2C (gas stations) and B2B (industry). Because the carbon footprint reduction is only 3% by using green hydrogen, which does not decrease in significant amounts, this industry is not likely to be influenced by CFC. Next section will discuss the third industry, ammonia.

8 Value-chain analysis Ammonia

8.1 The Ammonia chain

In most consumer's eyes is ammonia mostly known as a home-used cleaning product. However, this is only a small demand section of ammonia production. About 80% of all ammonia produced is used in the manufacturing of fertilizers with end products like urea and nitrates, and phosphate-based NPK (nitrogen, phosphorous, and potassium fertilizer) (IEA, 2019a) (Venkat Pattabathula, 2016) (HydrogenCouncil, 2020). Fertilizers market in Europe is mainly nitrate-based, while the rest of the world is often urea-based. A smaller amount of ammonia applications is in industrial products and explosives, which is negligible for the research. As far as value chain research into ammonia goes, all conclude that the fertilizers are back integrated into ammonia. This changes the hypothesis that a consumer-facing stakeholder will valuate a green product higher as the upstream producer is the same entity.

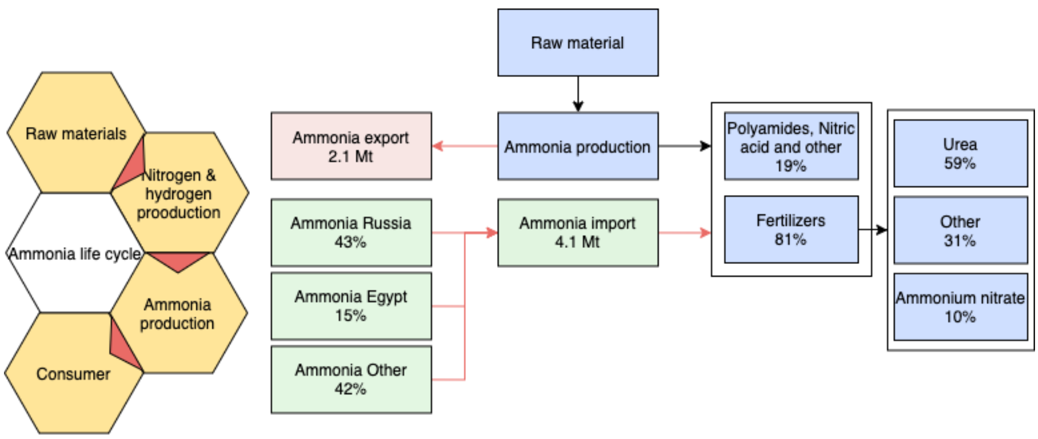

Figure 23: Value chain of ammonia including data from Bicer's research (Bicer et al., 2016)

An exciting development with green ammonia production for fertilizers is that it could see a shift throughout its current supply chain. The current fertilizer production is found at few central locations and distributed further into its end applications. Research by Reese discussed the idea of small scale, decentral, Haber processes, based on renewable power (Reese et al., 2016). While current investments are into the up-scale of ammonia plants in the industry, locally produced ammonia would go into the different direction of down-scaling. Leaving out stakeholders in the value chain to make the product cheaper. For example, wind speeds in the US are much higher in areas where ammonia (e.g. fertilizer) demand resides, hence providing favourable conditions for decentral production (Reese et al., 2016) based on wind energy to produce the hydrogen and consequent ammonia. Caveats to this concept are the diminishing advantage of economies of scale. Whilst decentralization might have the advantage of cheaper feedstock; it does have the disadvantage that products need to be stored, as fertilizer application is seasonal (applied maybe twice per year). Such storage is adding costs for small scale finished product production. For this research, however, the promise of decentral green ammonia is not of great importance as it will not be of significant quantity.

The highly increasing demand for ammonia fuels could be used in the power system, automotive applications, and agricultural machinery (Frattini et al., 2016). Ammonia has been used for a longer time in transport as buses were fueled by ammonia in World War II (Ikäheimo et al., 2018). Still, the consumer market of ammonia fuel seems far away and most importantly, is fragmented in undefined downstream players. Hence, as the scale is small, and market players are not yet defined, no further analysis is conducted in this application.

As the value chain is relatively condensed (compared to steel), the ease in changing is much higher as fewer stakeholders are affected by it. Like the Hydrogen Council states about implementing green ammonia production:*'Furthermore, such projects often involve few entities in the decision-making process and do not require a system change, which can accelerate uptake compared with the distributed usage characteristics common in segments like mobility or space heating'* (HydrogenCouncil, 2020). On the one hand, this market feature is useful for making decisions as less complexity arises to the problem. On the other hand, the need for demand-pull from the supply chain could be lower as the full impact of costs come to that one player. Hence, for the fertilizer entity, an apparent demand pull from customers is required for them to transition.

8.2 Technical analysis

Current market price of ammonia is 300 \$/t (HydrogenCouncil, 2020).The only additional costs for renewable ammonia are storage for intermittent moments and the premium for green hydrogen over grey hydrogen (HydrogenCouncil, 2020). Centralized hydrogen delivery could make up for some CAPEX increase as the front end of a conventional SMR ammonia plant will decrease.

Following the research by Arora on the natural gas-based ammonia represents the gas price of about 25% of the total costs per metric ammonia (Arora et al., 2018). Research by Ikaheimo shows marginal costs of power-to-ammonia to be at 431–528 EUR/t, at the current exchange rate about 483-592 \$/t ammonia (Ikäheimo et al., 2018). Other research concludes that production costs are around 655 \$/ton ammonia (Ikäheimo et al., 2018). The research states that the main costs are related to the electrolysis process, which accounts for 51% of the ammonia costs. The final finding is that renewable ammonia is close to being competitive to the current market price if the natural gas price rises significantly. At current natural gas prices is the cost price of renewable ammonia 161-197% of conventional ammonia. The remark on rising natural gas prices could become a reality in the near future, as the historical variation of natural gas in Europe is high and has varied between 300-700 \$/ton (Ikäheimo et al., 2018). A caveat to this is that this does not hold in the current crisis conditions where natural gas prices have shown to be at all-time lows. The current situation is very disadvantageous for green ammonia of course.

Though the researches above show for some cases the technical capability of producing green ammonia being 1.6 times higher than the current cost, interviews state that a price is more likely to be twice as high. Taking this as a reality into account requires the impact of carbon emission reduction to be either very high or the cost aspect of ammonia in the final product to be very low. Having that in mind, the first interview conducted was with Yara about their view on a green ammonia market.

8.3 Output from upstream interviews

Yara is the largest ammonia producer in the world with the headquarters based in Oslo. The VP of ammonia business is interviewed to get to know the high-level market developments and understand the market positioning of ammonia. First of all, being the largest ammonia producer makes them also one of the largest hydrogen users. All hydrogen used in Yara's processes is coming from on-site natural gas SMR production. Following their cost structure, where about 80% of ammonia costs come from raw materials, the last years have been economically rewarding in terms of production costs as the natural gas prices were relatively low. Still, from the interview is emphasized, that their mission is to *'Responsibly feed the world and protect the planet'*. Hence, this mission resembles the number of investments held in green ammonia production: study for a green hydrogen plant design in Western Australia, test Nel's "next-generation" alkaline electrolyzer at Yara's ammonia production site, and participate in multiple consortiums.

While the steel industry showed a clear difference between producers and consumers of steel, the ammonia industry holds these two stakeholders often as one entity. Nevertheless, concern within business units of the company can be considered differently sometimes as each business unit has its own targets on trade. In terms of the fertilizer market, production is highly competitive and very fragmented. The three largest nitrogen fertilizer suppliers hold only less than 15% of the total market, which means that much production is decentral and local. On top of that, Yara is selling ammonia to fertilizer producers who directly compete with Yara's fertilizer business. Consequently, merchant ammonia supply in some way direct competes with business units within the company.

The crops from which nitrogen fertilizers are grown should be considered as the end product and not the fertilizer themselves. Concerning changing the scope to this idea, a relatively large field of CFCs would become the focus. The discussion of whether the fertilizer consumer will want to pay an additional premium for green ammonia is questionable. The end consumer does not see apparent changes in the product delivered, so the need for a farmer to use carbon-neutral fertilizers is small. A small advantage to this is that green ammonia usage would only increase a bread by more or less 3 euro cents. Hence, not being too much of an impact on the final product in the eyes of the end customer. Alongside that, governments are requiring the farming industry to become more responsible/sustainable. Attempts are made to require slow-release methods of fertilizer, for instance. The disadvantage is that the fertilizers farmers are only responsible for a portion of the total emissions in the upstream supply chain (equipment, fuels). A product (e.g. bread) would still not become totally 'clean' and does not enable farmers to differentiate as a carbon-neutral product by using a 'clean' fertilizer.

Yara has nine ammonia plants in Europe. That means that not a whole production plant would be converted to green hydrogen as only a small demand for clean ammonia would exist. A solution to not fully dedicating an ammonia plant to green ammonia can be done by using a mixed input of grey and green hydrogen into the reactor. Up to 10% of electrolyzed hydrogen does not require any adaptions to the plant layout, and as a result, 10% of the produced ammonia could be sold as green ammonia following a certificate system. The price of this ammonia sold would follow the input price of the green hydrogen, and not have to include any investment cost increase related required for an entirely green hydrogen process.

Still, opportunities exist to increase green ammonia among farmers. The hypothesis where CFCs would require the industry to change could still hold: Companies like Smiths Food Group, Unilever and Nestle exhibit significant buying power to farmers regarding potato (and other vegetable) consumption. Although most farmers would not feel the need to sell their products with a green label, large consumers give high importance to their brands to do do so. These products, falling under the category 'fast-moving consumer goods', require large amounts of crops throughout the year. This group was left out of the stakeholder analysis in figure 25 as it is not a direct consumer, nor a producer of ammonia/fertilizers. Still, should a respectable company of the size of Lays, include the production of potatoes in his LCA, then it could include emissions resulting from fertilizer production (see figure 26).

Eventually, Yara requires cost reductions in three different areas for carbon-free ammonia to become competitive without too much support: electrolyzer's CAPEX reduction of between 40-60%, low power prices, and a carbon price of about 30$/ton CO2 (preferably more). This statement shows the willingness of the company to change as often more extensive requirements in support or cost reductions are given. In the end, the interview concludes that for a company to make a large investment like discussed, a complete supply chain needs to be included in taking some share of the risk involved. Both short term financial aspects have to be covered as well as long term demand securities.

8.4 Background into downstream companies

8.4.1 Lantmännen

In cooperation with Lantmännen, Swedish largest agricultural cooperative, product differentiation is being discussed regarding the use of clean fertilizers. Lantmännen is an agricultural cooperative consisting of 25,000 farmers divided over Sweden and have varying products adhering a common standard towards their sales channels. The total revenue, about 4.5 billion EUR, is coming mostly from different grain brands. Lantmännen currently is trying its farmers to decarbonize and hence reaches out to Yara to discuss possibilities how they can help to do so. Lantmännen: *"Our target is to create prerequisites for a sustainable primary production with a halved climate impact every ten years to achieve climate neutrality by 2050".*

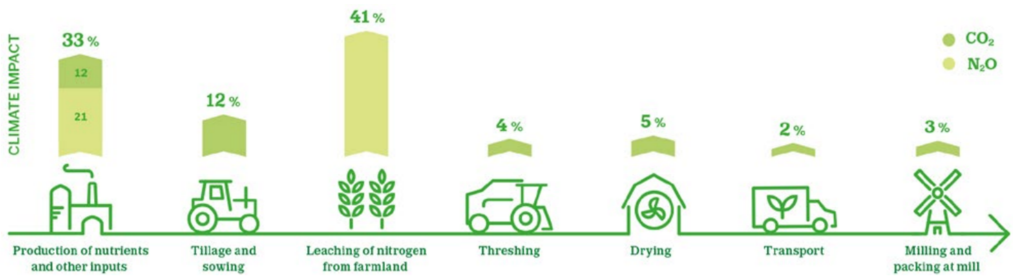

Figure 24: life cycle perspective of farming process from Lantmännen showing the impact of fertilizers on their supply chain's carbon footprint (Lantmännen, 2019)

8.5 Stakeholder analysis

The ammonia value chain with fertilizer usage as the final downstream consumption is shown in figure 25. The positioning of stakeholders is based on industry expert interviews and investments of Yara into green hydrogen, which gives them the lead against competitors. OCI and EuroChem are not unwilling to transition but have not made the same green hydrogen investments like Yara is doing. Corporations like Lantmännen are considered better capable to participate in green ammonia projects than individual farmers who encounter less peer-pressure. The green ammonia projects with Yara are consequently examples of the cooperation working together to achieve a green ammonia market and corresponding consumer products.

8.6 Output from fertilizer interviews

A product manager of fertilizers was interviewed to understand the potential added value of green ammonia for Lantmännen's farmers. With the cooperation working on green fertilizers together with Yara, this can be considered to become a first mover in the downstream market. Larger farmer corporations like Lantmännen have hundreds or even thousands of farmers working together for specific agricultural products. These corporations could if they as a whole, decide to be willing to pay more for a green fertilizer, drive some pressure and indicate the need for change in ammonia production. In terms of ammonia market share, a company like Lantmännen is no force at the worldwide market's level and consequently has not the power to demand multiple ammonia producers to change. Hence on their own, they, of course, could not incentivize a production process to change, but it will be a starting point of change.

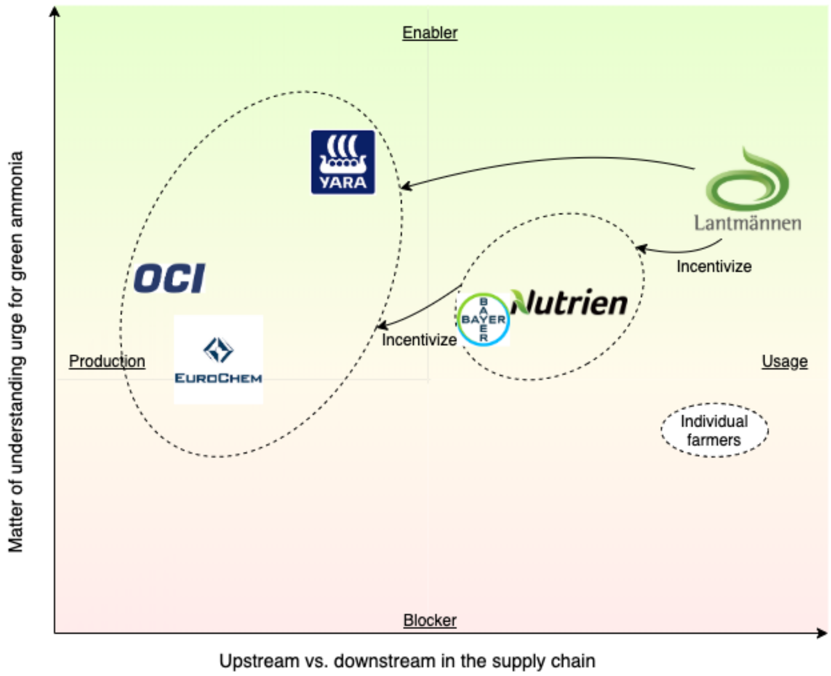

Figure 25: Some of the main stakeholders in the ammonia business

Figure 25 shows the value chain emissions of Lantmännen, where the footprint consists of N2O and CO2. The CO2 share is a total of 38% of the total footprint where the fertilizer production accounts for 12% of all emissions. This means that 32% of CO2 emissions relate to the production of fertilizers, which is, together with tillage and sowing, a larger share of the total value chain emissions. Thus, if decreasing fertilizer production emissions is important for Lantmännen to position their farmer's products as being sustainable, they should focus on these areas.

About 40-45% of the farmer's variable costs come from fertilizers purchases, making the question if they are willing to pay double for these materials difficult. Like for all other industries, the farmer will be only willing to pay more for a sustainable product as long as his crops are sold for the additional premium as well. Lantmännen does see the additional value in green ammonia and hence, is working with pilot farmers to implement them soon. According to the interviewee would public recognition uptake be one of the main contributes to the business case once the pilots are started. Though the willingness from consumers to pay more for the products is still uncertain, publicity for the green consumer product will enable them to create a market. For the farmer's sake, contracts should assure them to sell their crops against a premium, before they are willing to pay for the green ammonia. If we regard how fast the share of bio fresh foods (vegetables and fruits) in supermarkets is developing, one can see the business case for green ammonia coming within reach.

