COST EFFICIENT SCRAP METAL SOURCING

A design science research project to develop a strategy for how H2 Green Steel can source scrap metal with cost efficient logistics

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PREFACE

We are proud to present this thesis of our Master's degree in Logistics and Supply Chain Management at Lund University, Faculty of Engineering. Several employees at H2 Green Steel as well as from external partner companies and other industry sources have contributed to this thesis with their valuable knowledge and time. The encouragement, enthusiasm and interest from these people has motivated us to finish the thesis with satisfaction.

It has been an incredible learning process and we are thankful for the wide and interesting nature of our scope. Studying supply chain management and conducting a thesis on the practical logistics decision making process in a company has been a great combination.

The steel industry and scrap market are completely new areas for us that have been remarkably interesting to learn more about, as they influence and are intertwined with so many other areas of industry, society and sustainability. To see and better understand the development of H2 Green Steel, who have doubled their number of employees in the duration of this thesis and reached several project milestones towards their site in Boden, is another memorable learning experience. Especially as our research and thesis has contributed to the ongoing procurement and logistics work.

We would like to thank Bror Styren for always being very welcoming and eager to help, easy to reach, for giving us constructive feedback, motivating us and challenging us. We would like to thank the entire Procurement and Logistics team at H2 Green Steel for their encouragement and appreciation of our work. Also, for including us in all necessary meetings, providing us with data and connecting us to the right people.

We would like to thank Jan Olhager for his encouragement and help in defining our scope and finding the proper structure for our academic report, as well as for his detailed feedback on our work. Moreover, we thank Louise Bildsten, our examiner at LTH, for her very appreciated feedback on our thesis.

Lastly, we would like to thank each other and ourselves for always being honest, giving each other constructive feedback and having a lot of fun in our last months together as students.

Sophia Sandström & Sofia Ivarsson

EXECUTIVE SUMMARY

The steel industry in Sweden is responsible for 10% of the annual Swedish CO_2 emissions. As a way to abate this sector, H2 Green Steel are establishing a new green steel production site in Boden. Their way of producing steel, through the EAF route and by using hydrogen-reduced DRI will reduce the CO_2 emissions by over 90%. Besides iron ore, steel scrap is the most important input raw material for the EAF production. Scrap is generated where there is industry and society, meaning the local supply in northern Sweden is very limited. H2 Green Steel is therefore going to source a major share of the scrap in continental Europe and the UK, incurring additional logistical costs compared to their European steel competitors.

This thesis investigates the European scrap market and the scrap logistics to find the best sourcing strategy for H2 Green steel. The methodology used is exploratory design science research, implying a wide problem solving approach to find a context specific solution. Data is gathered through industry reports and many interviews with industry experts as there is limited academic research available.

The research shows that the scrap market is complex, with a high level of subjectivity regarding availability, quality, and efficient logistics. The largest scrap volumes are generated in Germany and the UK, and exported from Benelux and the UK. As scrap is a low value voluminous product, it is best transported in bulk vessels and bulk trains. The qualitative research resulted in a number of hypotheses regarding the best transportation options, the best origin harbors and regions to source from. These sourcing routes were then quantitatively investigated by using transportation cost data from a number of partner sea- and train freight companies as well as handling cost data from interviews with stevedore companies. The data was then extrapolated to make additional estimations.

Based on both qualitative and quantitative analysis, the recommendation is to utilize 35k DWT bulk vessels from Rotterdam and/or Amsterdam and Tilbury in the UK. Also, a 16k DWT bulk vessel from Gdansk and a 2k bulk train from Rheinkamp (in the Ruhr-area in Germany) is recommended. The train option is more expensive, but is important as it can provide high quality scrap directly from the automotive industry, reduce the bottlenecks of Luleå hamn and improve logistics sustainability. The recommendation also includes building strong supplier relationships to secure volumes and scrap quality, and minimizing sea freight during winter due to the more expensive ice-classed vessels required. Overall, the recommendation emphasizes the need to act on the strategy to secure volumes now, before scrap demand in Europe rockets.

Key words: Scrap sourcing, Scrap logistics, European scrap market, Sea freight strategies, Bulk shipping.

ABBREVIATIONS

H2GS - H2 Green Steel
EU - European Union
EAF - Electric Arc Furnace
BOF - Basic Oxygen Furnace
BF - Blast Furnace
DRI - Direct Reduced Iron
HBI - Hot Briquetted Iron
EOL - End-Of-Life
SME - Small and Medium sized Enterprises
ELV - End-of-Life Vehicles
DWT - Deadweight Tonnage
ARAGT - Amsterdam, Rotterdam, Antwerp, Ghent, Terneuzen
BIR - Bureau of International Recycling
JBF - Järnbruksförnödenheter
EMR - European Metal Recycling

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1. INTRODUCTION

1.1 Background

The steel industry in Sweden is currently responsible for 10% of the total yearly carbon emissions. As a response to the need of decarbonization within this industry, H2 Green Steel (H2GS) was founded in 2020. H2GS' project will become a lighthouse in terms of digitalisation and efficiency, utilizing Industry 4.0 and Sweden's beneficial energy prices and renewable energy resources to become the European cost leader within the field. H2GS will produce steel with approximately 90% less CO_2 than conventional steel production by using hydrogen. Furthermore, in Electric Arc Furnace (EAF) production, scrap metal can function as a raw material. Thus, sourcing scrap metal from customers, external partners and suppliers can enable circularity and a more sustainable way of producing steel (H2GS, 2022).

1.2 Problem description

H2GS is set to build a fully integrated steel mill in Boden, Sweden. The project will reach a capacity of 2,5 million tonnes hot rolled coil per annum by 2026 and 5 million tonnes by 2030. As a comparison, Sweden's current biggest steel producer SSAB has an annual capacity of 3,8 million tonnes. To ensure a smooth and efficient ramp up to this capacity, the project is dependent on securing large volumes of raw materials at favorable costs. Along with iron ore and electricity, scrap metal is one of the key components in the steel production of the company. H2GS aims to source some of its scrap from customers, but since the majority of scrap will be sourced from third party sources, the scrap metal market must be investigated and scrap suppliers evaluated (H2GS, 2022).

A key aspect in sourcing cost efficient scrap metal is logistical cost. As scrap is a recycled product with low density, transport costs can often equate to a large part of the total cost of the product. The main driver for this cost is distance and means of transport. Since the integrated steel mill will be built in Boden it becomes crucial to understand from which supplier H2GS can source scrap at a competitive total cost (H2GS, 2022).

1.3 Research purpose

The purpose with this thesis is to develop and formulate a strategy for how H2GS can source scrap from the European scrap market with minimized logistical costs.

1.4 Focus and delimitations

The main deliverables for fulfilling the purpose of the project are as follows:

1. First, the master thesis will collect new material and use current material to build a summary of the European scrap market, including geographical spread of supply, scrap suppliers, scrap logistics and scrap qualities.
2. Second, the focus will be on producing a report and associated model to evaluate sourcing locations and logistical costs:

    a. Evaluate which areas in Europe are most suitable to source scrap from.
    b. Evaluate different transport modes for scrap.
    c. Model total logistical costs for different sourcing routes, including a cost breakdown analysis.
    d. Evaluate how use of return flows can impact logistical decisions.
3. Third, develop a positioning for the company to adopt on where to source scrap metal from and what transport route to use in order to minimize logistical costs.

A delimitation in this thesis is to not investigate carbon emissions for the different transportation options on a detailed level. However environmental aspects are considered to a certain extent since sustainability is a major part of H2GS' purpose.

1.5 Report structure

This report is divided into seven chapters. It is introduced in chapter one (this chapter), where background, purpose and problem formulation is stated in order to give an overview of what the project will include and what it aims to answer. Thereupon, chapter two elaborates on the chosen research approach and research methodology, as well as data collection and credibility. The next chapter is a context description, where a thorough background to steel, scrap, the European scrap market, H2GS and some of the scrap logistics findings are presented. The following chapter is also discussing the scrap market and scrap logistics, but only the topics which are subjective, and where industry sources have varying viewpoints. Hence, chapter four is based on opinions rather than facts like chapter three is. As all the research has been presented in chapter three and four, chapter five contains the analysis and the results from the model. Finally, the recommendation is formulated in chapter six, and a conclusion is summarized in chapter seven.

Reading guidelines

The sources are stated in a parenthesis at the end of a sentence. Due to the nature of the thesis research, often several sources are utilized for describing the same concept. In these cases, all sources used for gathering the data are put at the end of the sentence. If the description of the concept transcends multiple sentences, all sources utilized are at the end of the last sentence in the segment.

2. METHODOLOGY

2.1 Research approach

The research approach in this thesis is abductive; a balanced combination of inductive and deductive, as demonstrated in Figure 2.1 (Golicic et al., 2005). It is inductive considering the large amount of data to collect in order to map the scrap metal market and the different scrap metal qualities, as well as the transportation options. Once a thorough understanding of the situation is accomplished, existing data and literature is used to find improvement possibilities and optimization options that can be applied to the situation in order to find the best, most cost-efficient solution. Thereupon, the results are verified. Thus, the research method is also deductive. Using the abductive research method enables back- and forth going between the two approaches (Kovác and Spens, 2005).