8.7 Industry sum up

The third industry of the total of four industries taken into account has been analysed on its drivers to change. The chapter shows that the ammonia industry shows to be promising to be driven to convert existing hydrogen demand into sustainable hydrogen. This industry is somewhat able to be influenced by a changing downstream product requirement. Here, the main reason to drive transition is likely to be related to regulations within the farming industry. Individual farmers, the buyers of the fertilizer (therefore considered as the end consumer), do not experience much pressure to initiate change in their current production processes. The main pull could possibly come from larger cooperations of farmers, provided that they jointly stand behind a radical change. Next section will discuss the last industry, methanol.

9 Value-chain analysis Methanol

9.1 The Methanol chain

Since methanol is used as feedstock for other chemical processes, the commodity itself will not be sold to consumers. Figure 26 shows the demand sectors of methanol, which exists of derivatives. These derivatives are in turn used for the final production of end uses which often is related to other stakeholders and a wide variety of sectors. Most growth is expected in MTO, this is the production of ethylene and propene, with demand based in Asia for over 80% (Alvarado, 2017). Europe itself is, in terms of methanol production, a large scale importer rather than exporter.

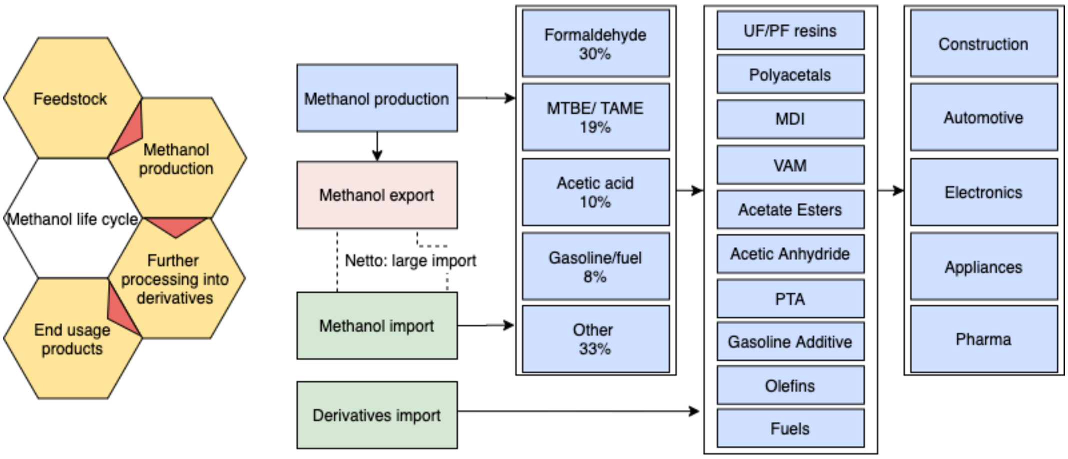

Figure 26: The methanol supply chain based on Ragaert's research and IHS market analysis (Alvarado, 2017) (Ragaert et al., 2017)

For the hypothesis to be tested in heavy industry's sub-sectors, a few requirements are needed to follow the reasoning. First of all, the clear distinction in the usage of end products is difficult to be determined as methanol is used as raw materials for a vast range of intermediate products. On top of that, many of those products are not the consumer-facing products, or they only have a small part of methanol consumption in them (e.g. automotive is an indirect user of products derived from methanol so in very insignificant amounts present). Also, though the application of methanol for transport could be argued to have a consumer-facing aspect, the application in the transport market is underdeveloped, and no clear (future) CFCs can be appointed. Hence, due to all of these reasons, no further consideration will be given to sustainable hydrogen in methanol production. Regardless, from the promising feature of using carbon dioxide as raw material (chapter 5.5). An interview will be conducted with an upstream methanol producer to confirm the understanding of the market.

9.2 Output from upstream interview

As mentioned above, methanol is possibly not the right market to test the research hypothesis. Still, an analysis with Carbon Recycling International (CRI) on the market was conducted to gain knowledge into the methanol business. CRI is ahead of other companies in terms of sustainability as it is producing methanol in an entirely green process. A salesperson had been interviewed to understand his view on the market. This department probably has the best view on how their product is differentiated in the methanol market, given that they already have the final desired green product. Since Iceland has a fully renewable grid, grid power could be used for the electrolyzers. This sustainable grid makes the circumstances from an economic perspective more favourable and requires less investment in power production units. CRI's future green methanol plants outside of

Iceland and across Europe are going to be connected to grid power (possibly not fully renewable) and power purchase agreements (PPAs) with power generators. A vital remark to this is that the purchase of renewable electricity from the grid as a base-load option provides a certainty of supply, and could facilitate an easier roll-out of green hydrogen production.

A caveat for future plants is that the carbon dioxide supply might become more difficult as the idea of capturing it from current industry processes sounds more straightforward than reality often shows. Utilization of CO2 is increasingly developing in different processes, and re-usage is becoming more competitive. Two pilot plants are developed in Europe to test carbon emission recycling for renewable methanol which should form the basis for large deals in Asia, as the highest demand market for methanol is located over there.

A second barrier is that a ton of methanol requires a feed of 200 kg hydrogen. CRI's plant designs are capable of reaching between 50.000 and 250.000 tons of methanol yearly. This requirement means that in the high case the hydrogen required is about 50.000 tons/year. Hence, the capability of supplying these amounts of hydrogen is one of the main problems, and the impact of hydrogen on the whole process is of such significance that a considerable amount of electrolysis increase is required first. Though the research acknowledges that this is an issue for large scale green hydrogen demand, it will not consider this to be a boundary. Still, this is one of the main risks for green methanol production to scale up.

Renewable methanol for fuel in the transportation sector might be a more differentiating factor against conventional methanol. Incentives provided by government mandates drive the transport sector. These mandates aim to support development towards transitioning from fossil fuels to power societies' mobility. Even allowing for full compliance with current mandates to reduce CO2 emissions, liquid fuel consumption in transport will continue to increase, mainly due to population growth and economic growth in non-OECD countries. Since increased emissions from transport are not compatible with climate targets, the dependency on liquid transport fuels underscores the need to develop the production of carbon-neutral fuels which can scale effectively, such as CRI's methanol process. There also is significant momentum for renewable methanol, like for ammonia, to use in the marine sector. A recent announcement from Maersk states that they see methanol and ammonia as the best future fuels. In turn, the consumer's willingness to purchase a more expensive renewable product is contingent on government support. Thus, the green premium of CRI's product is directly tied to the client's ability to leverage government mandates in a transportation downstream market. In market areas where such mandates are present or will be present, clients are likely to be willing to pay a premium. CRI's renewable methanol was the first to be sold with a premium across European markets back in 2013, for gasoline blending, biodiesel production, wastewater treatment and chemical production.

A final remark is that methanol has diverse pathways into existing value chains in the chemical industry with a wide variety of applications. The chemical industry uses nearly 45 million t/yr of methanol, and each 1% share of the market represents one commercial-scale ETL plant. The market could already support significant demand growth for ETL technology because green methanol is chemically identical to methanol from fossil origin. It is straightforward for chemical producers to switch to the more sustainable feedstock in the future as obligations arise to decarbonize. Till obligations come into play, little incentive is present as industry's products often depend on a minimal share on methanol. As such, no consumer pull could be identified. The additional value of green methanol over grey methanol depends on drivers in the downstream market which have to go through the first stages of the value chain before any incentive in the methanol production is required.

There are currently no government mandates or regulations that require chemical producers to lower the carbon footprint of their products. However, many producers have adopted such targets as part of their corporate social responsibility and sustainability policies. IHS Chemicals estimates that the global market for bio-based chemicals is already worth over EUR 50 billion based on 2017 prices, corresponding to 42 million tons of final demand. This will likely grow fast as companies become more aware of carbon footprint, and governments will try, through regulations, to push these chemical industries.

9.3 Stakeholder and technical analysis

Since literature research, as well as the interview, revealed no clear consumer path for methanol, no further analysis would be done as the consumer push would most likely not apply for this business.

9.4 Output from downstream interview

Since the fragmentation of consumers using methanol is high, and the CFCs are unidentifiable, further interviews are not required. The push effect from downstream companies is considered not to be relevant, and hence, value chain incentives from the consumer will not drive change throughout the methanol industry.

9.5 Industry sum up

The fourth and last industry of all industries taken into account has been analysed on its drivers to change. The chapter shows that the application of methanol is in industrial processes where the commodity is used as raw material, and is hard to trace in final downstream consumer products. The CFC-based hypothesis will not hold as methanol is only a fraction of the raw materials used in the final downstream product. Though methanol could be decarbonized in considerable amounts to a carbon-neutral product, the industry does not hold the ideal circumstances to be changed by CFCs.

Next section will discuss an overall overview of all industries where hydrogen could play an increasingly role to decarbonize. Focus will be given to what sector holds the highest capabilities to be driven towards decarbonization by CFC in its corresponding value chain.

10 The drive of CFCs to decarbonize industries

The value chains of the highest hydrogen potential holding industries have been outlined, and the interviews have been conducted. A general picture is obtained in these interviews to what sense CFCs are longing for decarbonized products, including stakeholder mapping and some public data. Alongside, some of the cost consequences of sustainable hydrogen decarbonization are discussed, both qualitatively and quantitatively. Also, whether the relative importance of hydrogen can be differentiated among product prices. For example, ammonia which price increases more than double by implementing green hydrogen, while refineries' products experience a price increase of a few percentage points. On the other hand, is the trade-off of emission reduction where the refineries show a marginal decrease and all other sectors have substantial reductions in carbon footprint. The value chains of specific sectors present downstream drivers to use sustainable products in order to increase value towards customers. The combination of chapter 2 and the latest ones are the foundation of the research's approach in arguing for hydrogen implementation to decarbonize the industry further.

The steel industry shows the highest potential to implement decarbonization partly through a demand-pull incentive from CFC. The product has an explicit end usage within consumer products and currently represents a large share of emissions related to the production of these consumer products. Interviews have shown that current CFCs are already demanding the steel industry to transition in the long term. In order to be ahead of the competition, they could try to incentivize the steel industry to do so even earlier on.

Ammonia shows to be the most promising industry to convert existing hydrogen demand into sustainable hydrogen. This industry is somewhat able to be influenced by a changing downstream product requirement. Here the main reason to drive transition is likely to be related to regulations within the farming industry. Individual farmers, the buyers of the fertilizer (therefore considered as the end consumer) do not experience so much pressure to initiate change in their current production processes. However, the main pull could come from larger cooperations of farmers, provided that they jointly stand behind a radical change. These larger groups, although they represent a smaller share of fertilizer demand, can sell their product against favourable prices in bio-markets.

Refineries turned out to be not so much of an attractive case for the hypothesis. The main issue is the relatively low achieved decarbonization (only 3% decrease) if the grey hydrogen would be replaced by green hydrogen. Hence, the final product would not adequately be differentiated. On top of that, this marginal win of decarbonization would vanish against sustainable fuels like renewable power and hydrogen as a transportation fuel. The research, however, does see some potential for a green hydrogen's business case within refineries as regulations become more tightened. Green hydrogen-based processes in refineries could place the end product in a specific renewable fuel group adhering to RED II. Still, no market pull is expected to exhibit itself, and hence, no further consideration for mechanisms will be given.

Methanol could, like with steel and ammonia, considerably be decarbonized through sustainable hydrogen. The value chain analysis though shows that the application of methanol instead is in industrial processes where the commodity is used as raw material. The CFC-based hypothesis will not hold unless a CFC incentivizes the methanol using midstream company to valuate "green methanol" differently. Only then could the hypothesis be valid.

Table 6 is a final product of the supply chain chapters where the first three categories relate to interviews with industry experts, and the last categories come from the corresponding technical chapters. Final scores are given on a qualitative basis regarding the matter of downstream capabilities and willingness to decarbonize their products bought. From the table, the steel sector is the most relevant for the hypothesis, followed by ammonia, methanol and refineries. As such, it is decided to

Category	Methanol	Steel	Refineries	Ammonia
Upstream willingness to change	0	−	+	+
Downstream willingness to change	n.a.	++	−	0
Downstream willingness to include scope 3	n.a.	++	n.a.	0
Upstream product cost increase	−	0	++	−
Downstream product cost increase	n.a.	++	+	−
Impact on product's carbon footprint	+	+	− −	0
Overall score, sector to change	0	+	+	+
Downstream to change upstream	−	+	−	0

Table 6: A table to sum up the qualitative results related to each sector with as end category the impact consumer-facing companies can have on sustainable hydrogen usage in the upstream industry. A '+' represents a favourable case to value chain decarbonization relatively to other industries

elaborate more on mechanisms to drive hydrogen-based decarbonization in the steel's value chain. Implications from this discussion could be used as learning for the ammonia value chains, as well as others.

11 Applicability of mechanisms on a hydrogen-based decarbonization

This chapter consists of two parts, section 11.1 describes a few market requirements for the mechanisms to be of use. Section 11.2 discusses the applicability of mechanisms to initiate a hydrogen-based transition

11.1 Requirements for CFC mechanisms to drive an EU hydrogen transition

Before any CFC related mechanisms for corresponding steel supply chains are discussed, a broader set of mechanisms is required to be put in place either through a bundle of cooperating CFCs and industries, or through governmental support. The following sub-paragraphs give the requirements for the later discussed sub-sector mechanisms and incentives to be successfully implemented.

11.1.1 Traceability of hydrogen

As there are various production options to generate hydrogen, with significantly different consequences to the carbon footprint, it is essential to know how the hydrogen is produced. For those not producing the hydrogen themselves onsite, traceability of the external supply of hydrogen would be an essential requirement. If hydrogen would be produced in decentral locations and if transport would go through vessels, trucks or customer-specific pipelines a user of hydrogen would precisely know the origin of the supply. On the contrary, the more hydrogen would be a commodity and supplied over bulk pipelines, the less easily traceable it would be. So, in the case that national networks are used for hydrogen distribution, like developed decades ago with the natural gas distribution system in Europe, traceability seems impossible. On top of that, worldwide trade through third-party traders is another topic to consider. This could emerge as it did for oil and gas trading. Certain producers, for example, China - with a large share of dirty coal-based hydrogen - could sell then hydrogen not necessarily be at the low-carbon footprint. Free trade in hydrogen between different continents should be encouraged to bring down costs but only as long as the carbon intensity is addressed and measured. In that case, a certificate system should be developed, similar to the renewable GoO described in chapter 2.4.2.

Initiatives like CertifHy have already started developing a European market for the sales of certificated green and low carbon hydrogen. Current certificates allow the hydrogen to reduce carbon emissions by 60% compared to hydrogen produced by conventional SMR. One could argue that a reduction of 60% in carbon emissions is far from a sustainable product, still for developing a demanding market of hydrogen is both high volume, as well as low price, required. CertifHy enables the premium valuation of sustainable hydrogen regardless of what geographical location it is produced. These certificates promote the possibility of producing hydrogen at central locations and transport it onwards to wherever demand arises. GoO is managed and controlled by an institution which provides issuance, transfer of certificates, and cancellation of a GoO once the hydrogen is consumed.

11.1.2 Standardization of scope 3 emission methods

The first and foremost essential requirement for the hypothesis to be valid is for scope 3 emissions to be taken into account consistently. Just like the example with timber certificates, a log should be made from products and what stages in a supply chain it went through before reaching its final consumer. The quote by the statistician W. Edwards Deming: '*you can't manage what you can't measure*' relates to the importance of being able as a consumer-facing company to measure the footprint your final product has.

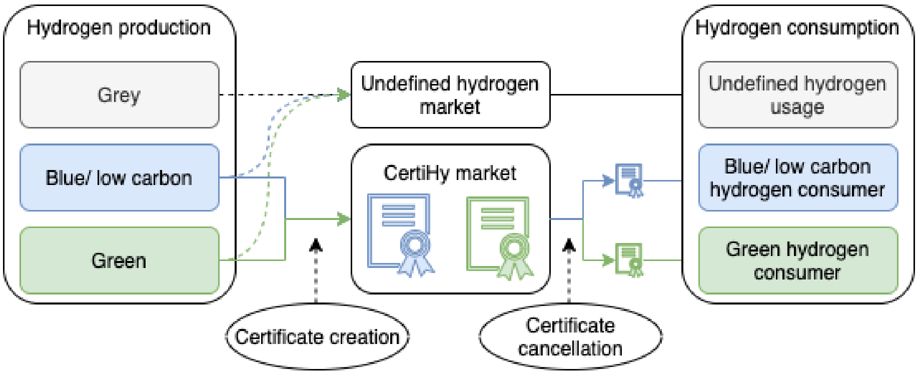

Figure 27: Schematic picture of hydrogen GoO market

There are tools available for emission measurement like the Scope 3 Evaluator Tool, which is web-based from the Greenhouse Gas Protocol in combination with Quantis. Using tools like these as a starting point provides a foundation from which iteration on the company level can be done to improve the actual modelling in the future. For future approaches, one standardized method should be presented to measure scope 3 emissions as having variation in methods is enabling companies to mislead statistics and figures. With companies developing their assessment methods on a short term makes them aware of what they are responsible for in current production. Future developments should, once companies are committed to setting targets, provide a standard method to make it easier to benchmark and compare among the competition. This consistent approach of scope 3 emissions will, in turn, make the whole process more transparent to the end consumer concerning what kind of emissions are related to the products bought.

By applying a scope 3 emissions approach, companies can set ambitious targets for themselves to reduce these emissions. These goals are for the hypothesis the starting point from which upstream suppliers could get the first identification that downstream changes are required in (near) future and give them time to formulate their own approach how to adhere to this. Most companies are starting to use absolute emission reduction targets, for example, BAM who wants to reduce scope 3 emissions with 20% by 2030 (BAM, 2019). A better target would be based on an activity like the emissions per revenue, which tackles situations where companies' businesses grow or decrease. On top of that, targets which are intensity-based of nature, better linked to how emissions can be reduced, as it is linked to the indicated output like revenue. One of the best ways to set targets is by using Science-Based Targets which is an initiative which helps the company through tools and guidance to set future targets (SBT, 2018). For the hypothesis to be valid, is it required to have detailed data on scope 3 emission and set targets accordingly to decarbonize. Only then, will implementation of sector-specific mechanisms be of use.

Though governmental policies are not directly part of the research is there an engaging role to play. Demand incentives for scope 3 emissions should be encouraged and where possible incentivize CFCs to create markets for decarbonized consumer products. Creating a decarbonized demand-side rather than governmental policies from chapter 1 could create a long term sustainable market.

11.2 Mechanism applicability on a hydrogen transition

11.2.1 Industry and market standards

Industry and market standards have shown to be valuable in the past with the timber and renewable power as examples provided in chapter 2. Both products have received certification to differentiate an upstream's product to increase value. It requires an industry to recognize a certification to hold value over the product. Most importantly, the consumer must see added value in the 'certificated' product in order for the CFC to pay for this. In the case of timber, public perception was at a certain point where its understanding to the issue had reached a certain level that the CFCs saw potential in adhering to this. Correspondingly, the same could happen for industry's upstream products.

CFCs can even try to promote the usage before the common understanding of the public is at the tipping point. Using certification holds the power to present a certain product as being premium worthy. Still, an industry wide cooperation will be required to set standards and assure that standards have been met. On top of that, industry wide recognition and large differentiation between the traditional product and the certificated one is required for the mechanism to be of use. As such, a decent amount of resources is required to be spend on achieving this goal. For an individual CFC though, resource requirement will be relatively low as the bundle of industries and segments all provide their resource share.

11.2.2 Collaborative innovation

Collaborative innovation methods focus on how a CFC has knowledge on existing decarbonization techniques in its production process or product. For example carbon reductions in handling materials, logistics and packaging which could be easily applied on an upstream's process. By sharing this with the upstream supplier, significant gains could be made to decarbonize by implementing the same procedures. Because knowledge is passed upstream, no extensive research is required, which means that resources required from CFCs to implement this mechanism are low. With the upstream industry well aware of its process' energy usage and footprint, the likeliness of a CFC being able to come up with a high impact, off-the-shelf, decarbonization solution, is low. Hence, not being of much importance to the hypothesis.

11.2.3 Supply chain optimization

Supply chain optimization will not be the mechanism to incentivize hydrogen usage in the upstream industry. During the interviews, a statement had been made that there are still a lot of global emissions present in the transportation of products, and hence, the industry could indeed implement some reductions by being incentivized to share data and optimize logistics. The hydrogen-based decarbonization, though, will not be initiated through such mechanisms and instead provides some emission reductions by an optimized supply chain where this transports and lean manufacturing mechanisms are implemented. Data sharing between stakeholders in the steel value chain could potentially reduce transport requirements and as such, emissions, but do not hold power to initiate massive scale emission reduction like with hydrogen-DRI implementation.

11.2.4 Business model innovation

Enabling suppliers to transition is key in this mechanism. Like Walmart and PepsiCo' Sustainable Farming programs are proactively trying to help their suppliers to move away from synthetic fertilizers and reduce water usage to change the business model. Financial tools to help the supplier is part of the whole mechanism to decrease the risks towards transitioning. Circular economy creation is part of this mechanism and tries to create value in multiple different parts of the value chain. For the business model to be innovated, effort and resource commitment from CFCs will be relatively high compared to other mechanisms as the mechanism requires a radical change in the value proposition as well as investments both for upstream and downstream processes.

11.2.5 Performance standards and incentives

Public recognition by CFCs of a supplier's capabilities to transition could be a positive influence on the whole process of promoting renewable integration in upstream production. For Apple's suppliers, the recognition of their 100% renewable power achievements was gratifying as they were not to be disclosed publicly in the past (RE100, 2017). Hence, it is of additional interest that not only the companies which attack climate change are acknowledged, but also the status of supplying to Apple is disclosed. The competitive advantage of these 100% renewable suppliers over the conventional supply has been proven a big motivation (RE100, 2017).

The caveat for hydrogen-based decarbonization promotion with the example of renewable power is the investment and time required for the industry's hydrogen-based processes to be active, which is not close to being compensated by the reward of recognition. The recognition on continuous decrease of carbon emissions in the supply chain could provide quite some motivation to do so for some industries, but a hard-to-decarbonize sector like steel requires more of a transformation. As such, other incentives along the recognition should help the industry to be rewarded. Resource requirement from the CFC to implement this could be low if only public recognition is used, but become higher as financial performance incentives are included as well.

11.2.6 Product design

This mechanism is more on how to express sustainability in the product design to increase the rewarding recognition from the general public and consumers. For example, changing the layout of a carton of milk which shows the recycled carton towards the consumer. This mechanisms is largely based on the exposure to the end customer. The discussed upstream materials are processed further in the value chain and as such, do not require any direct customer recognition from sustainability in the product's design. For example the hydrogen-based steel product design showing visually its green aspect will not allow the end consumer to experience this feature in the final product as the steel is further adjusted into a vehicle or a building. As such, the chance and ability to change the upstream industry is considered to be low. Resource commitment is expected not to be high as the mechanism is mostly based on the design rather than the process.

11.2.7 Industry and sector-level collaboration

This mechanism is close to the definition of solving complex problems where groups of multiple different stakeholders at different levels in the value chain come together. A financial incentive is often not elaborated upon, and risk-reducing solutions related to this mechanism are agreements or education sharing. Industry and sector-level collaboration could be very useful in combination with other mechanisms like industry certification. For certificates to be of most use, the industry and sectors collaborating and acknowledging its use could be valuable. A collaborated approach between an industry and a demand sector to tackle a problem requires a deep investigation and multiple discussions to come to an agreement. As such, the mechanism is likely to require larger amounts of resources to be of best use.

11.2.8 Supplier development and collaboration

Companies like Mercedes-Benz stated to be working together with suppliers to map out energy usage and become aware of the carbon footprint (Mercedez-Benz, 2020). With the steel industry being required to know their carbon footprint is it not that likely that collaboration with Mercedes-Benz identifies new carbon emission hot spots. On top of that, the primary mission is to improve efficiency programs, which do not incentivize any process transformation towards hydrogen usage.

This mechanism relates to collaboration between stakeholders to gain efficiency implementations. Research states that there remain potential efficiency gains to be won in for example steel: '*there remains an estimated 15–20% improvement potential using existing efficiency and waste heat recovery technologies, but this varies by country* ' (Rissman et al., 2020). Still, these efficiency gains will not result in any close-to-carbon-neutral steel. As such, supplier development collaborations should be considered to be useful for the near future, but may not require too much effectiveness on hydrogen decarbonization as the direct investments should remain focused on an actual process transition.

11.3 Conclusions on mechanisms

The discussion on mechanism applicability to drive a hydrogen-based transition comes down to what mechanisms require and contribute to a large scale transition rather than continuous improvements. There is no quantitative solution derived to the question and rather is the research staying on a holistic level where the relative applicability is discussed.

Figure 30 is a graphical representation to conclude the discussion of CFC-based mechanism applicability on hydrogen transition in the industry. The relative positioning of mechanisms is qualitatively sorted from explanations stated in the chapter above. Resource commitment is considered to be a combination of both financial as well as company's dedication required for projects and indicates the required commitment of a CFC to the goal of transition. The ability of mechanisms to initiate hydrogen-based decarbonization is based on the explained capability of a mechanism to initiate a transition, described above. Throughout the research, common knowledge has been obtained to discuss the applicability.

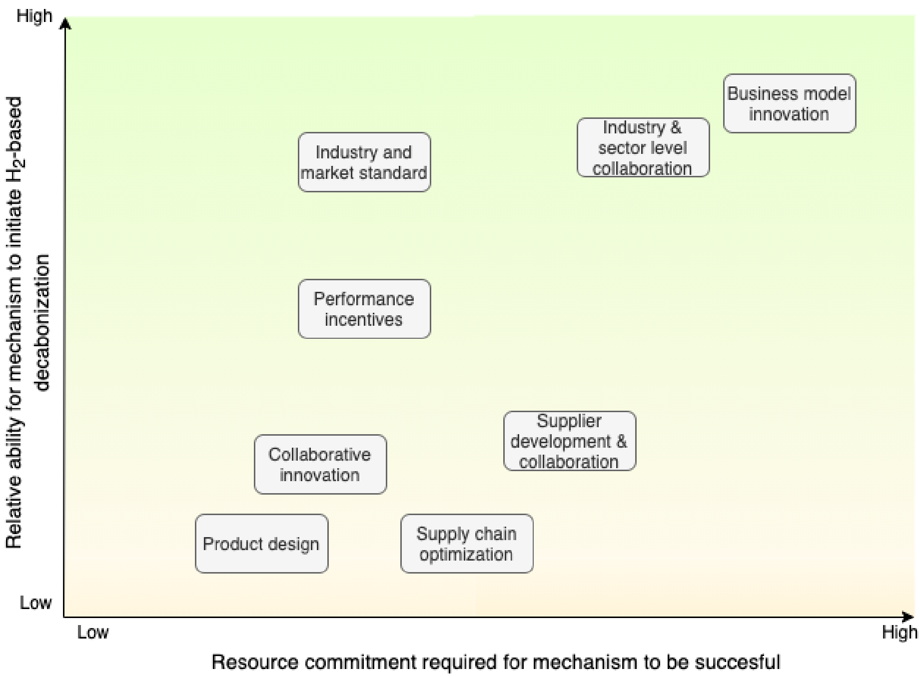

Figure 28: Steel incentives placed on their impact to hydrogen-based decarbonization of the heavy industry

12 The steel industry's decarbonization driven by mechanisms

Chapter 10 has concluded that the steel industry is most likely to have the highest influence of CFCs driving transition. Because of the chance of steel being more influenced by the hypothesis, this sector will be used for discussion in this chapter. In chapter 11, the mechanisms applicability on a hydrogen-based transition is discussed. A few mechanisms had been shown to be more promising to achieve the final goal of a larger decarbonization. For usefulness, and not elaborating too much, the mechanisms which are discussed not to be of use to initiate a hydrogen-based transition will not be discussed further. This chapter will combine the two outcomes of chapter 10 and 11 and discusses to what extend they can synergize and support each other. Section 12.1 will sum the main motivation and the extend for steel demand segments to participate actively in decarbonizing the steel industry. Section 12.2 will discuss in what way the presented mechanisms in chapter 11 can support this drive for carbon-neutral steel and 12.3 concludes on topic.

12.1 Motivation for CFCs to implement mechanisms

"We need policymakers to ensure there is a market for 'green steel' and other such low-carbon industrial products. Only in making the low-carbon transition a success across the economy can we harness the EU's leadership. The benefits to European society of this endeavour will be vast – if the whole transition can be tied together and invested in sustainably" - Axel Eggert, Director General of the European Steel Association (EUROFER)

The reference above is stated in news articles on July 8th, 2020. The quote synthesizes the research' hypothesis that the market should be designed in such a way that valuation for green steel becomes different than the conventional steel. During previous chapters it is shown that downstream companies of the steel value chain, will give a different valuation to green steel, provided that their business case does not worsen. Also, it has partly been shown that their products can become higher valued using a lower carbon footprint leaving the end customers the choice to choose for a slightly more expensive, but greener product. The sub-sub-paragraphs underneath represent major building blocks for incentivizing the transition from downstream companies throughout their value chain. This enables the steel producers to reduce risks and spread them throughout the value chain.

The motivation for the CFCs of the construction and automotive industry are explained in more detail before possibilities for mechanism implementation are discussed.

12.1.1 Construction

With DuBoCalc, the tendering calculation method explained in chapter 6, Rijkswaterstaat is placing emission boundaries that the tenders must adhere to. In this, financial premiums can be obtained by any additional emission reduction accomplished. The calculation includes a database where different kinds of emissions per material are given and what the respective incurred costs are. All effects related to material usage are taken into account varying from all scopes, according to LCA's ISO14040 specifications. The database gives average carbon emission calculations to products bought, which excludes the exact product-specific properties. If a construction company would want to use a material which is based on a lower carbon footprint, compared to what is listed in the database, a research can be made following certain standards to try to allow its use as per that data source. This adaption possibility in the database would mean that if green hydrogen-based steel is not in the database, doing acknowledged research enables its usage in DuBoCalc.

The first step for Rijkswaterstaat to use DuBoCalc was to get an idea of the impact their projects have. Next, other contracting authorities should use this among their tenders and indeed, following interviews, some are indicating to do so already. An example of a calculation is given in figure 29. Climate change has the unit CO2 equivalent, which results in a larger share of the final weight to the evaluation. The current situation does not make it too hard for constructors to adhere to the requirements. One reason to reduce carbon footprint related to tenders is the bonus a constructor can obtain. A linear line with bonus per reduction in EMVI is given, which can increase the contracted price to over 10%. This bonus means that not only scope 3 emissions are becoming more and more important to win a tender, but also additional profit can be generated.

Category	Exhausting resources	Exhausting fossil energy carriers	Climate change	Acidification	Eutrophication	Etc.
Factor	€ 0,16 / unit	€ 0,16 / unit	€ 0,05 / unit	€ 4,00 / unit	€ 9,00 / unit	€ x,xx / unit
Result (€)	€ 0,00	€ 0,05	€ 5,83	€ 2,12	€ 0,78	€ x,xx

Figure 29: A given example by Rijkswaterstaat with concrete related DuBoCalc calculation to get to an MKI level

The following statistic was used in chapter 6: German steel holds 1708 kg CO2/tonne crude steel (Hasanbeigi et al., 2016). This emission factor can be used in the example given by Rijkswaterstaat. Here the unit factor of climate change is measured in kg CO2, which gives the downgrade in customer value of an average tonne of steel. These emissions related to steel mean that in DuBoCalc, the CO2 value is 85,60 EUR/tonne steel equivalent to 101,37$/tonne steel. Hence, according to these DuBoCalc measurements, the contribution of using green steel instead of conventional steel, is a value addition which could partly cover the cost. Rijkswaterstaat, the governmental body, can indeed create a pull effect in the steel industry by incentivizing construction to use sustainable steel, as they are responsible for a large share of the tenders, and are the initiators of the DuBoCalc system. Over time, valuation given to the offset of steel could be increased to promote the carbon-neutral solutions even more. Example of this demand creation awareness is given in the latest hydrogen strategy by the European Commission. *'Explore additional support measures, including demand-side policies in end-use sectors, for renewable hydrogen building on the existing provisions of Renewable Energy Directive'* (Commission et al., 2020).