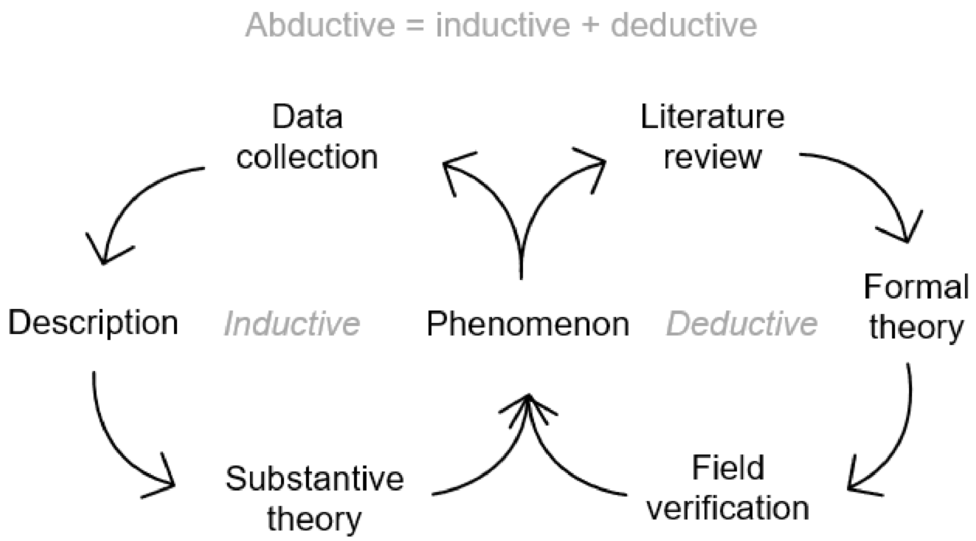

Figure 2.1: The abductive research method (Golicic et al., 2005).

2.2 Research methods

There are several research methods to choose from when conducting research. In order to decide which method is most suitable for a certain project, a framework can be applied.

2.2.1 Research method frameworks

Fisher (2007) has made one of those frameworks, shown in Figure 2.2, in which the decision can be made based on two criteria; the goal of the research and interaction with the world. The goal of the research can be prescriptive or descriptive. A prescriptive goal is to determine a recommended course of action based on empirical observations. A descriptive goal is to describe the phenomenon. Interaction with the world indicates how structured the interaction with the world is, highly structured or less structured.

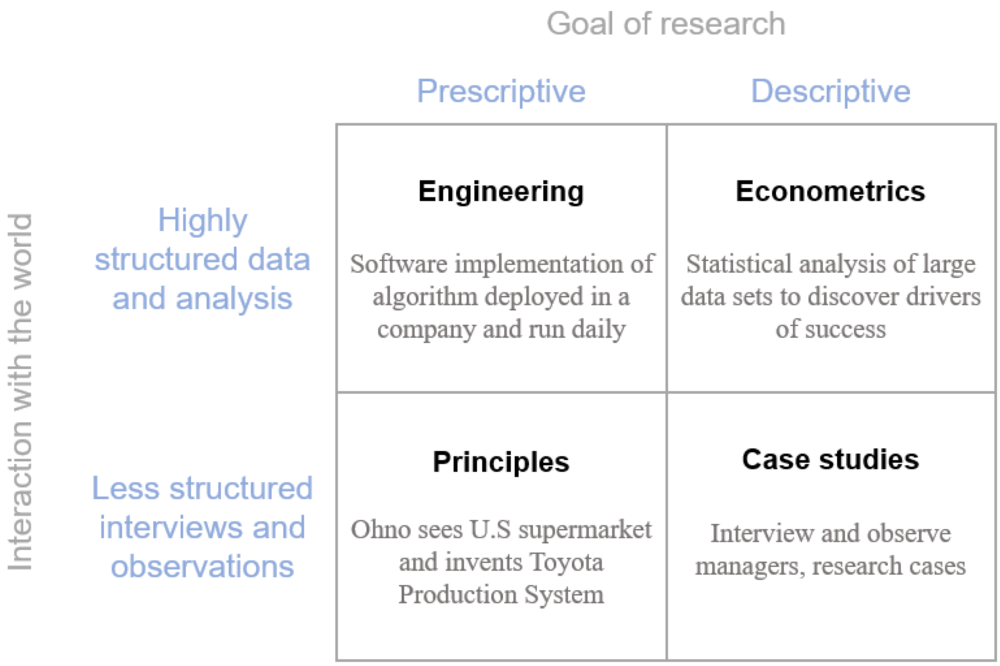

Figure 2.2: Fisher framework (Fisher, 2007).

Ellram (1996) has done another one of these frameworks shown in Figure 2.3, in which the two criteria are type of analysis and type of data. The type of analysis can be primarily quantitative or primarily qualitative, and the type of data can be modeling or empirical. Empirical data is gathered from the real world, while modeling data is hypothetical or real world data manipulated by a model.

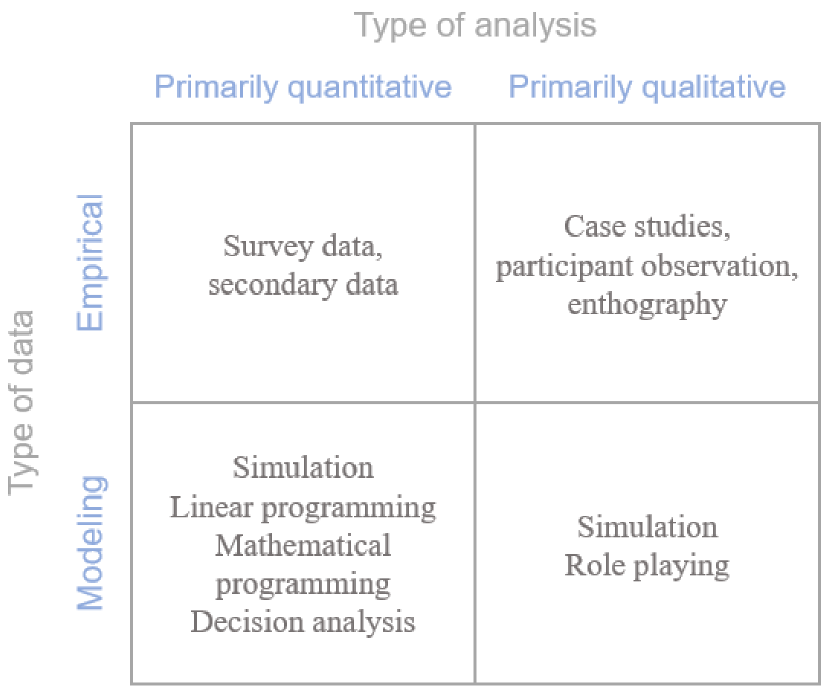

Figure 2.3: Ellram framework (Ellram, 2006).

Furthermore, Malhotra and Grover (1998) developed a maturity cycle of research, as seen in Figure 2.4, which can also contribute to the research method decision.

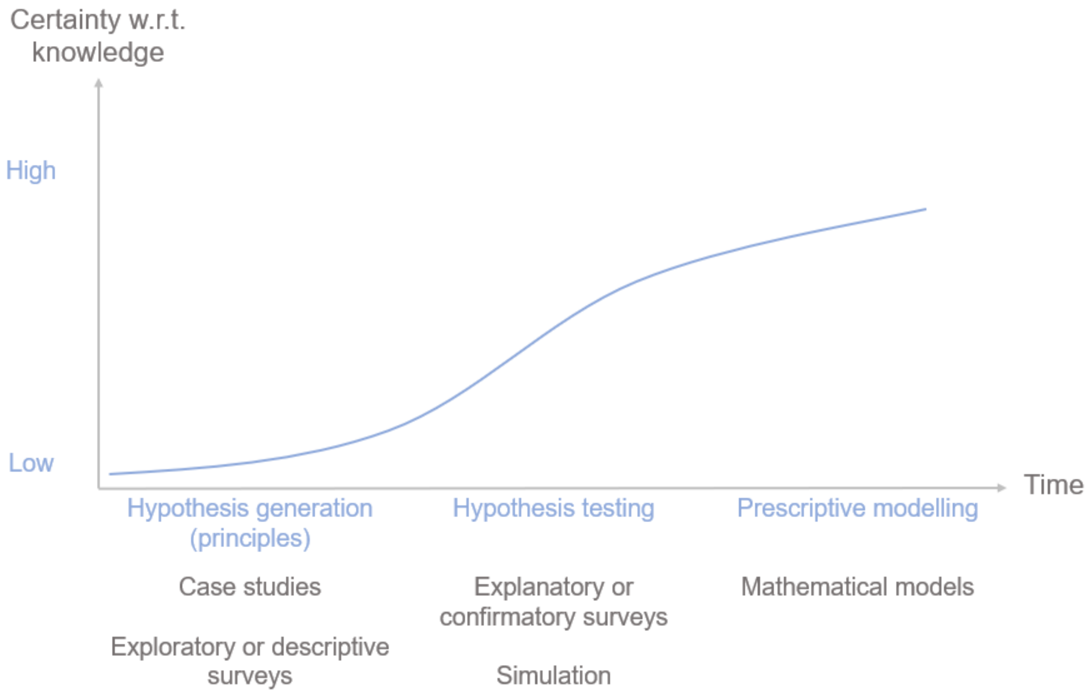

Figure 2.4: Maturity cycle of research (Malhotra and Grover, 1998).