12.1.2 Automotive

No financial mechanisms are active for the automotive sector alike for the construction tenders. In principle hydrogen-based steel for cars could be sold for an additional premium which customers potentially would be willing to pay (it only rises an average car cost by 1%). The main caveat however is that if hydrogen-based steel would be used, only 29% of emissions are being reduced sothat the product still would be far from being fully carbon-neutral. As such, the carbon-neutral label would not be attached unless other parts of the vehicle's footprint are neutralized as well. From the interview with FCA it is concluded that not all automotive manufacturers currently see the added value. Following the research's approach no automotive company has stated in interviews to be willing to pay more for carbon neutral steel. Still, from upstream steel interviews some companies seem willing to pay more for a decarbonized product. Also publications by automotive companies do show their commitments. Mercedez Benz, Toyota Motor and Nissan have publicly stated this year to transition, and they will help their suppliers to transition with them becoming carbon neutral fully either by 2039 or 2050 (Mercedez-Benz, 2020) (Nissan, 2020) (Toyota, 2019). On top of that, Volkswagen has led the way by announcing to produce the ID.3 model balance sheet carbon-neutral (Volkswagen, 2019). Still, for the research's conclusions, the outcome is that it is unlikely that transition costs will be fully bared by the downstream automotive.

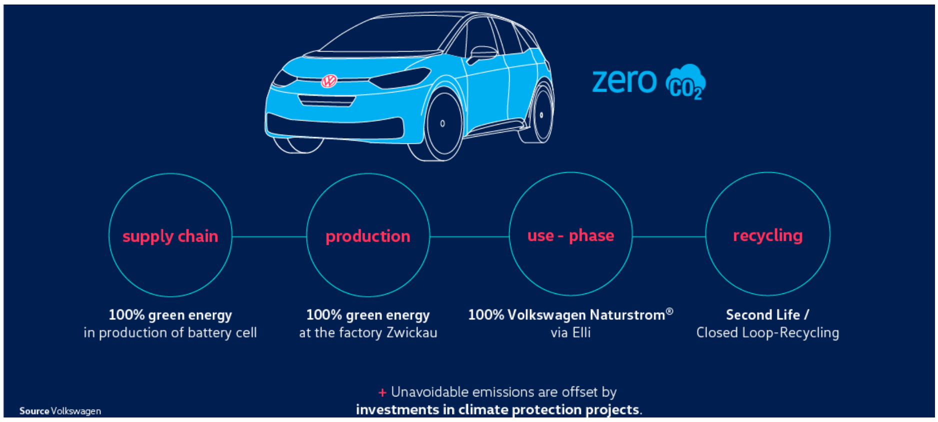

Figure 30: ID.3 model, designed by Volkswagen (Volkswagen, 2019)

If research into consumer's willingness to pay showed to be equal to the premium required for hydrogen-based steel, no specific mechanism would be required. CFCs would then pay more for the steel and shift this premium into their final product. Though it seems easy to shift the price increase downstream, some long term outlook to the industry should be given to reduce their investment risk and guarantee demand at a given premium. The mechanisms underneath could reduce some of the risks and provide some certainty required to make these large investments.

12.2 Driving the demanded transition through mechanisms

The question unfolds to what extend mechanisms can support the driving need for carbon-neutral steel and the corresponding industry to decarbonize. As such, the most important mechanisms for a transition discussed in chapter 11 are used to provide examples of its usage on the steel industry.

12.2.1 Industry and market standards

German and other EU produced steel has relatively low emissions and is generally considered more climate-friendly compared to other steel-producing countries in the world (BMWi, 2020) (Hasanbeigi et al., 2016). Interviews with steel market experts show that differentiation on the market is not based on any carbon footprint from production. Differentiation is more based on producing high-quality steels for very specific purposes. If an upstream company would want to implement a sustainable production process technique, it is of the highest importance that identification of this product would be developed. The industry and market standard through certification shows to be the ideal mechanism for CFCs to lobby for in order to guarantee the validity of low carbon steel bought. An institution, like for the timber or renewable power certification, should be built to oversee and licence those who produce steel in a carbon-neutral way.

With this institution and certification can the market incentivize their upstream steel suppliers to adhere to the requirements and standards of licences, as construction does by only using sustainable timber. Company statements of construction companies often include the share of sustainable timber (see appendix IX) as proof of differentiation. The same could hold for the automotive sector who has shown to be willing to use carbon-neutral solutions soon and attach a specific carbon-neutral label to their vehicles. Certification of the steel procurement is essential in order to have such a statement on the final consumer product. Steel production outside Europe could be incentivized similarly. Fairness in competition within the steel industry is of high importance. Sustainable steel producers outside of Europe will use these certifications to be able to adhere to the EU's sustainable steel demand and circumvent potential carbon border taxes.

As such, implementing this mechanism supports the promotion of carbon-neutral steel production according to CFC's wishes. In fact, the certification of steel can be considered to be a requirement like explained in section 12.1 in order for CFCs to obtain the desired upstream product.

12.2.2 Business model innovation

Through interviews has DuBoCalc been identified to be a mechanism already in place to drive CFCs in the construction sector to use sustainable products through changing the business model. This mechanism could if applied correctly, incentivize upstream steel production to act accordingly to demand developments. This incentive changes the business model compared to the generally low-cost decision-making of what steel supplier to choose and has the potential to add weight to carbon emissions as decision variable increasingly. The DuBoCalc method itself is not so much a direct mechanism towards the upstream production. It rather presents the business model of steel to change which needs to be translated towards the industry accordingly. The increase in added value for the carbon-neutral based steel is important for construction companies to communicate to the upstream industry, as they are directly influenced by DuBoCalc.

For automotive, cooperation to transition towards carbon neutral steel could become increasingly important as part of their business model. If the carbon-neutral ID.3 model by Volkswagen shows to be a high valued product, other automotive companies will go around the table with strategic positioning to look into applying the same business model. This will result in differentiation in vehicle production against traditional vehicles. The differentiation allows them to pay premiums for carbon-neutral steel and work together with the upstream production to realize this. The research has not directly identified this to be valid. The interview with Tata Steel has shown interest from premium vehicle brands into the latter. Still, interview with the more low-cost vehicle producer, FCA, has resulted in a negative prospect where any additional cost against a carbon-neutral steel is not likely to be paid.

12.2.3 Industry and sector-level collaboration

For the industry and sector-level collaboration, some interesting developments could be used to reduce risks for upstream steel production to transition. Providing security when upstream parties have to pay large capitals to invests in a high-risk transition can be accomplished through long term contracts (Creti and Villeneuve, 2004). Bilateral contracts between steel producer and their user could, with room for margin, agree on prices and quantities like the natural gas market did when expanding the distribution network. Only this could incentivize the steel industry to adhere to questions from downstream to decarbonize while reducing the risk of being out-competed by others. General long term contracts are valid for between 20-30 years and would require to take or pay clauses. For the application of the automotive and construction against the steel industry, preferably a variable agreement would be pursued as the buyer commits itself to a reasonably high-risk investment where potentially CCS would provide a similar product against lower prices. Therefore, the resource requirement of a CFC to use this mechanism is relatively high as a long term commitment with large impact is decided on.

On the other hand, interviews show that a wide variety of CFCs communicated their carbon-neutral steel target by 2039. This could result in an under-capacity of this carbon-neutral steel. As such, CFCs could prevent themselves from the need to participate in a high bidding process for carbon-neutral steel in the future by committing to the long term contracts (reliability of supply against known costing). To this end, the long-term contract approach would work as a win-win for both parties. Therefore, this mechanism can support the transition of the steel industry greatly and accelerate developments into hydrogen-based steel as it reduces large part of investment risks on the steel producer's side.

12.2.4 Performance standards

Though in the construction sector already a performance score is awarded on construction companies to tackle climate change, interviews have shown that all large constructors have the highest scores awarded. Hence, sustainable steel should enable construction companies to differentiate in these performance scores. In order to make the performance score of significance, criteria need to be more stringent.

For automotive, performance standards could be of value. Considering BMW or any other large automotive to be proudly presenting all of their carbon-neutral steel to be produced by company X gives them a large presence throughout media and CFC landscape. BMW is currently applying a financial bonus for managers who act sustainably in order to promote sustainability from the company within and increase their branding on sustainability (BMW, 2019). Such financial bonus incentives for suppliers, alongside the public recognition, could be a long term program which incentivizes steel producers to continue decarbonization year-to-year.

12.3 Conclusion on drivers to decarbonize alongside mechanisms

The value chain chapters show that there is a possibility that CFCs will be able to pay somewhat more for a decarbonized product. The steel industry holds the foremost possibility to shift some of the decarbonization costs on to the downstream companies and ammonia does seem to have niche markets available to do the same as well. Nevertheless, the full burden of decarbonization will not be able to be bared by the CFCs as it would not provide enough value increase in the consumer's product. As such, only a share of the transition costs could be spread over the value chain.

As the CFC's product increases in value to some extend, the CFC can be partly the initiator of the decarbonization. A conclusion on the synergy of mechanisms and driving decarbonization forces is that some mechanisms hold the opportunity to incentivize the industry to transition according to downstream needs. Through these mechanisms, risk reduction and sharing of investment required can be obtained, and mechanisms will support the drive to decarbonize in this way. Mechanisms alone will not do the trick, rather are other forces required to play alongside. Still, the amount of other forces required can be reduced following inclusion of the CFCs.

13 Discussion

13.1 Scientific contribution

The heavy industry has years to overcome the complex problem to decarbonize while staying competitive among those who focus on low-cost production. Through which mechanisms decarbonization of the heavy industry will take place is often focused on the governmental side of implementations (Bataille et al., 2018) (Haas et al., 2011) as industries try to protect their competitiveness. The creation of a clean industry demand market might ensure long term growth rather than a continuous supply of incentives to keep sustainable production competitive. Creating a demand-pull for niche markets was concluded to be a requirement by Ahman et al. (2017). This research's approach evaluated the potential creation of such a demand market and how a CFC can react to incentivize this demand creation through mechanisms. Something not discussed in literature research yet.

Whereas Sovacool's research evaluates existing mechanisms implemented by governmental institutions (Sovacool, 2010), this research has shifted the focus to (1) identify a potentially premium for CFCs on their consumer products, which can be a driver to use value chain mechanisms, (2) identify what heavy industries have the highest potential to be influenced by CFCs to be decarbonized, (3) what mechanisms show the highest potential to initiate hydrogen-based decarbonization. The first discussion point is discussed by Russel (2015), Killip et al. (2019) and Rissman et al. (2019), that it is possible to increase a product's value by decarbonizing it, is shown to be valid. The second and third discussion points are not discussed throughout scientific research and hence, contribute to scientific literature.

Acting on what demand is developing downstream in a value chain and translating this into upstream production could be applied on any kind of topic. This thesis, looked into the value of a green product, based on hydrogen. The same could be argued for replacing acidic, toxic or rare materials in upstream production as long as the new product is differentiated differently downstream. If so, the mechanisms are likewise able to translate the downstream product requirements into the upstream industry. Possibly are the relative applicability of mechanisms different compared to the relativity among them provided in chapter 11. A similar application of the presented research could be done for well-being of animal life in production of consumer goods. Like with green ammonia, downstream consumers could demand the CFC to adhere to animal life quality standards following the mechanism industry and market standards. This application is close to having a sustainable character like with hydrogen. Though any requirement could follow the same reasoning, applications with sustainable propositions could be argued to hold the highest potential as it places the end product in a potentially premium segment. Following this reasoning, the research's approach should not be limited to its scope, but rather implemented on any topic or size. Preferably should an economic view be used as the hypothesis tries to fill the transition risk through differentiating the product differently on the market compared to the conventional product.

The main contribution of this research is the discussion on the value chain incentives to decarbonize the heavy industry by a CFC. Existing research has not included downstream companies to be a stakeholder of significant influence on the heavy industry's decarbonization. Instead, through a change in mindset, these downstream stakeholders should be included by pushing the demand requirement for clean upstream products, by which decarbonization could be driven.

To look back at the research's approach, the research calculated the steel production prices for each production route through a specific model. The model shows that the costs related to avoided emissions in final consumer product are not of too significant size. The model created to calculate hydrogen-based steel prices corresponds to research by the IEA and Energy Transition Committee. These state that hydrogen-based steel prices increase about one-and-a-half till two times compared to current steel prices (IEA, 2019b) and that a vehicle's price will increase by 1% by using this steel (ETC, 2018b). The price increase of sustainably produced ammonia, obtained from interviews, is confirmed to be about twice the current price by scientific literature (Ikäheimo et al., 2018).

The stakeholder analysis does not include the whole market segment of an industry. Rather are a few stakeholders presented who have shown to be extraordinary either on the sustainable side, or the pollution aspect. As the figures are based on interviews, CDP scores and company statements towards transitioning, relative positioning of a stakeholder can be argued. As such, the recognition of similar results in order research acknowledges the findings to a certain amount. A research by McDougall (2020), an energy consultant, based for oil & gas companies the stakeholder's positioning on Transition Pathway Initiative (TPI) data. Though the scientific nature can be argued, the result is close to being similar. For the steel industry's stakeholder analysis is no research providing anything close to the graph. As the findings are based on industry experts, investments into the decarbonization will be the closest approach to evaluate the correctness. With SSAB being the only larger scale hydrogen-based steel producer (HYBRIT) and Voestalpine participating in the large H2FUTURE pilot steel project, its positioning are rather solid. Differentiation in investments of other steel producers seems to be somewhat lower, confirming their positioning close to each other.

The efficiency or effectiveness of CFC mechanisms to transition their upstream supply chain to use hydrogen has not been discussed among scientific literature. First, mechanisms have to be implemented to enable research on these parameters. Sovacool (2010) and Mitchell (2006) both confirm efficiency and effectiveness to be valid by correlating renewable power implementation with corresponding mechanisms. On the other hand, the research should focus on CFCs implementing mechanisms rather than governments. Literature research does not address the CFC aspect, and as such, examples from Apple and other companies are used to show the added value of mechanism implementation (Apple, 2020). It could be questioned if this comparison between renewable power promotion, and hydrogen-based decarbonization initiation, is too much of a difference. Still, this is the closest example of confirmation that CFC-based mechanisms may work.

The interrelation between the increase in cost and the perceived value is qualitatively shown to be different for companies. The coming years will have to show if there is proof of added value. Volkswagen, which is actively pursuing carbon-neutral vehicle production, will provide the first indication of whether consumers are willing to pay more for a carbon-neutral product. If so, the research's approach and mechanisms may be used for later research to identify more value chain mechanism applicability.

13.2 Societal value

Throughout the years, an understanding of the need to decarbonize has been created, which has encouraged consumer's knowledge regarding the issue. This understanding of the consumer could lead to a change in its willingness to pay for products adhering to sustainable trends. To what extend could consumers be willing to do so? Furthermore, if they do, how will the consumer-facing companies make sure that the consumer's wishes are catered for?

Societies are showing that demand creation for carbon-neutral products is developing through many different consumer industries by promoting carbon-neutral footprint production in commercials or through company statements. This research discusses how some of the more difficult decarbonized consumer products potentially follow these developments to create understanding among the industry that the cost gap of decarbonization might be lower than they think.

Carbon-neutral product demand creation could happen in any well-developed area or country as long as consumer product price increases can be accounted for. Underdeveloped countries will unlikely be in reach of the hypothesis and require the government to be the sole incentivizing stakeholder of industrial decarbonization through policy-driven actions. Developed countries should protect a rapidly changing world from global warming and as such, require decarbonization of polluting industries.

13.3 Reflection on research method

Mechanisms identified

With a gap in scientific research on CFC-based decarbonization mechanisms in value chains, the CDP has been chosen as a source to generate a list of mechanisms. As discussed in chapter 2, the CDP has a position in the question if value chain mechanisms are effective or efficient, as they try to stimulate companies to use them. Thus, these mechanisms should be researched to show their effectiveness and efficiency of decarbonizing value chains. Future research into these mechanisms might conclude that results from mechanisms show to be insignificant and hence, reduce the impact CFCs can have on their supply chain. Still, through the company-specific examples like Apple and Walmart, some prove is shown that indeed mechanisms are beneficial. This research is not focused on proving the efficiency or effectiveness of mechanisms. Scientific research, focused on these aspects, should look into this in order for the thesis to hold value. Before any research could be done into this, as Sovacool did for governmental mechanisms, mechanisms should be implemented on a large scale to be evaluated.