The purpose of this thesis is to research a market, learn how it works and understand where there is scrap supply, followed by calculating the logistical costs of transporting scrap from the relevant scrap regions up to Boden, and then develop a strategy and recommend the most cost-efficient scrap sourcing solution. When applying this thesis to Fisher's framework, it fits somewhere in between "principles" and "case studies", as the aim is to recommend a strategy, and action, based on the findings gathered from the investigation of the market and its costs. The interaction with the world is less structured since it involves many different actors and the plan of data collection changes as more information is gathered and analyzed.

According to Ellram's framework, this thesis is primarily qualitative and the data is empirical. Thus, it is similar to a case study. Finally, when applying the thesis to the maturity cycle, it fits in the beginning of the curve, where the hypotheses are generated. Thereby the thesis can be a case study or an exploratory or descriptive survey.

Combining all of these frameworks, this thesis is an exploratory case study. However, the goal of a case study is to be descriptive, while the goal of this thesis is to be prescriptive (Fisher, 2007). Thus, another rather similar research method called design science research is the chosen method for this thesis. When using design science research, a researcher starts with finding insights about the phenomenon, in this case the scrap market and its logistics, and then the researcher designs a solution based on those insights (Pello, 2018). According to both Horváth (2007) and Baskerville et al. (2015), there is a dual mandate of design science research, where the first part is to utilize the gained knowledge to solve problems, create change or improve existing solutions, and the second part is to generate new knowledge, insights and theoretical explanations. Overall, the aim with design science research is to solve a problem (Holmström et al., 2009). Since the mission of this thesis is to investigate the scrap market followed by finding a cost efficient logistics solution to scrap sourcing, and since there is limited available literature on this subject today, design science research is the best fit. This method will enable the exploratory approach required in order to gather enough data to recommend qualified solutions to the scrap sourcing problem.

2.2.2 Design science research

Design science research usually involves a number of steps which can be described in different ways. For example, the UK Design Council (2019) defines the process through a double diamond in four steps; discover, define, develop, and deliver, demonstrated in Figure 2.5. Moritz (2005) defines six steps; understanding, thinking, generating, filtering, explaining, realizing. Brown (2009) uses three spaces of innovation; inspiration, ideation, implementation. The process has also been defined in two steps; an analytic step of problem definition and synthetic sequence of problem-solving by Johansson-Sköldberg et al. (2013).

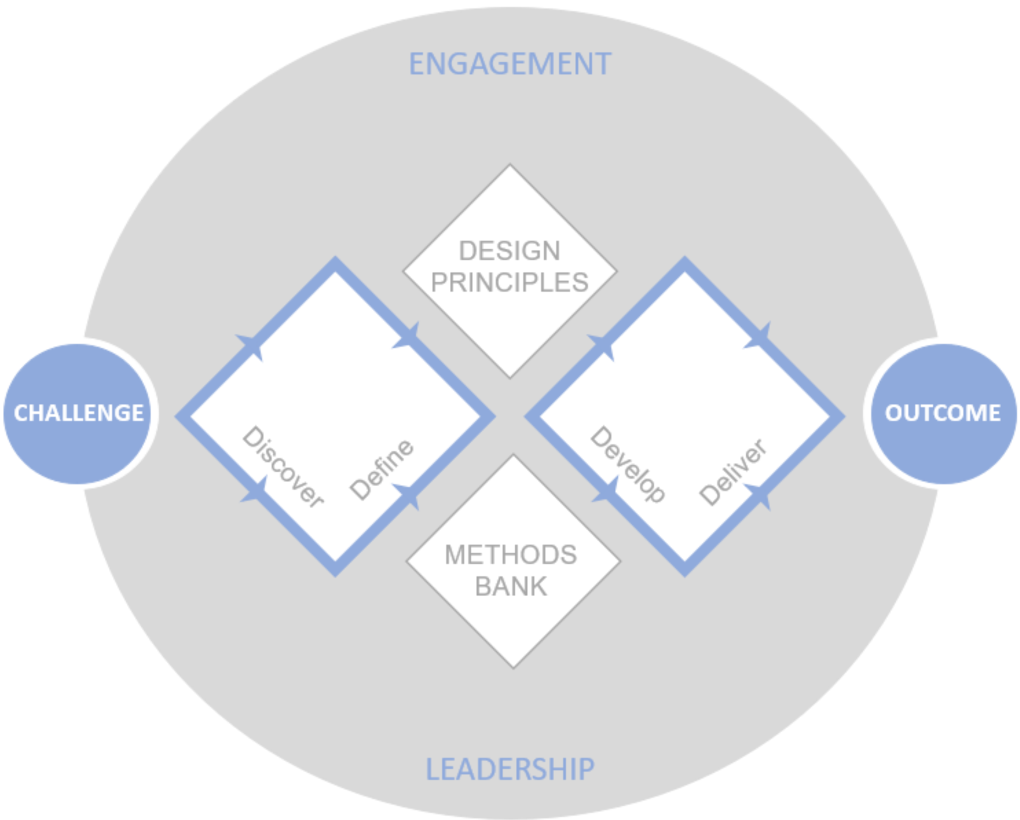

Figure 2.5: The double diamond (UK Design Council, 2019).

Elaborating further on the phases of the Double Diamond according to Kochanowska et al. (2021), the first step, Discover, is where the majority of research is conducted. The point is to stay broad and open minded to information in order to get a thorough understanding of the challenge and the objectives. In the double diamond figure, the lines widen in this phase to symbolize the openness.

Define is the second step, in which the lines in the figure converge to symbolize how key points are made to narrow down the scope. This step is about analyzing the data and information gathered in step one in order to find patterns, draw conclusions and decide what to focus on. Thus, the main challenge of the project is framed here.

The third step is Develop, and the main activity is to use creativity and experimentation in order to start developing solutions to the problem. Similar to step 1, the lines of the figure widen to encourage openness and thinking outside the box.

The last step is Deliver. This is where complementary analysis and testing is conducted to develop a final solution. Hence, the lines of the figure are again converging to narrow down the number of solutions and end up in a final recommendation.

However, regardless of how one chooses to describe the steps of the method, they all involve divergent and convergent thinking (Enninga et al., 2013). In short, divergent thinking involves creativity and flexibility while convergent thinking involves logic and focus. More specifically, divergent thinking is about idea generation and brainstorming without specific criteria to follow, and where several solutions can be correct. Convergent thinking is instead about finding the one solution to a specific problem (Guilford, 1950; Runco, 2010). In the double diamond, step 1 and 3 are divergent and step 2 and 4 are convergent.

In Table 2.1 below, design science research is summarized.

Table 2.1: Summary of design science research (Holmström et al., 2009).

Factor	Design science
Phenomenon	“Artificial phenomena” have to be created by the researcher
Data	Created, collected, and analyzed
End product	Solving of a problem
Knowledge interest	Pragmatic
Disciplinary basis	Engineering, fundamentally multidisciplinary

One of the strengths with design science research is its main focus on solving problems, and thus gathering data and conducting analysis that is immediately useful and important in order to develop a hands-on solution (Holmström et al., 2009). Another strength is that design science research does not have fixed rules, on the contrary, it is a method that can be operationalized differently depending on the subject and scope of the research (van Aken et al., 2016).

A challenge with design science research is to include enough theoretical insight and review sufficient academic literature. Since solving the problem is the highest priority, theory that is not directly necessary to develop a recommendation, i.e explanatory theory rather than exploratory data, has lower priority. Consequently, there is a risk that not enough new knowledge is created (Holmström et al., 2009).

2.3 Data collection methods

This section aims to explain the different techniques and methods used to gather data for the thesis project. The methods used include interviews with key internal H2GS employees and with relevant external industry sources and experts. Also, synthesizing and gathering already existing data from H2GS' internal systems and H2GS' partners. Lastly, web research, including both academic literature review and professional web resources.

2.3.1 Literature review

A literature review is necessary in most research projects, in order to ensure the project contributes to the subject field without "reinventing the wheel" (Höst et al., 2006). Some other reasons why a literature review is relevant for this thesis is to build an understanding of concepts and terminology, identifying the collective level of knowledge of the phenomenon as well as analyzing and interpreting results (Olhager, 2022).

The literature gathered in this project is obtained through Google Scholar, due to its well-developed search algorithm, and LUBsearch, the Lund University academic article search engine. The search strategy used is mainly "Citation pearl growing" where the search starts with a few reports and articles and then utilizes suitable terms and the references in these to retrieve other papers (Rowley and Slack, 2004). By selecting precise keywords and using them in a relevant combination, fewer, but more relevant, initial reports and papers are found.

The literature covers the European scrap market, scrap yields, steel production and raw materials for steel. The literature also covers transport logistics and how to minimize transport costs. The academic literature is combined with professional literature and European Union (EU) papers through internet searches in order to find all the specific data the academic literature was unable to provide. The academic literature and internet sources are evaluated based on how old the source is, how often it is referred to from other sources, and the alignment with the information provided in the primary and secondary data collection described in the following chapters.

2.3.2 Primary data collection

Interviews

A benefit of utilizing interviews in a research project is that they provide in-depth knowledge pertaining to the interviewees own expertise and experience of a topic (Turner, 2010). According to Höst et al. (2006), interviews can be used to collect feedback regarding a potential solution. One way to categorize interviews are; structured, semi-structured and unstructured, as seen in Table 2.2. The categorization depends on the level of freedom the interviewer has to be adaptive and tailor the questions (Williamson, 2002).

Table 2.2: Interview types and their characteristics (Williamson, 2022).

Interview type	Characteristics
Structured	Each respondent is asked the exact same question in the exact same order
Unstructured	Each answer generates a new question. Usually to explore a new subject
Semi-structured	Uses a standard list of questions but allows the interviewer(s) to ask follow-up questions. A combination of the two other types but closer to the unstructured.

Throughout this thesis project, a great share of the primary data is collected through interviews. The main reason for this is because scrap is a complicated industry, and there are not many good descriptive internet sources or academic literature available.

Initially, to gain understanding of the background to the thesis topic, unstructured interviews are held with H2GS employees to discuss the steel industry, steel production routes, scrap qualities and the scrap market. As these are all new subjects to the thesis writers, the approach resonates with Williamson (2002), who says that unstructured, exploratory interviews are appropriate in the early stages of research, when the researcher does not yet know the subjects nor the types of interviewees to involve. After a period of unstructured internal interviews the knowledge is deeper and semi-structured interviews are conducted with different industry experts. The semi-structured approach allows the researchers to ask different industry experts the same questions regarding the same topic, in order to see the alignment, yet at the same time ask more follow-up questions in specific topics that the industry expert has specific knowledge about. Interviews are held with members of recycling and steel industry organizations, employees and managers at scrap suppliers, logistics consultants and experts, shipping and train freight company employees, harbor operations and commercial managers and employees at stevedoring (port handling) companies.

In total 18 external interviews and approximately 10-15 informal internal interviews are conducted. After an initial period of research, the thesis writers became so-called "Scrap experts" at H2GS and participated in several purchasing and logistics discussion meetings. The reason for this was for the thesis writers to provide their own knowledge as well as gain new insights from the logistics and procurement team.

2.3.3 Secondary data collection

The secondary data is collected both through internet searches and data provided by H2GS as well as their partner companies and affiliated consultants. As mentioned previously in the Literature review chapter 2.3.1, internet searches are used to find industry sources that describe the steel production, raw materials and scrap market. Internet searches also provide information about the scrap suppliers and harbors to investigate, as well as logistics and transportation facts for different trains and vessels.

Internal data from H2GS are excel files with previously done logistics costs calculations for different outbound routes. Also, internal data in excels and powerpoint slides with assumptions for inbound and outbound flows, scrap volumes in phase 1 and phase 2 and share of scrap grades.

From a partner shipping company, sea freight estimates are provided for two ports, including a non-exhaustive cost breakdown. This includes data regarding different vessel sizes, their fuel consumption, and their charter rate per day.

From the partner railway company, train freight estimates are provided for four domestic routes, and one international route. The train freight estimates have limited cost breakdowns, varying for the different routes.

2.4 Data analysis

The gathered data for the thesis is presented in chapter 3 and chapter 4, divided into context description, i.e. objective data, and managerial perspectives, i.e. more subjective data.

The context description includes qualitative data from academic and professional literature, combined with H2GS data and data from other internet sources. Qualitative data gathered in the interviews is analyzed and if it is well-aligned with information from the previously mentioned sources as well as multiple interviewees, it is included in the context description chapter. The remainder of the relevant interview data is presented in chapter 4, the Managerial perspectives, as there is a lot of subjectivity and differing opinions regarding a number of scrap sourcing topics.

In order to build the model, the quantitative data gathered from interviews and internal- and partner data is analyzed in different ways. Retrieving the right data to build the model is a challenge. Due to this, calculating logistical costs requires making many assumptions based on the different data available. Description of the data analysis for the model is presented in chapter 5.2.1, and excerpts from the excel model are found in Appendix 1.

2.5 Credibility

To ensure the credibility of this report, both to the university and H2GS, three overarching aspects are considered; validity, reliability and objectivity. Validity means measuring what is supposed to be measured. Reliability refers to the reliability of the measuring instrument, i.e., would the same results be received if the study is repeated. Objectivity is the extent to which the study is free from personal opinions (Olhager, 2022).

In this study, the main method for ensuring both validity and reliability is through data-, method- and evaluation triangulation. Data triangulation refers to using multiple data sources when studying a phenomenon. Method triangulation means using multiple methods when examining the same phenomenon. Lastly, evaluation triangulation is when different people are used to evaluate the same material (Olhager, 2022).

As described in previous chapters, data is gathered from multiple sources and by using multiple methods. During the interviews, control questions, i.e. asking multiple interviewees the same question despite knowing the answer, are used to ensure validity and reliability.

Complete objectivity in this thesis is a challenge due to the fact that the scrap sourcing and logistics work is happening at H2GS in parallel to the thesis. This means new assumptions and new status quo regarding suppliers, harbors and transportation methods are presented during the thesis research. In order to remain objective towards the thesis purpose, choices and assumptions that are the outcome of new H2GS decisions are stated and thoroughly motivated in the remainder of the thesis. This is in line with Björklund and Paulsson (2012) who argue that higher levels of objectivity are achieved by clearly stating and motivating choices and assumptions.

Also, as described in previous chapters, the collected data is divided into context description and managerial perspectives. This division ensures clarity regarding the origin of fact and opinions that later on are used to formulate the model and analyze the best solution for the thesis purpose, in an objective manner.

2.6 Research ethics

Ethical aspects need to be considered when conducting research within the operations field and when collecting data through interviews. Yin (2014) describes ways to protect the parties involved in the study:

1. Gain informed consent from everyone participating in the study, i.e. make sure they know the nature of the study and choose to willingly be part of it.
2. Avoid any type of deception from the researchers, something that is especially important during the data collection phase.
3. Protect the privacy and confidentiality of participants so they are not put in any undesirable situation.

The data collection and research involves many interviews where sensitive information regarding the scrap market and supply volumes, among other things, are shared and the aforementioned points by Yin (2014) are considered throughout the thesis project. In addition, to protect H2GS confidential information, names of business partners and affiliations have been anonymized as “partner company” or “partner consultant”. The names of most interviewees are also anonymized, and instead with references to their title and company name. Certain data points and assumptions made in the model have business secret value to H2GS and will therefore be excluded from the public report.

2.7 Conclusion of methodology

The chosen methodology is a design science research project with an abductive approach, as this is an exploratory study.

The data collection is heavily focused on interviews, as current literature and internet-provided sources are not sufficient to achieve a comprehensive understanding. The qualitative data is analyzed and sorted into the objective and descriptive chapter 3, Context description, and the subjective chapter 4, Managerial perspectives.

Quantitative data is gathered both through interviews and through internal- and partner systems, and provided excel sheets and powerpoints. The quantitative data is analyzed and together with qualitative aspects, assumptions are made in order to calculate logistical costs.

3. CONTEXT DESCRIPTION

The context description chapter is an extensive chapter due to the exploratory nature of the research. It is the factual background to the thesis study area. The data has been gathered from academic research papers, industry and EU research papers, steel and recycling organizations, as well as from interviews with industry experts. It begins with a description of steel production, including the raw material and the different grades of scrap. This is followed by a brief introduction to the EU steel consumption after which the European scrap market is thoroughly elaborated on. The fourth chapter of the context description consists of logistics aspects and lastly the final chapter describes relevant H2GS aspects.

3.1 Steel production

3.1.1 Steel as a material

Steel is a very significant material for the development of societies. It is also important for the transition towards a green and sustainable society due to the intrinsic features of steel materials; its durability, versatility and recyclability. The lightweight potential is another key feature of steel (ESTEP, 2021). These and further characteristics of steel can be seen in Figure 3.1. It is a fundamental component in structures and products that make up and enable our modern world, such as buildings, infrastructure, transportation, electrical devices and domestic appliances. Thus, there is a strong correlation between the development of a country's Gross Domestic Product (GDP) and their consumption of steel. The global steel demand is not expected to decline considerably unless radical changes with regard to the circular economy happen (World Steel Association, 2022).

Figure 3.1: Characteristics of steel (ESTEP, 2021).

Steel is produced primarily through two routes, the integrated Blast Furnace/Basic Oxygen Furnace route (BF/BOF) and the Electric Arc Furnace (EAF) based route. The two routes are synergistic as they utilize different raw materials, the electrical one represents about 29% of steel production worldwide but the share is very different between countries globally (ESTEP, 2021; World Steel Association, 2021). How the two methods are distinguished will be explained more thoroughly in the following sections, and are shown in Figures 3.2 and 3.3.

3.1.2 EAF (DRI) production route

EAF steel production melts the prime raw materials into liquid steel by using graphite electrodes. The heat necessary for melting the metal comes from an electric arc that arises when the electrodes make contact with the metal. The EAF steelmaking process in general utilizes scrap steel, up to 100%, and/or Direct Reduced Iron (DRI), Hot Briquetted Iron (HBI) and hot metal (pig iron) to make steel (EUROFER, 2021a). The EAF steel production method is more common in areas where there is less natural supply of iron ore, as iron ore is inconvenient to transport due to the weight and equipment needed (JBF, 2022).

EAF steelmaking is flexible with regard to the selection of charge materials. Traditionally it has been, and in many places today it is 100% scrap. The type of scrap steel charged into the EAF has an effect on the steel produced. Because of the residuals in many types of scrap, high quality steels with stringent requirements on impurities can be more difficult to manufacture with the EAF process, compared to BOF (Hall et al., 2021). An option is to use other iron-containing charge materials for the EAF, such as the previously mentioned DRI, HBI and hot metal. The restrictions imposed by scrap in making some steel grades due to residual elements combined with issues with scrap availability and market price fluctuations cause EAF operators to choose the alternative charging materials (Kumar Sarna, 2013). The scrap quality and impurities will be discussed further in chapter 3.1.5, Raw materials for steel production and the scrap market issues in chapter 3.3, European Scrap Market.