Value chain analysis

A first shortcoming is the number of interviews used to arise to an understanding of a sector. Though interviews take considerable amounts of time, a whole market segment's understanding can not fully be understood on a couple of expert perceptions. Therefore, the study should be repeated on sub-industry specific detail, like researching the relation between the steel industry and the automotive steel demand solely, to have in greater detail an understanding of the added value of green steel.

Secondly, the research has not incorporated certain demand sections like metalware, mechanical engineering and pipes. These sectors could show to hold some carbon-neutral steel demand. For example, Corinth Pipeworks, the first pipe manufacturer to reach net-zero over scope 1 and 2 carbon emissions (Corinth, 2020). This does not directly imply that they will require carbon-neutral steel to decarbonize their whole supply chain further but does show that climate awareness is translated into their product design. Though these demand sectors are smaller, drivers for clean products could still show to be of value and have a significant impact. Therefore, again, sub-industry specific research will provide further detail on how drivers are present in which industry's value chain to extend the analysis.

Mechanism applicability

The qualitative discussion on mechanism applicability does give insights on the relative use of mechanisms but is a shortcoming on the actual quantitative meaning of resource requirement and size. For research to include this, a smaller scope is required where again, on a sub-demand sector level, like the automotive industry, an approach is made to give quantitative requirements per mechanism.

Driven transition through mechanisms

The research tries to connect both research strings in chapter 12 in a qualitatively approach to discuss in what way the transition drive can be supported through mechanisms. Alongside, some detailed examples of mechanism implementation possibilities is given like the long term contracts or DuBoCalc. These examples are just a tipping point of all possibilities and others were not touched upon as the main focus is not this detailed. As such, the conclusion to what extend mechanisms can reach is not fully covered but rather opened for further research.

13.4 General shortcomings to the research

Though the research maps out different industries with high potentials to be decarbonized by hydrogen, the relevance of mechanisms is solely discussed for the steel industry. The comparison of mechanism applicability could be similar for all industries but do include differences. Sustainable hydrogen implementation in refineries, for example, could have different prioritization of mechanism. This is mainly due to the ease of implementation of sustainable hydrogen, compared to steel, where the whole production process is re-designed. Following reflection of the research, some other shortcomings are listed underneath.

Industries taken into account

In chapters 4 and 5, the research presents the sub-industries of the heavy industry, including the restrictions made regarding what sectors to take into account. For example, cement and aluminium were, from that moment on, not included, while they do hold some potential for hydrogen-based decarbonization. In hindsight, refineries should not have been included either as the impact of sustainable hydrogen is too low on the final carbon footprint. The methanol business was valid to include as only in the value chain chapter was concluded that the business does not hold high potentials from a CFC perspective to be decarbonized. If the sector had been excluded from the beginning, arguments would not have been comprehensive. Hence, the research should have included steel, ammonia and methanol to be the hard-to-abate sectors where sustainable hydrogen can have such a significant impact, that the product can be differentiated downstream.

Required hydrogen

The research does not take any restrictions on hydrogen production into account though the required green hydrogen would not be close to current production capabilities. For example, if all European ammonia would switch from the current grey hydrogen to green hydrogen, then 13Mt of ammonia would turn sustainable, which means that 2,6 Mt of green hydrogen is required. The power-to-hydrogen conversion is 0.019 kg/kWh which means 0.019 ton/MWh converting in 19 Mt/GWh (Glenk and Reichelstein, 2019). This results in a required 684TWh of renewable power generation yearly. Considering current Europe's renewable power generation is 969 TWh means that two-thirds of the total production would have to be dedicated for renewable ammonia at the loss of household, industry, and other renewable power consumption (Eurostat, 2020).

It could be argued that even if hydrogen-based decarbonization were promoted, chances of sufficient hydrogen on short term notice would not be there. It will be an exciting development to see to what amount hydrogen will be used in what sectors. The research has not tackled any issues related to the availability of hydrogen supply and assumed that there would be enough to support an transition.

Furthermore, once sustainable hydrogen production increases, case-by-case, industries will transition. It is most likely that transportation will encounter a more extensive sustainable hydrogen usage before any of the other industries mentioned. For example, chemical industries have the choice to use CCS while transport can not implement this, which means that the value of sustainable hydrogen might be higher for the transport sector.

Methanol and ammonia for transport

The applications of methanol and ammonia were primarily described as materials to be used in applications besides transportation fuels. Numerous researches state that these two commodities could be utilized in long-distance transportation in the future, which means that the value chain chapters might change in terms of the final destination of the products. These new applications could result in CFCs to use methanol and ammonia, based on sustainable hydrogen, which might change the conclusions of this research that the steel industry holds the largest drive from CFCs to be transitioned.

Identifying ammonia's CFCs
During the value chain analysis, and interviews with upstream ammonia producers, farmers were identified as the CFC. Instead, one could argue that farmers are not the CFC, rather large corporations like Smiths Food Group could have been identified to be willing to pay more for a sustainable product. These companies could incentivize the farmers to decarbonize their fertilizer supply. Though, farmers could indeed be identified to be consumer-facing for products in bio-markets. Instead, the research should have focused on corporations like Smiths Food Group to discuss their view on the matter. To nuance missing out on this issue, the interview with Lantmännen did not show any development from larger corporations to demand a change in their farming operations.

Iron mining
This research has not included iron ore mining emissions related to steel production. As discussed by various researchers, (close to), carbon-neutral steel can be made. If hydrogen-based DRI is labelled to be carbon-neutral, iron ore mining, the process before steel making, should be transitioned as well. Possibly is this process more accessible to transition than steel plants as machines could run on sustainable fuels wherein the steel process a radical change is required. Still, this should be taken into consideration.

Steel model
The steel model must be considered to be an approach towards the discussion on what price decrease is required for the steel industry to make hydrogen-based DRI competitive. Focused research on the topic will give a better presentation of what the actual price in a particular region will be. The model could have been more extensively made in case of increasing its usage over the thesis, but, as it is of small significance, no further consideration had been given besides going over the model with industry experts.

Reaching carbon neutral products
A drawback from the research is that the upstream carbon-neutrality does not result in a CFC's carbon-neutral product. For example, the carbon-neutral steel decreases an average vehicle's emissions by 29%by increasing the price by 1%. The price of a fully carbon-neutral vehicle is uncertain as the different aspects to reach this are not discussed. The same holds for the farmer's product which does not become fully carbon-neutral by using green fertilizers.

Green purchasing during an economic crisis
This section will be the first time that Covid-19 will be discussed in the research. During the research, the world has experienced a global health crisis which is about to be followed by an economic crisis. Believes are, that this situation could both be a threat to hydrogen investments, as well as an opportunity to transition. One could argue that CFCs have to focus on their own processes rather than try to decarbonize their supply chain. This situation could be comparable to the economic crisis in 2008, where green power was still in its upcoming phase. Research by BCG at that time shows that the 'green' aspect to products is resilient to any economic crisis and that awareness among people has risen in such way that the current situation does not necessarily have to downgrade any valuation to a green product (Manget et al., 2009). Therefore, should Covid-19 not necessarily mean that CFCs will not consider further decarbonization of the value chain relevant.

14 Conclusion

The main research question had been formulated as: *what probable impact can consumer-facing companies have on the heavy industry's hydrogen-based decarbonization?* The study can answer the following sub-questions from which the main research question can be answered.

Through what mechanisms can consumer-facing companies influence hydrogen-based decarbonization upstream in the value chain?
Literature research does give indications that a demand-pull from a consumer market can incentivize the upstream industry to promote decarbonization. Still, scientific research has not been able to define a strict set of incentives and mechanisms that have been used by CFCs to do so. Hence, as the CFC's choice on a mechanism to be used is not clearly defined in the scientific literature, CDP's research alongside different company projects was used to show that different mechanisms are, and can be used. Following these researches, a framework of mechanisms is listed to decarbonize industries. On the one hand, there are efficiency-focused mechanisms, and on the other hand, transformation mechanisms. Transformation mechanisms change processes radically and have the potential to initiate more significant amounts of decarbonization compared to efficiency measures, where the current process is optimized.

How to identify changes in demand for clean heavy industry products?
Through scientific literature research has the paper by Sovacool (2010) been identified to be used as a guiding structure for a qualitative research approach. Interviews with industry experts from different sector levels follow a semi-structured approach to identify drivers for CFCs to use decarbonized products. This method is used to identify whether CFCs can get additional value from sustainable upstream industries which are decarbonized through sustainable hydrogen. Identifying the level of change is based on the incentive CFCs have, to differentiate products to their consumers successfully.

What sub-sectors in the heavy industry are dependent on sustainable hydrogen to be decarbonized and what consumer-facing segments are in the downstream value chain of those sub-sectors?
After identification of the four primary industries where hydrogen is critical to decarbonize, these hard-to-abate sectors are analyzed to identify their supply chains and look into consumer-facing demand sectors correspondingly. For the methanol industry, the final application of the commodity is hard to distinguish. Hence, the research is not able to answer the sub-question in detail. The refinery sector sees its products going as fuel into industries and consumer transport. Ammonia is mainly used as fertilizer. The steel industry's products are used mainly in automotive, construction and other appliances like mechanical engineering and metalware.

What industries have the highest chance, desire and capabilities to be influenced to decarbonize by consumer-facing segments to produce hydrogen-based products?
Scientific literature, a model, and interviews show the cost increase related to both the upstream material, as well as the effect on the downstream product price sold to the end consumer. Interviews with industry experts state that for some downstream applications, the willingness to pay more for a carbon-neutral product is valid. Not all segments within a demand sector seem willing to pay more as the low-cost producers like FCA will not be able to demand an additional premium on their vehicle using decarbonized steel. Table 6 shows variables of sectors related to the applicability of the hypothesis and corresponding scores of the industry's sectors qualitatively assigned to them. The steel industry has the highest potential to be incentivized by CFCs to decarbonize following their downstream supply chain. Interviews with steel producers show this pressure increasingly being communicated to them, which confirms the outcome that the consumer's desire is to decarbonize industries to a certain extend.

What mechanisms hold the highest impact potential on hydrogen-based decarbonization?

Through the mechanisms identified in chapter 2, a qualitative assessment is made on mechanisms that could potentially affect hydrogen-based decarbonization. Business model innovation, industry & sector level collaboration, and industry & market standards are considered to have the highest potential among mechanisms to reduce risks in transitioning the steel industry. These mechanisms ensure CFCs to engage in discussions on how the industry should be transitioned.

To what extend can CFC-initiated mechanisms support the request of hydrogen-based products from the heavy industry?
The full costs of steel price increase can not be bared through the CFCs on their own. Rather, part of the solution on how to decarbonize the heavy industry can come from CFCs participating in stimulating mechanisms. The three mechanisms holding the largest opportunity to initiate a hydrogen-based decarbonization approach the problem as a complex issue where stakeholders from different levels are involved. These mechanisms transform the business model by not solely relying on the stakeholder upstream to change production but rather look at how downstream acts as well and creates value by doing so. Instead, a differentiation of the final downstream product is a possibility to gain additional value to support and finance costs from decarbonization.

The main research question is answered throughout the sub-questions, and the research shows that there should be a position for downstream companies at the industry's decarbonization discussion table. The steel industry has the highest potential to be decarbonized by its value chain, which is mainly due to the clear identification of the commodity into the consumer's end product. Though not all steel demand sectors have been interviewed, feedback from upstream steel industry interviews tell that there is a larger pull of future carbon-neutral steel demand ahead. Hence, besides governmental influences, the industry is experiencing pressure from downstream to produce products with reduced emissions. Also, the availability of mechanisms is presented for CFCs to use if they want to move the industry according to their wishes. The combination of both the clean product wishes, as well as the mechanisms presented, provide opportunities for downstream and upstream to work together on solving the issue. Though transition will depend on much more factors, part of risks can and should be solved by the value chain.

14.1 General recommendations

Consumer-facing companies
Consumer-facing companies should not be the ones waiting for the heavy industry to decarbonize. These companies can look at green differentiation possibilities of their consumer-facing products to engage in the transition process. Preferably, they should be included in the solution of decarbonizing the heavy industry and look at what way they can reduce transition risks. Often is the high-level government policy aspect introduced to be the sole identity to ensure decarbonization while, on the demand market level, an increasing willingness to pay might make it possible to finance part of the transition.

Upstream companies
Upstream companies should open dialogue to CFCs and express their goals and capabilities. If CFCs are showing to require carbon-neutral products in the near future, without supporting through any means, upstream producers can refer to the discussed decarbonization mechanisms. This approach should be reinforced by showing the potential added value of decarbonized products for CFCs. Though the research assumes that CFCs will implement these mechanisms on their own incentive, industries could educate those customers who are not aware of mechanism availabilities.

Governmental influence
The requirements described in chapter 11.1.1 and 11.1.2 are a must to be pursued in order for the mechanisms to be of use. Hydrogen certification is already being developed, and scope 3 emissions

projects to standardize are investigated. Governmental influence in these two could be of importance to supervise and reduce fraudulent risks.

Governmental influence, both for the two requirements as well as all mechanisms, can positively influence all of the research outcomes. Creating a favourable carbon-neutral product market enables the CFCs to increase pressure to the industry for decarbonized products. Thus, implementing mechanisms in the supply chain to do so. As such, governments should not be excluded from this research to be of interest as their influence can be of meaning.

It is the researcher's opinion that the European governmental bodies should implement carbon (border) taxation in order to decentivize fossil fuel usage and gain resources to fund renewable projects. These governmental influences will encourage CFCs to push their supply chain to transition even more as the gap between the traditional product and a carbon-neutral solution will decrease.

14.2 Recommendations towards Shell

Within the thesis' scope, Shell should not be considered to be mainly a refinery owning stakeholder. Instead, Shell should become an enabler of transition by supplying hydrogen soon. The added value for Shell is a first-mover positioning in a developing market which can be of considerable size. Most importantly has been shown that there might be an upcoming demand for carbon-neutral products, some of which need to be provided through hydrogen-based decarbonization. As such, Shell could play into this knowledge by enabling hydrogen usage as a supplier as well as provide other consultancy related services. This knowledge of where hydrogen could make a business case in the future should, for Shell, be considered as a strategic piece to act accordingly on.

In relation to the thesis, Shell is not directly involved in actions related to the outcome. Except for the refineries, where the thesis's approach does not hold much value, Shell is not in the downstream CFC area, nor is it in the upstream process. Being merely a provider of the upstream energy demand, **the knowledge of what is coming at your client in terms of energy demand is of importance**. As such, within Shell, the departments holding most interest in the topic are B2B sections in power, gas and services. These B2B accounts could keep an eye on developments into the changing energy demand following results from the research and even advise on the companies to do themselves. To act on this changing energy demand, investments have long lead times and as such, an energy provider should be ahead of its competition to be able to supply the energy needs.

Knowing the approach of this research, and confirming that CFCs are demanding the heavy industry to transition, Shell could also play as an advisory and communicating role between the two value chain ends. In order to assure the company to be a key player in future energy demands, Shell could initiate the dialogue by participating in mechanism implementation programs and roll these out over different market segments. This, is less of a strategic approach to win future energy business and positions the company to work its way positively into an enabling player. As such, the strategic approach of looking far ahead in the value chain to act on developments in energy demand is considered the most important takeaway for Shell to use as their approach.

14.3 Future research

The approach of CFC mechanisms should be further researched scientifically, and mechanism-specific research could include specifics overseen by this research. Though this research shows some potentials of mechanism implementation from the demand market level, validation on a scientific level should be elaborated. The CFC mechanism-specific research could incentivize CFCs to consider implementation and contribute to their upstream supply's decarbonization.

Over time, research should look into the effectiveness and efficiency of by CFC's placed hydrogen-decarbonization mechanisms and validate the usage of it. To validate, mechanisms should be implemented first before looking into the applicability of hydrogen promotion becomes possible. Possibly could scientific research first look into the effectiveness and efficiency of renewable power mechanism implementation and scientifically approach these incentives by CFCs rather than focus on the governmental policy level.

On top of that, long term contracts might be interesting for both the steel producer by reducing risk and the consumer by ensuring the security of carbon-neutral steel in the near future, from which differentiation of the traditional business model becomes possible. Research into how bilateral contracts, like the natural gas distribution market used, may provide security for both ends of the value chain and could be valuable research.