The DRI process reduces the iron, i.e. removing the oxygen from iron ore, with H_2 or CO. If H_2 is used, the reaction is endothermic and the H_2 must therefore be heated to 850-950 degrees celsius. Some of the advantages of using DRI for EAF include that DRI can be charged into an EAF in a blend with scrap which means cheaper scrap grades can be used (Kumar Sarna, 2013).

3.1.3 BOF production route

The BF/BOF production starts with blast furnaces that produce iron from iron ore. In a second step a basic oxygen converter turns iron, with some additions of scrap, into steel. The blast furnaces rely on the chemical process of reduction. Iron ore is an iron oxide and in order to remove the oxygen, carbon is needed as a reducing agent. In the process it combines with oxygen and forms carbon dioxide. This is why CO_2-emissions are unavoidable in the BF process. Coal is used as the carbon-bearing material, and is also burned to generate the high temperatures necessary to melt the iron ore. In the second step, the iron is converted to steel in the basic oxygen furnace. Oxygen is blown onto the liquid iron to burn unwanted elements, thereupon the iron has turned to steel (EUROFER, 2021a).

Figure 3.2: BOF and EAF production routes (ESTEP, 2021).

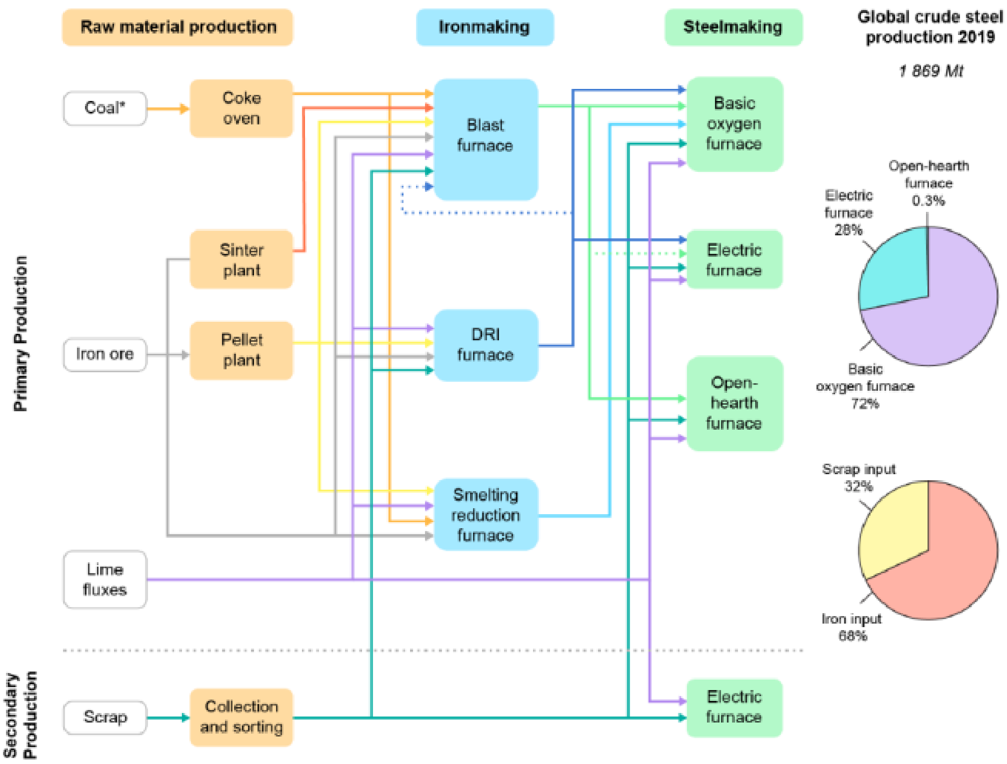

Figure 3.3: Main steel production flows and pathways in 2019 (ESTEP, 2021).

3.1.4 Steel production in Europe

Steelmaking in the EU includes both BF/BOF and EAF routes. DRI production is very limited today in the EU but is increasing worldwide in the last few years. In the European context, EAF accounts for 41.4% of the steel produced, and the share between BF/BOF and

EAF has been stable the last 10 years (ESTEP, 2021). The total crude steel production per EU country can be seen in Figure 3.4 and the different BF/BOF and EAF sites are shown in Figure 3.5.

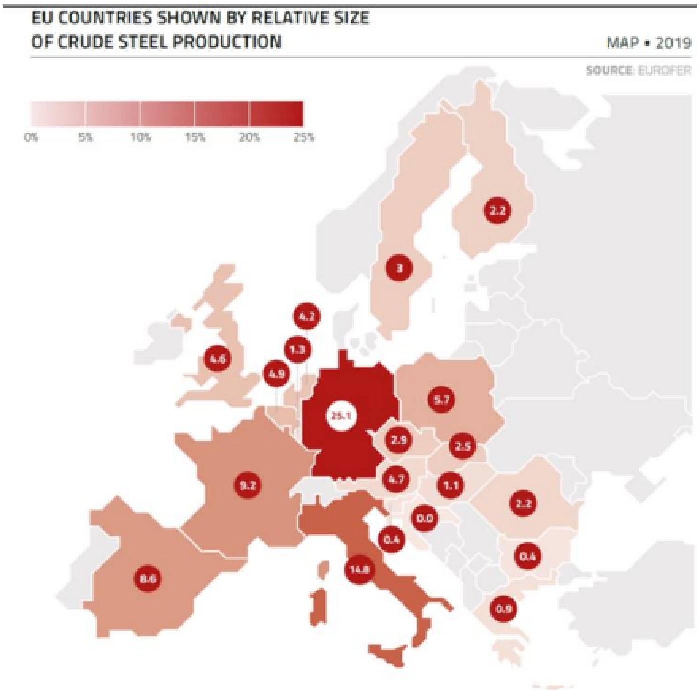

Figure 3.4: Crude steel production levels in EU countries (EUROFER, 2020a).

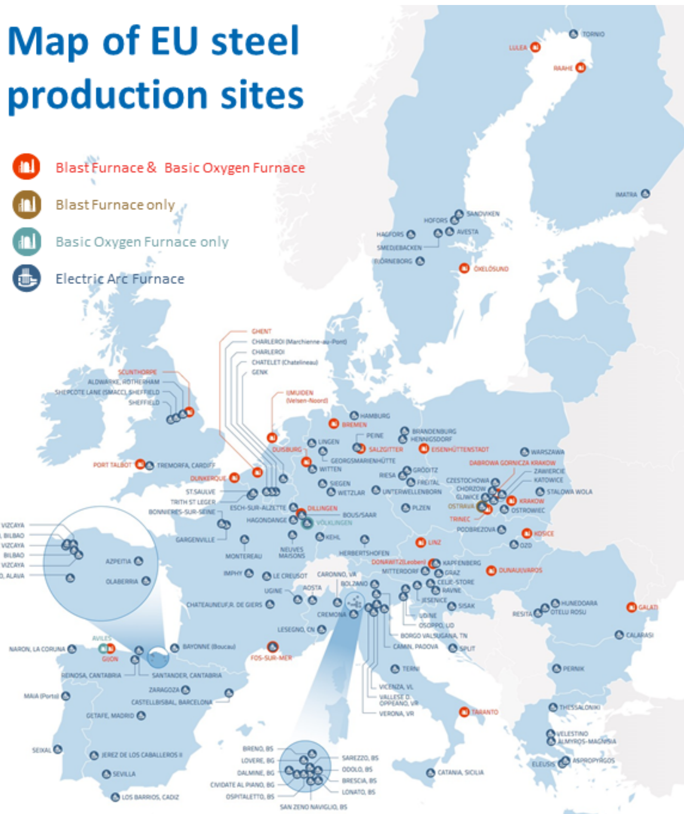

Figure 3.5: BOF and EAF EU production sites (EUROFER, 2021b).

3.1.5 Raw materials for steel production

It is estimated that the global steel industry uses 2 billion tonnes of iron ore, 1 billion tonnes of metallurgical coal and 575 million tonnes of scrap steel to produce approximately 1.7 billion tonnes of crude steel (World Steel Association, 2021). As mentioned earlier, in both steel-making routes, iron ore and scrap are used as raw materials but in different mixes where EAF can use 100% scrap and BOF can use 30% (World Steel Association, n.d). The steelmaking materials are among the world's biggest commodities in terms of volume of production, consumption, and transportation. Ferrous scrap is the world's biggest commodity recycling activity with a yearly volume over 600 million tonnes (World Steel Association, 2021).

Iron ore

Steel is an alloy consisting mainly of iron and less than 2% carbon. Iron ore is therefore essential for steelmaking, and 98% of all globally mined iron ore is used to make steel. Iron is one of the most abundant metallic elements and its ores (oxides) make up about 5% of the earth's crust. Average iron content in high grades ores are 60-65%. The largests mined volumes comes from Australia, Brazil, China, India, the US and Russia, where Australia and Brazil dominate the global iron ore exports. The extreme growth in China's steel production in the 2000s caused a very strong increase in the export markets for steel-making materials. Global iron ore exports grew from 0.5 billion tonnes in 2000 to 1.5 billion tonnes in 2016 (World Steel Association, 2021).

As much of the iron ore has been exploited globally, the mining goes deeper and deeper which requires more energy. In addition, the quality of the iron ore found at these deeper levels is worse, i.e. less iron content. Thus, using iron ore today and onwards means more emitted carbon dioxide and worse quality of the raw material (BIR, 2022).

Coal and Coke (and Hydrogen)

Coking coal is another key raw material in steel production. The iron is oxidized in the earth's crust and thus the iron ore must be converted by using carbon. Coking coal is the primary source of carbon. Heating the coking coal in high temperatures without oxygen (carburising) produces coke which is the primary reducing agent of iron ore. The coke reduces iron ore to molten iron ore saturated with carbon, called hot metal (World Steel Association, 2021).

By using the DRI/EAF route, the iron ore can be reduced with hydrogen as well, as explained in chapter 3.1.2, EAF (DRI) production route. The hydrogen is generated from natural gas or water (H2GS, 2022).

Scrap metal

Steel scrap or recycled steel is a key input needed for all steelmaking process routes. Steel's 100% recyclability ensures resources invested in steel production can be reused, and thus are not lost. Due to the magnetic properties of steel, it is easy to seperate from waste streams which enables high recovery rates and avoiding landfills (World Steel Association, 2021).

Some steel products contain 100% recycled materials. As mentioned above, steel is the world's most recycled material, 670 million tonnes in 2017, including pre- and post consumer scrap (World Steel Association, 2021). It is estimated that 80% of post-consumer steel is recycled globally. Recycling rates are highest for heavy structures, motor vehicles and machinery (85-95%) and lower for smaller appliances and packaging (around 50%) (ECSIP, 2013).

Recycling scrap steel results in significant energy and raw material savings; between 1100 - 1400 kg of iron ore, 630-740 kg of coal and 55-120 kg of limestone are saved for every 1000 kg of steel scrap made into new steel (BIR*, 2022; World Steel Association, 2021). Steel recycling uses 74% less energy, 90% less virgin material and 40% less water. Also, it produces 76% fewer water pollutants, 86% fewer air pollutants and 97% less mining waste. A BIR-commissioned study done by the Imperial College found that CO_2 emissions are reduced by 58% when using ferrous scrap in steelmaking rather than virgin ore (BIR 2019; Ministry of Steel India, 2019). See summary of resource saving benefits in Table 3.1 below.

Table 3.1: Raw material and resource savings for scrap (BIR*, 2022; World Steel Association, 2021; Ministry of Steel India, 2019).

Raw material	Savings (kg) for every 1000 kg scrap made into new steel
Iron ore	1100-1400
Coal	630-740
Limestone	55-120
Resource/environmental impact	**Savings (%)**
Energy	74
Virgin materials	90
Water	40
Water pollutants	76
Air pollutants	86
Mining waste	97
CO_2 emissions	58

Scrap is generated through several sources such as steel plants and rolling mills, construction and building, vehicles and transportation, large equipment and machinery, domestic goods, electronics and electronic equipment and packaging (Ministry of Steel India, 2019; ECSIP, 2013). If the scrap is originating from the initial manufacturing process, the steel processing, it is referred to as return scrap or home scrap. Scrap generated from downstream production processes or production of final products is referred to as new scrap or industrial scrap. Scrap originating from products after their final use, end-of-life products, is called old scrap or obsolete scrap (ESTEP, 2021; Kumar Sarna, 2017).

The availability of home- and industrial scrap correlates strongly with the current domestic steel production levels, whereas the availability of obsolete- or old scrap relates to levels of past steel production, average product lives and efficient recycling programmes (World Steel Association, 2021). Return scrap is not commonly sold in the market but stays within the steel plant to be reused and re-melted (ECSIP, 2013). There are several classification schemes for different types of steel scrap, depending on their physical and chemical characteristics (JBF, 2000; Rimeco, 2018). Depending on the characteristics, different pre-treatments are necessary before transporting, handling, and re-melting the scrap to create steel. The chemical characteristics, i.e. the residual contents of the scrap, also determine the grade of steel that can be produced. Hence, different grades of scrap in different volumes are used to produce steel (Kumar Sarna, 2017; H2GS, 2022).

Return scrap

Return scrap or own scrap can include both completely non-coated non-residual alloys steel, and galvanized steel, i.e. with zinc, a by-product after the galvanizing lines, depending on where in the steel processing plant the scrap (by-product) is generated (Jernkontoret, 2018). Regardless, this scrap steel is very valuable as it can be directly used again in the steel melt shop. Hence, this grade of scrap steel is seldom bought outside the steel processing plant (Kumar Sarna, 2019). As this scrap is mainly generated and reused within the steel plant, there are no international, EU or US standards for the scrap grade (H2GS, 2022).

New production scrap

New scrap is often referred to as Primes (Stena Recycling, 2021). It is mainly and regularly originating from the automotive manufacturing industry, but other steel-consuming sectors also generate it. In general, the larger the steel product, the greater the new scrap generation (World Steel Association, 2022). Certain construction and demolition projects can also generate significant volumes of new scrap, but these projects lack regularity (Kuusakoski, 2022). Scrap yields, the varying yields of new scrap from different production processes, will be discussed more in detail in chapter 3.3.2 Supply of scrap.

New scrap can be both in loose and packed format, i.e. baled scrap. Depending on the thickness and density it can be referred to as E2 or E8, and E6 which is baled E8, see Figure 3.6, 3.7 and 3.8 (JBF, 2022). New scrap is uncoated scrap steel with low levels of residuals (Rimeco, 2018; JBF, 2000). This makes it a higher quality, premium scrap that is sought by many steelmakers as it allows them to produce higher grades of steel. The export flows of E2 and E8 are small as the generated volumes are not very large and the local demand is often high (World Steel Association, 2022; JBF, 2022). The UK is an exception with regard to this as they do not have significant domestic steel production (EMR, 2022). Germany generates the largest volumes of E2 and E8 in Europe. Most of E2 and E8 scrap is sold in auctions held by the car manufacturers, and some scrap suppliers have long-term contracts to receive scrap from the car manufacturer, who wants to get rid of the scrap. This makes the pricing less transparent than for the old scrap that are global commodities (TSR, 2022; JBF, 2022).

Figure 3.6: E2 (Rimeco, 2018).

Figure 3.7: E2 and E8 (Rimeco, 2018).

Figure 3.8: E6 (Rimeco, 2018).

Old shredded scrap

Old scrap that has been shredded is called shredded scrap or E40 according to the European standard, see Figure 3.9 (Rimeco, 2018; JBF, 2022; Nilsson, 2022). It is created by putting the old steel scrap in a shredding machine that shreds, separates and processes the scrap (Kuusakoski, 2022). E40 is a commodity with global pricing and large export flows, particularly from the UK and Benelux region (SteelConsult, 2019; World Steel Association 2022). It is also referred to as ISRI211 in the American standards or 117 in the Swedish system (JBF, 2022). It originates from all types of end-of-life products, vehicles and buildings, both from municipal and industrial waste (ECSIP, 2013). In other words, it is found in large quantities where there are cities, people and industry. It is not tied to a specific industry like E2 and E8 (EMR, 2022; JBF, 2022; World Steel Association, 2022).

Residual elements that are allowed in small levels are tin and copper, with levels from one specification allowing for less than 0.02% and 0.025% respectively (Rimeco, 2018; JBF, 2000). It is not as premium a material as new scrap, especially because of the higher levels of copper. The more pure the E40, i.e. with less copper, the higher is the quality of the scrap product (World Steel Association, 2022).

Figure 3.9: E40 (Rimeco, 2018).

Old sheared scrap

Old sheared scrap is also called HMS, heavy melting steel, which can be seen in Figure 3.10 (Rimeco, 2018). Standard index HMS quality is represented as Swedish class 11 (JBF, 2022). It is both old thick and old thin scrap, the difference to E40 is that it is not shredded but simply sheared (Rimeco, 2018; EMR, 2022). It is the same obsolete scrap raw material for HMS and E40, but the shearing machine is less capital intensive than the shredding machine (EMR, 2022). HMS1 and HMS2 are the two major categories, where HMS1 does not contain galvanized and blackened steel which HMS2 does (Melbourne Metal Recycling, 2018). HMS1 and HMS2 are the largest exported scrap qualities. In general, the density for HMS scrap is a bit lower than for E40. However, HMS bonus is equal to Swedish class 100 and has higher density and more homogenous material than regular HMS1 and HMS2 (Kuusakoski, 2022). HMS is, like E40, a global commodity and it exists where there are shearers, i.e where there are people, industry and infrastructure. The export flows for HMS are similar to E40 (EMR, 2022; World Steel Association, 2022).

Figure 3.10: HMS (Jansen group, n.d).

Variations in the scrap mix and qualities

In steel production today, a mix of all mentioned scrap grades can be utilized (H2GS, 2022). As stated earlier, depending on the quality, i.e. requirements, of steel to be produced, different shares of scrap grades are used. For reinforcement bars used in construction, the lowest quality of steel is necessary, implying that E40 and HMS can be utilized despite potential high levels of residuals such as copper (World Steel Association, 2022). The highest requirements for steel stems from the automotive industry. Hence this type of steel production benefits from using the new production scrap. But it can also utilize old scrap when the supplier can provide sufficient quality control for residuals. EAFs are flexible which means it is easy to switch daily or weekly what quality of steel to produce based on the raw material inserted to the EAF (H2GS, 2022; Kumar Sarna, 2013).