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15.1 Appendix I - Hydrogen demand scenarios

Figure 31 shows the expected sustainable hydrogen demand from different researches (BloombergNEF, 2020) (ETC, 2018a) (Shellsky, 2018) (Guidehouse, 2020) (EC, 2018). Some of these researches include both a European estimation as well as a Global estimation of hydrogen demand. Others only include a European hydrogen demand. Extrapolation is used for the scenarios that only include the European estimations following the ratio of the researches, which include both EU as well as global.

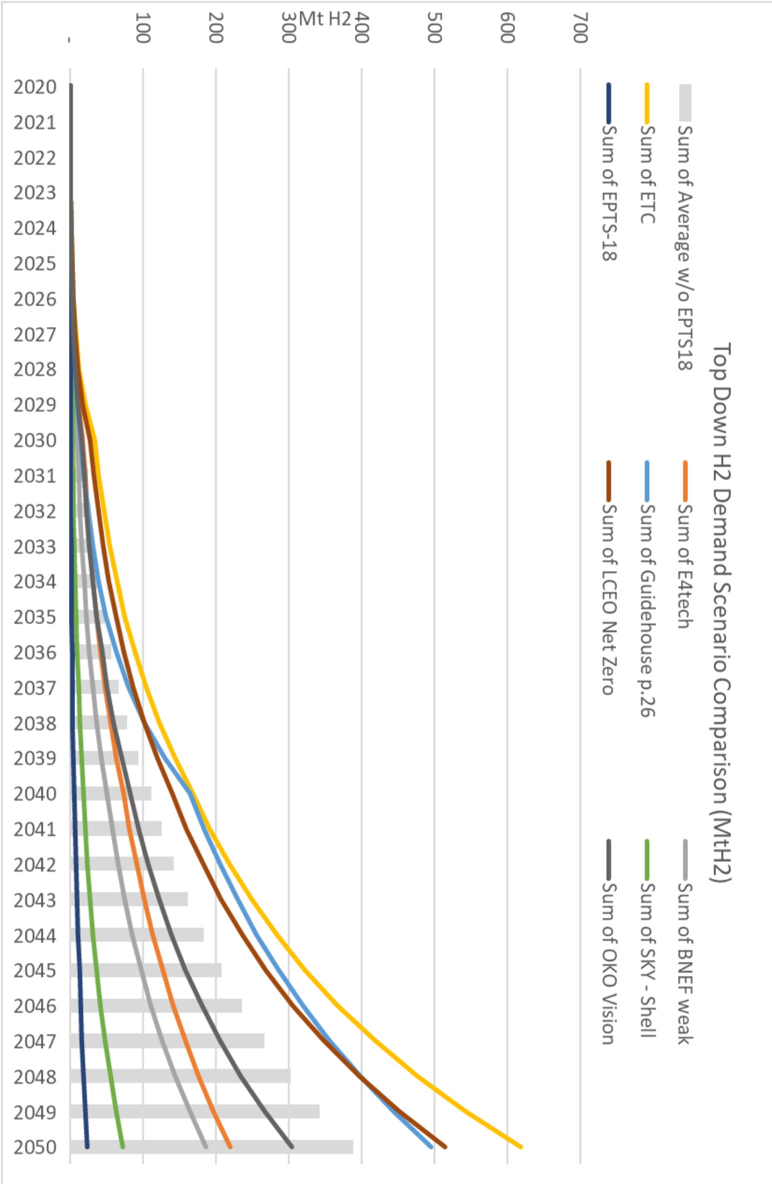

Figure 31: Sustainable H2 demand scenarios

15.2 Appendix II - Governmental policies to decarbonize industries

Carbon pricing

On the incentives side is a broad range of possibilities to initiate a transition in the heavy industry. Carbon pricing, among one of the most important ones, discourages CO2 emission-intensive processes and pushes towards using sustainable technologies (Bataille et al., 2018). The cost gap between a mature process and a new technology is decreased and in some cases could the obtained money be spent on these carbon-neutral technologies to bring down price differences even further. This mechanism resolves the issue of heterogeneity as the implementation validates consequences over any process. An essential addition for an implementation like this is the avoidance of 'carbon leakage' from other countries (Åhman et al., 2017). Production could see a shift towards countries where no carbon tax is implemented, which makes it difficult for companies adhering to the tax to stay competitive. Compensating through free emission allowances, exemptions from taxes and support energy efficiency policies have shown that there is currently no carbon leakage under the EU ETS system (Åhman et al., 2017). Hence, the implementation of a high carbon tax would possibly not lead to carbon leakage if the right market protection mechanisms are applied. It is not this research' concern to go into more detail as these are no value chain incentives.

Carbon contracts for difference

Carbon contracts for Difference (CCfD) is a mechanism which rewards sustainable production process investments by providing a fixed price for the emission certificates bought in excess. This mechanism only holds significance under an EU ETS system where the prices of ETS carbon emissions have fluctuated over the past years, which made the investments in a sustainable new kind of technology unreliable on its competitive advantage (Sartor and Bataille, 2019). This unreliability of investments is a result of the traditional production processes, potentially experiencing a low increase in carbon costs given the fluctuating carbon price and increase the uncertainty to invest in sustainable processes.

First movers of these sustainable new kinds of processes should be supported through CCfD, which is similar to the renewable power feed-in-tariff. A strike price will need to be determined beforehand (see figure 32). The difference in the carbon certificate price multiplied by the avoided emissions through the sustainable process will have to be paid by the government. Further implementation of this mechanism will not be elaborated upon because the focus will be given on supply chain mechanisms. Still, if the EU ETS system would endure in the future, CCfD could be a powerful driving mechanism to decarbonize and promote investment in a high-risk hydrogen solution.

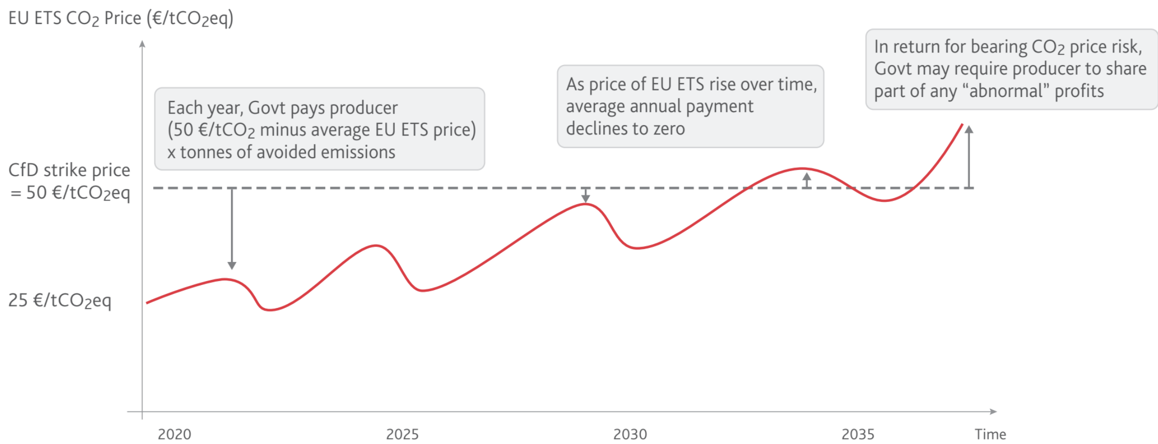

Figure 32: CCfD mechanism explained (Sartor and Bataille, 2019)

EU carbon border constraints
As value chains and trading markets of heavy industry's commodities are traded on global market levels, the importance of differentiating between a green commodity, and a conventional dirty commodity is of importance. A general approach for the EU to protect the green and high-cost commodity is through EU carbon border constraints.

Carbon border adjustments (CBA) create an appropriate level of playing field for the sustainable EU companies who use decarbonized production processes. Third country export of polluted goods into the EU will be discouraged following a non-discriminatory mechanism which would be allowed following WTO regulations. Applying CBA restores some uncertainty to invest in green solutions by taxation of carbon emissions related to goods imported into the EU. CBA is an industry-wide approach and can be implemented for any commodity or good. With the additional money obtained could the EU use these resources to even further promote sustainable development, for example, by financing the CCfD mechanisms. Initial implementation could start through only a few sectors which hold the highest share of emissions (like with steel), and gradually include more and more sectors as the mechanism proofs to be of value.

Research by BCG states that for a CBA price of 30$/ton CO2: '*The levy could reduce profits on imported flat-rolled steel, in particular, by roughly 40%, on average. The impact of the added costs would be felt far downstream.*' (Ben Aylor and Voigt, 2020). This impact on the downstream sector would, in turn, reduce the price gap with the sustainable option.

Quotas
Gradually implementing quotas could be a mechanism to provide a certain degree of certainty in the transition as, for example, aviation fuels will be required to contain a certain sustainable part (Rahman, 2020) or inject sustainable gas into the gas distribution network. Quotas are not creating a demand in the hydrogen market from the demand incentive but instead implying its usage on the industry.

Research and Development support
Another bespoken topic in literature, to decarbonize the heavy industry, is through governments providing support by investing in Research and Development R&D (Åhman et al., 2017). Though it would not immediately result in direct emission reduction, this method is considered to be more of a long term approach to supporting sustainable technologies to develop. Research shows that governments promoting renewable growth through R&D investments have increased renewable energy consumption in their countries (Paramati et al., 2020). The renewable energy increase through R&D has shown to reduce CO2 emissions which acts as a plead to incentivize EU policymakers to provide financial assistance in decarbonization (Paramati et al., 2020).

Research, development and demonstration (RD&D) is an even further step where the demonstration enables research to address barriers for large scale implementation. Governmental support during this scale-up stage can speed up commercialization and market uptake (Rissman et al., 2020). There are many different examples of governments supporting RD&D, amongst them laboratories, academic funding, industry partnerships, entrepreneurial and innovative technology support, and financial incentives for corporate giants (Rissman et al., 2020).

Energy efficiency standards
Quick wins in emission reductions can be obtained through energy efficiencies and energy standards (Rissman et al., 2020). Standards for electric motors, which accounts for two-thirds of power consumption in the industry, have shown to be a major impact in power consumption (Rissman et al., 2020). Over the last decades, have many of the efficiency gains been implemented and was the financial recovery of investments in energy reduction worth it. On top of direct financial gains

shows research that there are many more additional advantages of energy-efficient processes (Russell, 2015). Some of the most outstanding proven advantages of companies becoming energy efficient are listed underneath (Russell, 2015):

- Increased energy security due to improved knowledge of energy usage
- Reduction of air pollutants enhancing public health
- Increased market shares through market alliances with like-minded companies who want to work together
- Premium pricing through a more sustainable product
- Higher employment as businesses improve sector competitiveness

Data transparency
Data knowledge shows to be fundamental to industrial decarbonization as it gives better insight into the plant's energy use, emissions and potential reductions (Rissman et al., 2020). On the other side of data transparency is the pressure from other stakeholders like governments and environmental organizations to publicly disclose company data to understand the impact of business on the environment. The CDP is one of such organizations disclosing company data and scoring yearly environmental company reports on their decarbonization plans. Alongside this initiative is the goal-setting of reducing emissions and stating this to the public. Following these statements can the CDP identify companies which are proving to adhere to their goals, and those who are lagging.

15.3 Appendix III - Examples of renewable power incentives

Some companies were not included in the description of companies tackling carbon emissions trough renewable power in chapter 2. To give a more detailed picture of CFCs using mechanisms to promote renewable power usage are the additional examples given underneath.

- Biogen - With 70% of the carbon impact coming from supply chain partners, Biogen has committed to working together with high impact stakeholders to align climate strategies (Biogen, 2019). Hence, the company has since 2015 engaged with over half of its suppliers to become more efficient and increase renewable power usage.
- Clif Bar - Clif Bar started tracking value chain emissions in the early 2000s and decided around that same time that it would implement renewable power over its own facilities (Bar, 2020). The 50/50 program was launched in 2014 to assist 50 suppliers to use at least 50% renewable power by 2020. In order to help suppliers to transition, Clif Bar began paying for energy experts to either make a business case for on-site renewable power production or through other forms of agreements (Bar, 2020). Eventually, over 90% of Clif Bar's suppliers have used these consulting service, and the company has become active in hosting wind turbines on supplier's properties as well (Bar, 2020).
- British Telecom - British Telecom (BT) started supply chain programs in 2012 and extended the five years program again in 2017 (RE100, 2017). The target for the supply chain is to ultimately reduce 29% emission by 2030, which mostly should be accomplished through renewable power. The progress entails a campaign with Npower who can supply renewable power at a favourable tariff.
- Nike - Nike, being one of the strongest brands in the world, the company is fully aware of its carbon footprint throughout the value chain and hence, initiated its Environment Minimum Programs to transition the value chain to decarbonize (Nike, 2020). The main goal is to help the suppliers understand their impact areas and track data on these performances. By providing energy consults, Nike can lobby for solutions to decarbonize suppliers and pushes them to set goals (Nike, 2020). Data-driven decisions with energy-related analysis are critical alongside best practice sharing among suppliers.

15.4 Appendix IV - Interview one-pager

Context: The heavy industry holds a large potential to reduce carbon emissions. Green hydrogen can be used in current processes of DRI-based steel, ammonia and methanol production, or replace existing grey hydrogen demand of refineries. The research question is whether the downstream consumer-facing companies can influence the upstream commodity process to decarbonize and produce 'clean' commodities. Hence, I try to get in contact with upstream producers to discuss their opinion about developments in green hydrogen and whether they think their customer basis will gain demand for this (and with that willing to pay a premium). After interviews with upstream stakeholders, the research will interview commodity using companies (automotive, construction & fertilizer users) to see if their demand for green hydrogen-based commodity is expected to shift or not.

A semi-structured outline of the interview is given underneath:

- Get to know the business:
  o What does the supply chain look like?
  o How is -'commodity x'- bought in the current situation? Is there one company supplying or multiple?
  o How strong is competition and how to differentiate?

- Get to know the future:
  o What sustainable production projects are they working on? How important is development in carbon-neutral -'commodity x' -?
  o Implications on the costs. I made a model on the steel price increase, shows on average 1% increase in vehicle production costs. Is this acceptable?

- Get to know the customer demand:
  o How are customer requirements changing?
  o Is there a willingness to pay for these new requirements? o How would the value proposition differ if carbon-neutral products are used?

- Technical:
  o How big is the impact of -'commodity x'- on the final emissions of a product?
  o How big is the impact of -'commodity x'- on the final costs of a product?

- Future development with the steel industry:
  o How could the automotive sector incentivize the steel production to become carbon neutral?
  o Considering capital intense investments have to be made in the steel industry, would X be willing to have long term contracts which take away some risks for the steel industry to transition?

15.5 Appendix V - Grey Hydrogen

Currently, by far the larger share of all industrially produced hydrogen comes from natural gas through the steam methane reforming (SMR) process (Simpson and Lutz, 2007) (Sanusi et al., 2017). The process is an endothermic reaction where a nickel-based catalyst at high temperatures typically catalyzes methane and steam (see equation 6) (Simpson and Lutz, 2007).

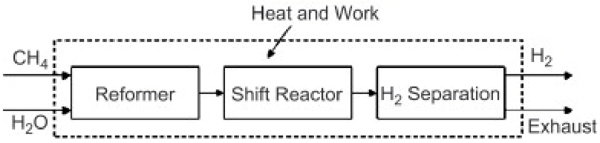

Figure 33: Simplified graphic representation of the SMR process (Simpson and Lutz, 2007)

$$CH_4 + H_2O + 251MJ/kmol_{CH4} \longrightarrow CO + 3H_2 \tag{6}$$

The process is shown in figure 33, where the described reaction takes place in the reformer. The CO which is obtained as a by-product, follows a second reaction which is shown in equation 7 and is, contrarily to the first reaction, an exothermic reaction. The net reaction is endothermic since the energy required in the first reaction is far beyond the released energy in the second reaction.

$$CO + H_2O \longrightarrow CO_2 + H_2 + 41.2MJ/kmol_{CO} \tag{7}$$

The last step is the separation of hydrogen, this is known to be mature, but energy-intensive process (Simpson and Lutz, 2007). Because the whole SMR process is energy-intensive, research currently conducted is to electrify parts of the process in order to reduce the emissions. For example; electrified methane reforming reduces the fossil fuels needed in heating the whole process, which in turn reduces the overall carbon footprint (Wismann et al., 2019).