Besides the fact that the quality of scrap has an effect on the quality and type of steel that can be produced from scrap, it has a significant impact on the energy efficiency, productivity, waste generation and costs for the steelmaker. Scrap with high iron content and low steriles is always preferable (Hall et al., 2021).

No single international standard exists for the different qualities of scrap steel, but the EU, the UK, the US and Japan have aligned standards. Most exports to Asia refer to the US (ISRI) standard scrap specification in the contract. The main differences between these standards and certain other national standards, such as the Swedish, relates to the limit on residual elements (Hall et al., 2021). Swedish, German and other national standards as well as metal recyclers' own specifications include more detailed guidance on the specific scrap grade, including density, thickness and levels of residuals (Kuusakoski, 2022). However, due to the widely varying quality of the scrap that is delivered to scrap processing plants, the suppliers often provide materials with high variability between the minimum and maximum requirements defined in those specifications (ESTEP, 2021; Hall et al., 2021).

The preferred quality and thus content of E40 and HMS is mixed and subjective. The quality can change and ground presences and industry "know-how" are critical (Stena Recycling, 2022). Most scrap suppliers have experts walking in the harbors or scrap yards checking the quality manually (World Steel Association, 2022). Scrap buyers from Sweden and other countries with more stringent requirements are likely to have to do their own analysis and control of the scrap (Kuusakoski, 2022).

Summary

In this chapter, the main raw materials used in steel production today have been described. Iron ore and scrap are somewhat interchangeable, especially in the EAF production route that can utilize 100% scrap metal. The scrap can be categorized in four main categories, summarized in Table 3.2 below.

Table 3.2: Summary of scrap qualities.

Scrap quality	Common classifications	Characteristics
(New) return scrap	(internal)	Reused within the steel mill, highest quality, few contaminants/residuals.
New production scrap	E2, E8, E6	From steel-using manufacturing sectors, mainly automotive, high quality with few residuals, steel of different origin can be mixed.
Old shredded scrap	E40	Global commodity. From end-of-life products, shredded to a smaller more weight/volume efficient scrap product. Sorted and cleared of residuals to varying degrees depending on demands of the end customer.
Old sheared scrap	HMS1, HMS2, HMS-bonus	Global commodity. From end-of-life products, sheared to pieces that are easy to transport, but lower volume/weight efficiency. Usually higher share of residuals.

3.2 Steel consumption in Europe

Steel used in the EU includes both EU domestically produced steel and imports from third countries. The steel-using sectors in the EU are construction, automotive, mechanical engineering, metalware, tubes, domestic appliances, other transport and miscellaneous (EUROFER, 2022; EUROFER, 2020a). The steel consumption per sector can be seen in Figure 3.11 below.

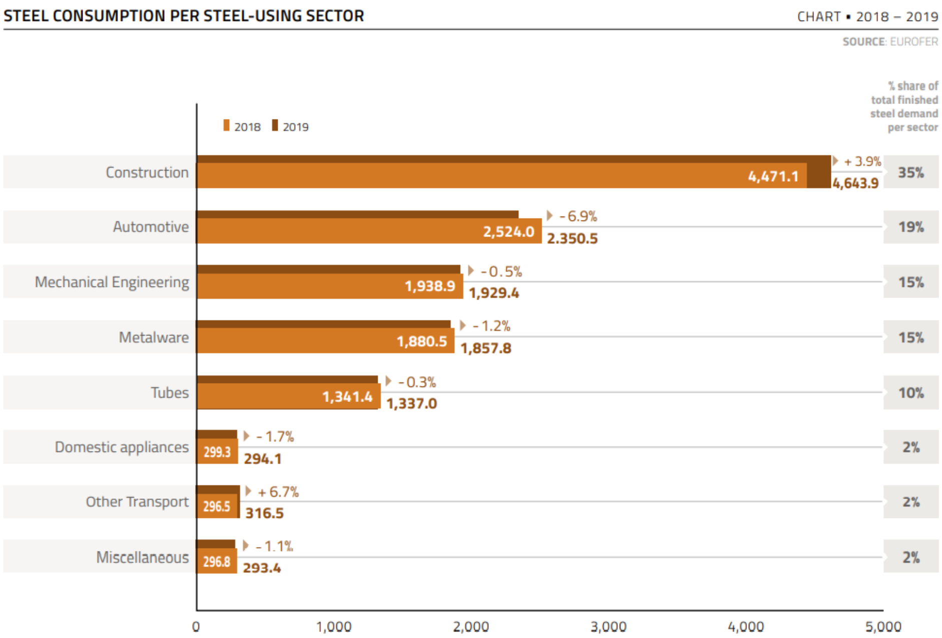

Figure 3.11: The steel consumption per sector (EUROFER, 2020a).

Sustainability is becoming more important for the end-consumers. Among the steel-using sectors, automotive is the one driving the transition towards net-zero and thus putting more stringent demands on CO_2-emissions from their suppliers, especially steel. An increase of electrical vehicles that are fueled by clean electricity entails that the life cycle emissions are mainly from the production phase, where steel is the main raw material (Scania, 2021). The European scrap market is highly impacted by decarbonisation trends driven by the automotive industry and steel consumers are pushed to buy their steel from greener suppliers (Kuusakoski, 2022; BIR, 2022).

3.3 European scrap market

The EU-28 remained the world's leading scrap exporter in 2019 with outbound shipments growing from the previous year by 0.6% to 21.793 million tonnes. The main buyer is Turkey with 12.021 million tonnes. This gives Turkey market arbitrage, implying they have great influence over price levels (World Steel Association, 2022; BIR, 2022; JBF, 2022). Similar to other major scrap exporters, the EU-28 is a major net scrap exporter, i.e. with a large export surplus that was 18.9 million tonnes in 2018 (BIR, 2019). The development of EU scrap exports is demonstrated in Figure 3.12. The export flows of EU scrap is shown in Figure 3.13, and the export volumes for the main scrap countries, both within and outside EU, are presented in Figure 3.14.

Historically and still today, developed countries export and developing countries import scrap (JBF, 2022; World Steel Association, 2022). However, the European Union is taking actions to increase the retention and use of scrap within the EU, i.e. decreasing exports. This is because scrap is realized as a strategic secondary raw material for decreasing the carbon intensity of the steel sector which is vital for the EU Green Deal, the EU ambition to become climate neutral by 2050 (European commission, 2022; European commission, 2021; EUROFER, 2020b).

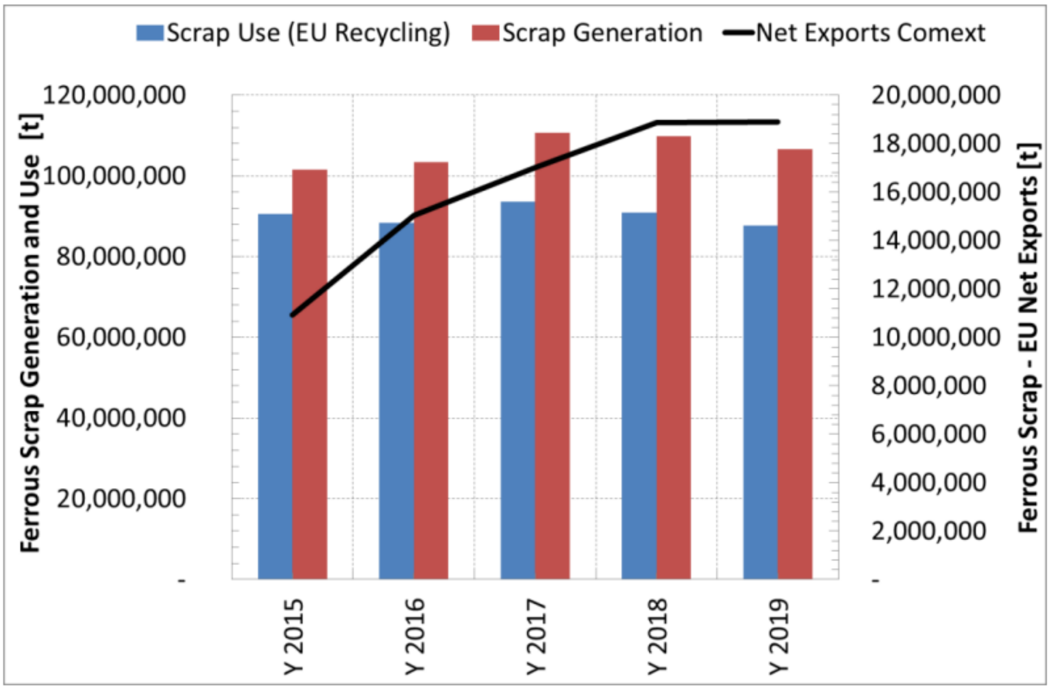

Figure 3.12: Ferrous scrap use (ferrous scrap recycling into new steel in EU) and estimation of the ferrous scrap generation of the EU (EUROFER, 2020a).