A second, but currently less industry-wide used production method, is by using natural gas in Autothermal Reforming (ATR). The investment costs of an ATR plant are between 15-25% lower compared to the SMR plant and produce hydrogen at about 1/3th lower prices per kg (Nikolaidis and Poullikkas, 2017). Equation 8 shows the reaction, which is exothermic due to the oxidation of methane.

$$4CH_4 + 2H_2O + O_2 \longrightarrow 4CO + 10H_2 \tag{8}$$

The remaining production of grey hydrogen is originated from coal or oil as a raw material. Pure oxygen is used to oxidize the hydrocarbon feedstock, and the last step is the same as the SMR process. The plant required are highly capital expensive, and thermal efficiency is between 60% - 75% (Nikolaidis and Poullikkas, 2017). Producing hydrogen from coal gives the lowest hydrogen price (between 1.34-1.63$/kg) but in turn, emits the highest amount of carbon dioxide emissions compared to the other production techniques (Nikolaidis and Poullikkas, 2017).

15.6 Appendix VI - Competitiveness of Green Hydrogen

For stakeholders to use hydrogen, prices of the carbon-neutral hydrogen should decrease as much as possible towards substitutes for the industry to need the lowest amount of willingness to pay to use the resource. The research will, later on, analyze where the willingness to pay for carbon-neutral energy carriers grows. The current cost of hydrogen production is highly dependent on the fuel used. According to the IEA are the fuel cost component between 45% and 75% of the total costs per unit produced (IEA, 2019a). Natural gas-rich countries like Russia, North America and the Middle East have relatively the lowest hydrogen production costs. On the contrary, Europe and Asia, with prices increasing largely as the natural gas price sometimes doubles (IEA, 2019a).

For green hydrogen to become feasible, part of the costs will be related to low electricity prices. Capital expenses of electrolyzers are the second large aspect of the green hydrogen production costs. Electrolyzer costs, as well as solar and wind-based electricity costs, has been decreasing and keep on doing so, which increases the interest in green hydrogen. These electrolyzers should be located at places where renewable electricity productions are excellent for the hydrogen to become as low cost as possible. The transport from these low-cost production locations to demand locations are often lower than production on-site where it is needed (IEA, 2019a). A caveat to production; if the current demand for hydrogen globally, which is almost all produced following the grey method, would be changed to green hydrogen, the electricity demand for this would be 3,600 TWh (IEA, 2019a). This is more than the current annual electricity demand of the European Union, which resembles the increase in power required for hydrogen to become of real scale. As a final remark to the supply chapter shows figure 34, the discussed hydrogen production technologies and their corresponding price range. The figure shows that current hydrogen production methods have a price gap between renewable and fossil fuel-based hydrogen, which is considerably high. On the other hand, it could be argued that the high case natural gas and low case renewables seem almost to reach each other, which could imply for some regions, competitiveness is close to reality, as costs keep declining over the coming years.

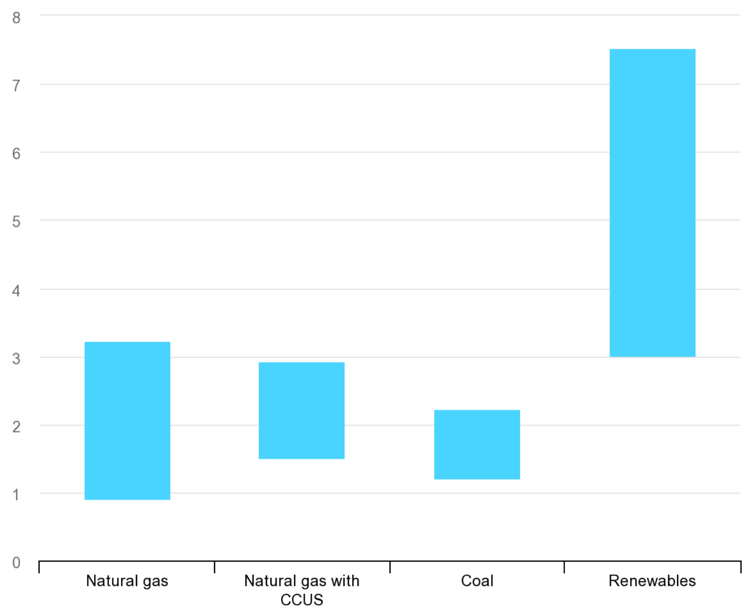

Figure 34: Hydrogen production costs in USD/kg of different techniques (IEA, 2019a)

15.7 Appendix VII - Details on market trends

15.7.1 Iron & steel

Since trade in steel supply is global, all producers from different continents compete with each other. The supply of iron ore is highly concentrated with four companies accounting for 71% of the iron shipments in 2014 (WSJ, 2015). The market for steel producers, in contrast, is very different from this high end upstream because the ten largest users of steel products account for 27% of the produced steel (NERA, 2016). Downstream towards users of steel are even more fragmented stakeholders losing more bargaining power. European producers have the biggest problems remaining competitive as operative costs remain higher compared to other continents. While Europe accounted for around 23% of global steel production in 2000, it decreased to 9.3% in 2018 (EuroFER, 2019) (NERA, 2016) (IISI, 2002). Possibly, European should companies start to differentiate the commodity and change their value proposition in order to survive in the highly competitive market of steel.

Over the past years have emissions in the heavy industry increased significantly and resulted in the steel industry to account for 2.0 Gt CO2 in 2017 (IEA, 2019b). Steel from the European Union, with 11% of the global steel production in 2017, generated around 10% of the global CO2 emissions coming from steel production (Mandova et al., 2019) (IEA, 2019b). Hence, the cleanness of the steel produced in Europe is not that much higher compared to steel from other continents. The EUROFER, who represents the European steel industry, according to interviews, has been busier with protecting the European industry against Asia by lobbying for import tariffs rather than providing an incentive or chance to become cleaner. In EUROFER's Green Deal on Steel has a calculation been made for the possible reductions given that the ideal circumstances are handed to them. *The sector would be able to develop, upscale and roll-out new technologies that could reduce EU steel production's CO2 emissions by 30% by 2030 and by 80 to 95% by 2050, while contributing to greenhouse gas mitigation across all sectors* (EuroFER, 2020).

15.7.2 Refineries

The increase of refinery's hydrogen demand in the future could, without any process changes, be replaced by this fossil-free hydrogen and provide producers with a carbon reduced product. Figure 35 shows the margins from refineries and the affiliated hydrogen costs from on-site SMR hydrogen production. It shows that the hydrogen costs are small related to the refining margins. Still, the margins of refineries are low due to the competitiveness of the market, which means that a small cost advantage like low hydrogen cost, is easily taken to its advantage. Before 2014, margins were low due to overcapacity and low demand for products (Orkestra, 2018). Over time, more complex refineries have shown to generate about 2-3% more profit from the market, and do not have the negative margin periods as for simple refineries (Orkestra, 2018). This is due to the decreased demand for conventional gasoline, which in surplus is available, and increase in bio-gasoline.

Hydrogen in refineries is expected to grow by 7% towards 2030 after which demand growth will slow down (IEA, 2019a). Hence, the crux is not to focus too much on the growing demand for hydrogen in this sector. Rather needs the hydrogen origination to be changed towards sustainable alternative which brings the incremental change in emissions and changes the product specifications. This is in line with research from BCG concluding that the more complex refineries providing differentiation in its products show higher margins compared to conventional refineries (Orkestra, 2018).

15.7.3 Ammonia

On the longer term, ammonia growth towards 2050 does not hold back as the need for efficient food production keeps on growing, and with that, the demand for fertilizers as well. The trends of the growing population, higher urbanization, fewer farmers and resource scarcity like clean water

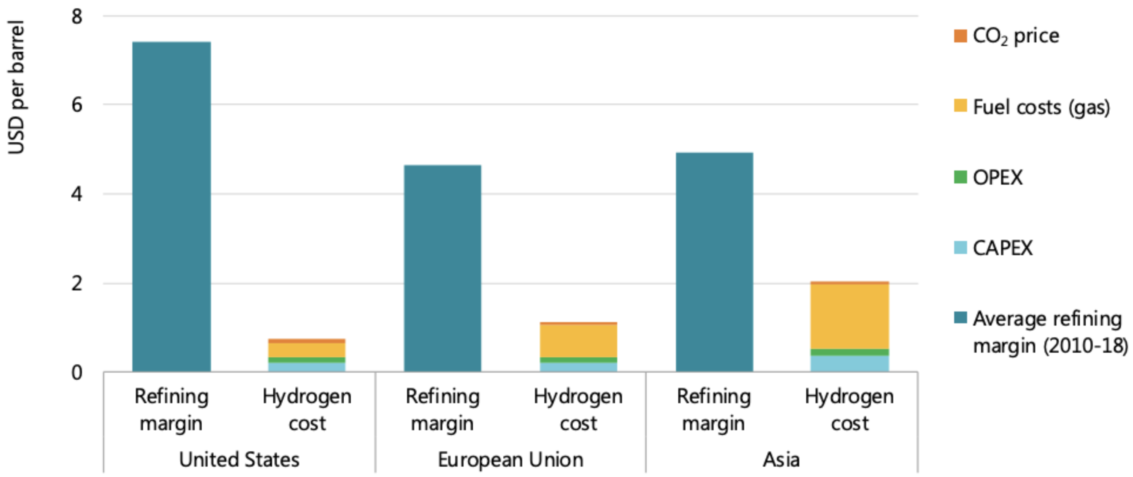

Figure 35: Margins of refineries (IEA, 2019a)

form the ideal macroeconomic setting for the fertilizer industry to gain market power. With this development of more demand, companies like Yara are adjusting their production to become more sustainable and provide green products for the farmers.

On top of that goes the demand increase for ammonia along with the demand for clean hydrogen-based fuels. Future questions in how to store hydrogen on a large scale will resolute in ammonia as storage methods. The storage of hydrogen by alternative chemical fuels provide a high density of the fuel since molecular packing increases the energy content per volume as it allows more hydrogen per volume (Verleysen et al., 2020) (Grinberg Dana et al., 2016). With methanol as the example for hydrogen storage in carbon-based fuels, ammonia is the commensurate in nitrogen-based fuels (Grinberg Dana et al., 2016). Hence, for these fuels to be clean, they require clean hydrogen. The main application of these fuels could be found in the power system, automotive applications, and agricultural machinery (Frattini et al., 2016).

15.8 Appendix VIII - Outcome of the steel price model

The model is used to give an approach to how much more sustainable hydrogen-based steel costs. The model would have to be adjusted on specific business cases and may differ substantially per continent and region. The general costs related to the BOF process are taken from (SotN, 2020a). EAF and natural gas-based DRI variables were obtained through research by (Vogl et al., 2018), (SotN, 2020b) and (Baig and Murray, 2016). The natural gas-based variables were kept constant for hydrogen-based DRI, and the same energy content replaced the natural gas required in MMBTU in terms of hydrogen. Interviews with Tata Steel concluded that this was the best approach to the question. Hydrogen costs were taken from the ICIS and were calculated in dollars following a 1:1.13 euro: dollar ratio (ICIS, 2020). The IEA shows similar results in their hydrogen-based steel analysis (IEA, 2019a) (IEA, 2019b).

Overview

Total Cost of Ownership			Low	High
BOF	Steel output price	USD/Tonnes Steel	412,23	
EAF scrap	Steel output price	USD/Tonnes Steel	400,77	
EAF, DRI, Natural gas	Steel output price	USD/Tonnes Steel	506,60	
EAF, DRI, Hydrogen	Steel output price	USD/Tonnes Steel	695,50	924,72
DRI Natural gas	DRI output price	USD/Tonnes DRI	337,83	
DRI Hydrogen	DRI output price	USD/Tonnes DRI	546,75	805,47

Figure 36: Model of steel costs through hydrogen DRI-EAF against BOF

Total Cost of Ownership - BOF output price

				2020
BOF	Price	USD/Tonnes Steel		412.23

TCO Breakdown - BOF

Capex	USD/ton steel	34.26
Opex fixed	USD/ton steel	24.6
Opex variable 2	USD/ton steel	353.37
Total 2	USD/ton steel	**412.23**

TCO Breakdown - Capex

Blast furnance	$	600mn	34.26
Total			**34.26**

TCO Breakdown - Opex fixed

Maintenance	USD/ton steel	
Captial charges	USD/ton steel	
Labor	USD/ton steel	24.6
Total	USD/ton steel	**24.6**

TCO Breakdown - Opex variable - raw materials

		unit price	cost per ton of steel
Iron ore	USD/ton steel	97.73	145
Iron ore transport	USD/ton steel	6.47	9.64
Coal	USD/ton steel	121.86	104.8
Coal transport	USD/ton steel	5.91	5.08
Steel scrap	USD/ton steel	224.46	33
Steel scrap transport	USD/ton steel	5	0.74
Industrial gasses	USD/ton steel	0.1	17.23
Ferroalloys	USD/ton steel	1028	19.54
Fluxes	USD/ton steel	45.03	23.46
Refractories	USD/ton steel	1061	4.03
Other costs	USD/ton steel	19	19
By-product credits	USD/ton steel	-4.62	-4.62
Thermal energy	USD/ton steel	5.73	-36.77
Electricity	USD/ton steel	94.77	13.24
Total	USD/ton steel		**353.37**

Total Cost of Ownership - EAF scrap output price

				2020
EAF scrap	Price	USD/Tonnes Steel		400.77

TCO Breakdown - EAF scrap

Capex	USD/ton steel	15.84
Opex fixed	USD/ton steel	27.51
Opex variable	USD/ton steel	357.42
Total	USD/ton steel	**400.77**

TCO Breakdown - Capex

EAF plant	$	15.84
Total		**15.84**

TCO Breakdown - Opex fixed

Maintenance	USD/ton steel	
Capital charges	USD/ton steel	15.84
Labour	USD/ton steel	11.67
Total	USD/ton steel	**27.51**

TCO Breakdown - Opex variable - raw materials

		unit price	cost per ton
DRI	USD/ton steel	300.67	0
DRI transport	USD/ton steel	14	0
Steel scrap	USD/ton steel	224.46	252.06
Steel scrap transport	USD/ton steel	5	5.62
Industrial gasses	USD/ton steel	0.1	1.63
Ferroalloys	USD/ton steel	1028	16.45
Fluxes	USD/ton steel	133.89	4.82
Electrodes	USD/ton steel	9500	18.38
Refractories	USD/ton steel	1061	1
Other costs	USD/ton steel	12.31	12.31
Thermal energy	USD/ton steel	5.73	-0.41
Electricity	USD/ton steel	103.55	45.56
Total	USD/ton steel		**357.42**

Figure 37: Model calculations on BOF and scrap based EAF

Total Cost of Ownership - EAF gas DRI output price

				2020
EAF gas DRI	Price	USD/Tonnes Steel		506.60

TCO Breakdown - EAF gas DRI

	Capex	USD/ton steel	15.84
	Opex fixed	USD/ton steel	27.51
	Opex variable	USD/ton steel	463.2491
	Total	USD/ton steel	**506.5991**

TCO Breakdown - Capex

	EAF plant	USD/ton steel	15.84
	Total		**15.84**

TCO Breakdown - Opex fixed

	Maintenance	USD/ton steel	
	Captial charges	USD/ton steel	15.84
	Labour	USD/ton steel	11.67
	Total	USD/ton steel	**27.51**

TCO Breakdown - Opex variable - raw materials			**unit price ($/tc**	**cost per ton steel**
	DRI, gas based	USD/ton steel	337.83	331.0739
	DRI transport	USD/ton steel	5	4.9
	Steel scrap	USD/ton steel	224.46	26.9352
	Steel scrap transport	USD/ton steel	5	0.6
	Industrial gasses	USD/ton steel	0.1	1.63
	Ferroalloys	USD/ton steel	1028	16.45
	Fluxes	USD/ton steel	133.89	4.82
	Electrodes	USD/ton steel	9500	18.38
	Refractories	USD/ton steel	1061	1
	Other costs	USD/ton steel	12.31	12.31
	Thermal energy	USD/ton steel	5.73	-0.41
	Electricity	USD/ton steel	103.55	45.56
	Total	USD/ton steel		**463.2491**

Total Cost of Ownership - EAF hydrogen output price

				Low	**High**
EAF hydrogen	model	USD/Tonnes Steel		695.50	924.72
DRI hydrogen	Price	USD/Tonnes DRI	Low case	360.00	640.00
DRI hydrogen	Price	USD/Tonnes DRI	High case		

TCO Breakdown - EAF hydrogen

	Capex	USD/ton steel	15.84	15.84
	Opex fixed	USD/ton steel	11.67	11.67
	Opex variable	USD/ton steel	667.99	897.2051
	Total	USD/ton steel	**695.5**	**924.7151**

TCO Breakdown - Capex

	EAF plant	$	15.84	15.84
	Total		**15.84**	**15.84**

TCO Breakdown - Opex fixed

	Maintenance	USD/ton steel		
	Labour	USD/ton steel	11.67	11.67
	Total	USD/ton steel	**11.67**	**11.67**

TCO Breakdown - Opex variable - raw materials			**unit price**	**cost per ton**	
	DRI, Hydrogen based	USD/ton steel	variable	535.8148	789.3588
	DRI transport	USD/ton steel	5	4.9	4.802
	Steel scrap	USD/ton steel	224.46	26.9352	3.232224
	Steel scrap transport	USD/ton steel	5	0.6	0.072
	Industrial gasses	USD/ton steel	0.1	1.63	1.63
	Ferroalloys	USD/ton steel	1028	16.45	16.45
	Fluxes	USD/ton steel	133.89	4.82	4.82
	Electrodes	USD/ton steel	9500	18.38	18.38
	Refractories	USD/ton steel	1061	1	1
	Other costs	USD/ton steel	12.31	12.31	12.31
	Thermal energy	USD/ton steel	5.73	-0.41	-0.41
	Electricity	USD/ton steel	103.55	45.56	45.56
	Total	USD/ton steel		**667.99**	**897.2051**

Figure 38: Model calculations of EAF with DRI as raw material which is based either on natural gas or green hydrogen

Total Cost of Ownership - DRI gas output price				2020
DRI gas literature	Price	USD/Tonnes DRI		300.00
DRI gas model	Price model case	USD/Tonnes DRI		337.83

TCO Breakdown - DRI gas

Capex	USD/Tonnes DRI	200
Opex fixed	USD/Tonnes DRI	12.93
Opex variable	USD/Tonnes DRI	124.9005
Total	USD/ton DRI	

TCO Breakdown - Capex

DRI plant	USD/Tonnes DRI	200
Total		**200**

TCO Breakdown - Opex fixed

Maintenance	USD/Tonnes DRI	
O&M	USD/Tonnes DRI	12.93
Total	USD/Tonnes DRI	**12.93**

TCO Breakdown - Opex variable - raw materials

Iron ore pellets o	USD/Tonnes DRI	87.3264
Scrap steel	USD/Tonnes DRI	
Electrodes	USD/Tonnes DRI	
Electricity	USD/Tonnes DRI	10.60304
Hydrogen	USD/Tonnes DRI	0
Natural gas	USD/Tonnes DRI	26.97107
Oxygen	USD/Tonnes DRI	
Flux	USD/Tonnes DRI	
Air	USD/Tonnes DRI	
Total	USD/Tonnes DRI	**124.9005**

Total Cost of Ownership - DRI hydrogen output price				Low	High
DRI hydrogen	Price	USD/Tonnes DRI	Model case	547	805

TCO Breakdown - DRI hydrogen

Capex	USD/Tonnes DRI			
Opex fixed+varia	USD/Tonnes DRI		310.86	310.86
Hydrogen, rawma	USD/Tonnes DRI		236	494.61
Total	USD/ton DRI			

TCO Breakdown - Capex

DRI shaft	USD/Tonnes DRI		200	200
DRI				
Total			**200**	**200**

TCO Breakdown - Opex fixed

Maintenance	USD/Tonnes DRI		50	50
Total	USD/Tonnes DRI			

TCO Breakdown - Opex variable - raw materials

Iron ore pellets o	USD/Tonnes DRI			
Scrap steel	USD/Tonnes DRI			
Electrodes	USD/Tonnes DRI			
Electricity	USD/Tonnes DRI			
Hydrogen	USD/Tonnes DRI	3100 - 6500 E	236	495
Natural gas	USD/Tonnes DRI		0	
Oxy	USD/Tonnes DRI			
Flux	USD/Tonnes DRI			
Air	USD/Tonnes DRI			
Total	USD/Tonnes DRI			

Figure 39: Model calculations of DRI based on natural gas and green hydrogen

15.9 Appendix IX - Backgrounds into companies

15.9.1 Detailed background into BAM

BAM only accounts scope 1, 2 and a very small part of scope 3 (employee transport emissions) in their analysis and excludes all other emissions related to products bought upstream in the process. The company does show a willingness to extend this scope in the future as they proclaim to focus on the following (BAM, 2019):

- Work with clients and supply chain partners to reduce carbon emissions in the value chain;
- Bring low or zero-carbon products and services to the market to scale up its positive impact

	2013	2014	2015	2016	2017	2018	2019	CAGR '13-'17	CAGR '17-'19
CO2 emissions (ktonnes)	272	242	230	203	186	193	170	-9.1%	-3.0%
CO2 emissions (t/mEUR revenue)	38.6	33.0	30.9	29.1	28.1	26.8	23.5	-7.6%	-5.8%
Certified timber (FSC & PEFC)	n.a.	n.a.	n.a.	98	97	94	99	n.a.	n.a.

Table 7: Key takeaways integrated reports BAM 2013-2019 (BAM, 2019)

Especially the first remark is related to this research's hypothesis where companies will require upstream supply to reduce emissions. BAM is known to be a leader in reporting how to tackle climate change throughout their business and could take the lead by showing increased importance in actions taken for scope 3 reductions as well (BAM, 2019). BAM's ambition to drive progress into more emission reduction is recognized by the Carbon Disclosure Project (CDP) who lists the most pioneering companies leading transparency and performance of the tackling emissions. BAM submitted their report of 2019, which includes the scope 3 emissions that were left out of the company's sustainability report of 2019. The CDP ranks all of the reports following a score from A till E (and an F is no report was submitted). BAM Group scored the highest among its competition, obtaining an A for its climate change approach. The main findings related to BAM's carbon dioxide emissions to scope 1, 2 and 3 are presented as follows:

1. 159 ktonnes
2. 31 ktonnes
3. 7,686 ktonnes

It can not be underlined enough that scope 3, which is often left out, is by far the essential aspect of the whole business in terms of carbon emissions related to a process. *Purchased goods and services* (see appendix X) is a segment within the scope 3 which accounts for almost half of the emissions. Hence, for a company to start, including scope 3 in emission reductions will increase the valuation of carbon-free products upstream. BAM states that the company tries to engage with suppliers to look further into including scope 3 emission reduction projects and plans to adapt the strategy accordingly to more initiatives.

Sustainability is an increasingly important aspect to BAM as stakeholders with regulators, communities, and customers, demand more and more from reductions and sustainable solutions. As BAM positions itself to be the current and future sustainable market leader, a strategy complying with this is in place. Following BAM's official mission statement are they: '*providing solutions across the* ***total construction lifecycle*** *for the Group's clients and generating maximum value for* *its stakeholders* ' (BAM, 2019). This means that they should be including material lifetimes as well and valuate materials differently on carbon footprint. The overall goal for BAM is to become a net positive company by 2050, which means that there must be a positive impact on both people, resources as well as climate. To adhere to the mission statement has BAM committed to reducing scope 3 emissions with 20% by 2030 (BAM, 2019).

15.9.2 Detailed background into Boskalis

	2016	2017	2018	2019	CAGR '16-'19
CO_2 emissions (ktonnes)	1,249	1,223	1,180	1,110	-2.9%
Revenue (mEUR)	2,596	2,337	2,570	2,645	0.5%
CO_2 emissions (t/mEUR revenue)	481	523	459	420	-3.3%

Table 8: Key takeaways annual reports (2017-2019) Boskalis (Boskalis, 2019)

Boskalis shows promising initiatives to reduce emissions which could lead to differentiation in raw materials based on carbon footprint. The sustainability report of 2019 shows two different ways in which Boskalis wants to tackle climate change from their end. First, to support sustainable growth, Boskalis aims to become climate neutral by 2050 through emission reduction in scope 1 and 2. Secondly, and more importantly, for this research, Boskalis wants to reduce emissions of its supply chain and is investigating reduction in scope 3 emissions. Figure 40 shows a screenshot from the sustainable report where this desire to influence the supply chain is shown.

TOPIC	AMBITION	SCOPE	TARGET
Climate change: mitigation	Be an industry leader in carbon reduction and drive competitive advantage though our ability to offer low carbon solutions for our clients	Carbon emissions of own operations (scope 1 & 2)	Net Zero by 2050
		Carbon emissions of supply chain (scope 3)	Instigate initiatives for scope 3 emissions reduction where feasible on the basis of impact and influence

Figure 40: Screenshot of the Boskalis sustainability report (Boskalis, 2019)

15.10 Appendix X - CO2 impact of different scope 3 emission categories per industry

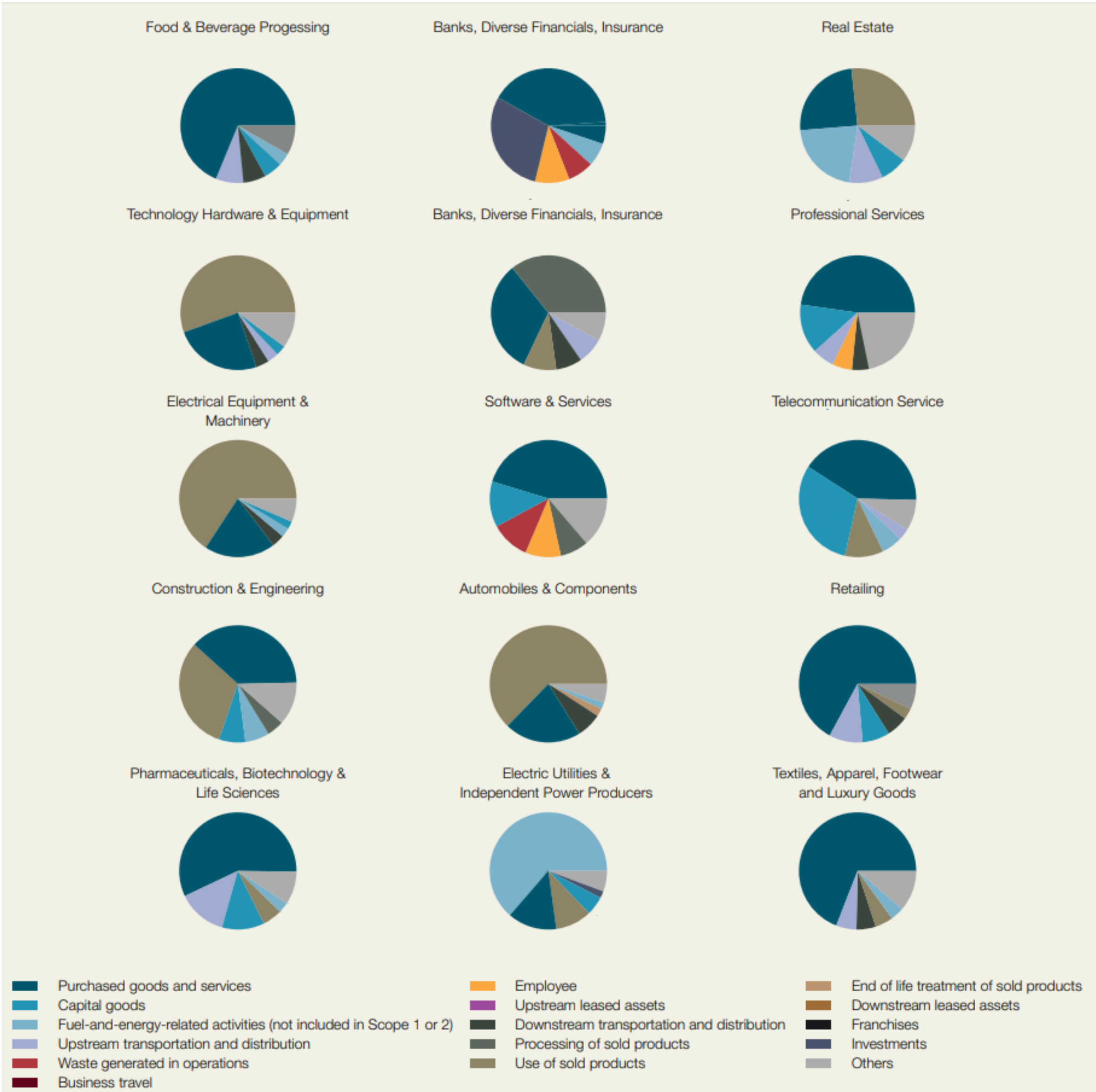

Figure 41: Research by Farsan showing relative impact of different scope 3 aspects (Farsan et al., 2018)

15.11 Appendix XII - Acknowledgements

Erwin Mul - Shell
Erwin, a strategist at Shell, started in 2012. Erwin is highly involved in multiple projects related to the energy transition with the Open Footprint project as his main focus area. He has accompanied multiple students during his time at Shell and ensured them to have their thesis being a meaningful function within the company.

Parth Reddy - Shell
Parth is the manager of the Shell strategy consultancy team focused on the hydrogen transition. Within his team of 5 are continental analysis made on the total cost of ownership of hydrogen businesses made to identify potential opportunities for Shell's new energy group to focus on.

Saskia Weis - Shell
Saskia is an internal strategy consultant in Parth's team after working for Shell for over six years. She ensured the research to reach out to contacts in the industry to conduct interviews.

Adam Eales - Shell
Adam joined Shell 5 years ago after obtaining his PhD in Chemical Engineering at the University of Cambridge. He worked on strategic scenarios within Shell and advised early on what this research could focus on (or rather should not focus on). His comprehensive expertise made him valuable to improve some qualitative aspects of the research.

Alice Elliott - Shell
Alice works with other organizations in the Netherlands and near countries to enable a transition towards a low-carbon future. Working at Shell for over 20 years as both consultant as well as energy transition advisor did she give insights on strategic decisions and trade-offs in the refinery market. As being a senior hydrogen engineer for almost seven years is she well aware of the applicability of sustainable hydrogen.

Marc Zwart - Shell
Marc is a TU Delft alumni working for Shell for almost 13 years. He is the deputy unit manager of Shell's refinery in the Netherlands and was interviewed to help out on insights on green hydrogen usage for refineries.

Ruben van Grinsven - Shell
Ruben is a TU Delft alum who joined Shell in 2003. After being part of Shell's strategy team, he became business opportunity manager of hydrogen integrated projects. He is active in the developments of Shell's biggest electrolyzer in Rotterdam and provided insights into the business case on the usage of green hydrogen in refineries.

Nick Silk - Tata Steel
Nick obtained his PhD in thermodynamics at the University of Sheffield and joined Tata Steel in 1999. He has worked as a researcher, knowledge group leader and product manager before becoming an advanced technology manager of the automotive sector. His expertise was both on the technical side of steel production as well as end consumer's valuation to steel.

Hyleco Nauta - Tata Steel
Hyleco joined Tata Steel through the management traineeship and worked for the chairman of the board. He assisted the interview with Nick and some of his own insights into the steel market.

Werner Wijne - Royal BAM Group
Werner has been in steel procurement for over 30 years. His expertise in the steel market was insight-

ful to understand the market mechanism from upstream production towards downstream purchasing. Werner helped out during multiple stages of the thesis by providing reports and market insight.

Annika Trignol - Boskalis
Annika is responsible for the coordination of sustainability within Boskalis Netherlands. Before, she was responsible for EMVI coordination which has shown to be a key mechanism to promote construction companies to use sustainable products.

Michele Maria Tedesco - Fiat Chrysler Automobiles (FCA)
After his mechanical engineering studies, Michele joined FCA at which he has been working for over seven years. He gave insights into technical sides of steel usage in the automotive industry.

Rob Stevens - Yara
Rob Stevens is a TU Delft alum who is VP of Yara's ammonia operations. Rob holds a PhD in Applied Thermodynamics with a biotechnological focus, knowledgeable in scope 1,2 and 3 climate actions. He is highly active in consortiums and research groups to contribute to the potential value ammonia could have in future applications. As an executive, he is contributing to Climate Neutral Solutions through collaboration.

Göran Larsson - Lantmännen
Göran is a product manager of fertilizers within Lantmännen. He has been working in the business for over 27 years and has expertise on the current developments with green ammonia.

Anonymous - CRI
The representative has been a sales and marketing specialist at CRI for over three years and helped to gain an understanding of the sustainable methanol business CRI has created.

15.12 Appendix XIII - Research Paper

See next pages