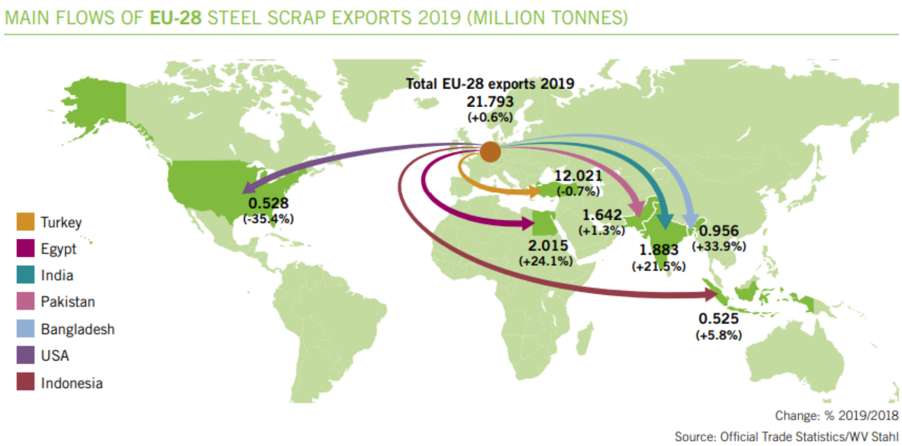

Figure 3.13: EU scrap export flows (BIR, 2020).

Figure 3.14: Scrap exporters outside and within EU 2019 (Stena Recycling, 2022).

The scrap market is not an easy industry to analyze and understand (World Steel Association, 2022). The following sections will further explain relevant aspects of the European scrap market.

3.3.1 Structure and conditions of the market

The scrap market structure in EU-28 resembles a reversed pyramid, as can be seen in Figure 3.15. There is a large number of smaller collectors, companies and organizations or even individuals, such as municipal waste centers that supply scrap to a smaller number of companies. These companies, scrap suppliers, treat the scrap in their scrap yards through several processes before it is supplied to a small number of larger steelworks or foundries for reprocessing into new steel (ECSIP, 2013). The metals recycling industry in the UK is similarly described as a pyramid (Hall et al., 2021).

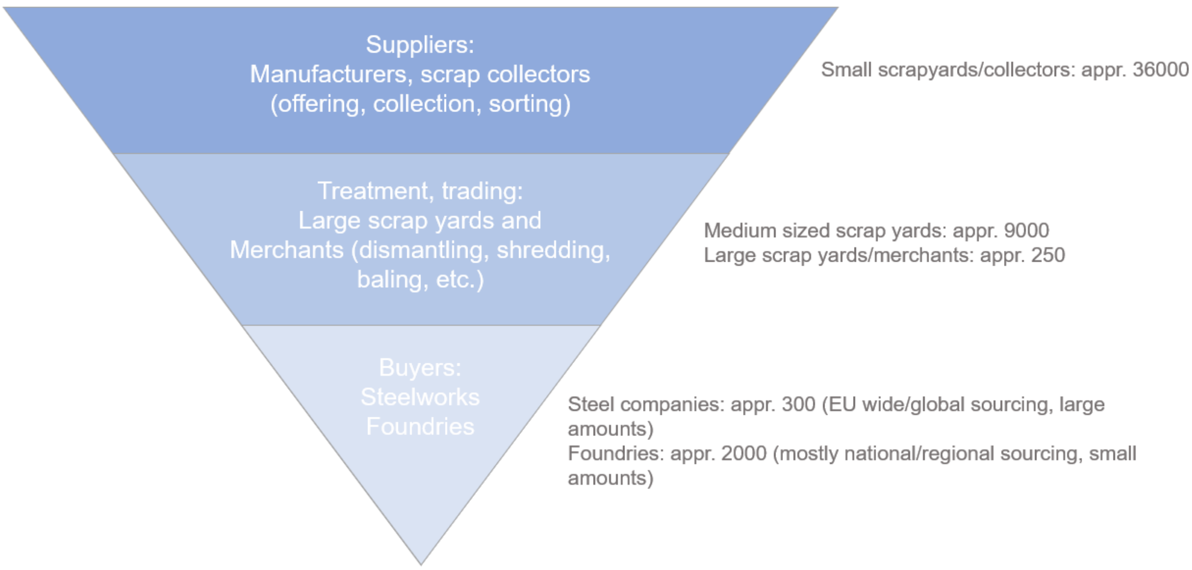

Figure 3.15: Structure of scrap market (ECSIP, 2013).

In 2010 there were approximately 45,000 scrap yards across the EU, with 250 considered large companies, 9000 medium-to-large companies that process over 120,000 tonnes per year, and the remainder, around 36,000 companies that can be categorized as small and medium-sized enterprises (SMEs). Over 300 dedicated end-of-life vehicles (ELV) shredding companies of varying sizes are included in the medium and large companies' segments (ECSIP, 2013). The inverted pyramid structure of the market can be seen in Figure 3.15 above and the EU scrap yard shares are summarized in Table 3.3.

Table 3.3: Share of scrap yard companies (ECSIP, 2013).

Type of scrap yard	Total amount
Large companies	250
Medium-to-large companies	9000
SMEs	36000

3.3.2 Supply of scrap

No official statistics exist on how much ferrous scrap is generated in the EU every year. Thus, it is not possible to say with certainty the exact recovery rates for steel and iron scrap. Every year some steel will be lost due to wearing or because it is too difficult or costly to recover (ECSIP, 2013). As stated previously, recovery rates differ per product or activity. Rates close to 100% are expected for steel processing or steel products manufacturing, whereas they are lower for end-of-life (EOL) consumer goods (ECSIP, 2013). Industry sources indicate that the EU collection rates are likely to be above global average due to the value of the material (World Steel Association, 2022). According to the EUROFER estimates, the ferrous scrap annual generation varies in the EU between 102,000,000 and 110,000,000 tonnes, which is seen in Figure 3.12 (EUROFER, 2020a). The reason Europe has a large scrap supply is mainly due to high industrial activity and large population, but also due to laws that restrict the amount of waste allowed. This in turn has caused Europe to have more shredders than steel to shred. According to industry sources, a good estimate is that for a developed country with a "mature" economy, 25% of the total population will be the annually generated old steel scrap in tonnes. For Sweden with 10 million inhabitants, 2.5 million tonnes of scrap is generated every year (Stena Recycling, 2022). Historical data shows slight increases or stable levels in total levels of metal scrap collected in the early 2000s, with a decrease during the 2008-2010 period due to the financial crisis and economic slowdown (ECSIP, 2013).

There is no available statistical data on EU level for specific product sources or for specific qualities of iron and steel scrap collected from different sources. This makes it difficult to make a detailed breakdown of e.g. volumes of scrap collected from buildings, different types of infrastructure demolition or specific types of ELV such as trains, trucks or ships. However, end uses of steel can provide an indication of the potential volumes and main sources of old scrap in society (ECSIP, 2013). However, Table 3.4 below provides insights on the share of scrap products on a UK level. Demolition, Thick old and Thin old scrap is corresponding to HMS, old sheared, scrap. Fragmented scrap is shredded scrap, E40. New scrap corresponds to the Manufacturing off cuts (Hall et al., 2019). Thus, it can be noted that old sheared scrap constitutes the largest share, followed by old shredded and then the new scrap.

Table 3.4: Scrap generation per category in the UK (Hall et al., 2021).

Scrap category	Scrap category proportion (%)
0A - Demolition	10,5
1 - Thick old	21,5
2 - Thin old	14,7
3B - Fragmented	28,5
6A - Cans & incinerated	7,6
7A - Turnings	1,1
8A - Manufacturing off cuts	10,4
9A - Old cast iron and rail	4,2
9D - Brake discs and wheel drums	1,0
12A - New cast iron	0,5
Total	**100**

Scrap is collected through various streams depending on the scrap generating activity. Iron and steel waste from households usually goes through municipal waste collection points by small scrap collectors, through yards at municipal level or by smaller waste management companies. These actors do not process the scrap themselves but rather sell it to larger scrap yards that have the (capital intensive) processing equipment. Scrap from larger iron and steel structures, such as bridges, buildings and trains, as well as ELV will be offered directly to large scrap yards, sometimes through long-term contracts between the manufacturer and the scrap processor (BIR, 2022; ECSIP, 2013). Infrastructure development, building and demolishing, provides a significant supply of scrap, especially during times of recession. Scrap from combustion facilities is a new source of scrap that is becoming more attractive for steel producers (Kuusakoski, 2022).

For new scrap, the generated amount depends on the manufacturing sector producing steel-based products. The new scrap is generated from cutting, drawing, extruding or other shaping of the metal to produce the final goods (J. Davis et al., 2006). The new scrap rates, or scrap yield, depend on the production process and differ across sectors, and will be further described in *Scrap yields* below.

Geographical spread of supply

The European scrap supply varies significantly over different countries and regions. In Figure 3.16 below the scrap supply is mapped in terms of export volumes from chosen European countries. Germany, UK, Netherlands and France are the largest exporters in Europe (Statista, 2020).

In Figure 3.17, the scrap supply is instead mapped in terms of scrap generation per country. As mentioned earlier in this chapter, approximately 25% of a country's population equals the volume of scrap generated per year in million tonnes (Stena Recycling, 2022). The countries with the largest generated volumes are Germany, France and the UK, but the areas which export a lot of scrap are slightly different. This is due to the large flows of scrap from central- and eastern Europe to steel hubs in Germany and to export ports in Belgium and the Netherlands. Thus, the largest export areas are Benelux, Germany, northern France and the UK (JBF, 2022; World Steel Association, 2022). One of the main reasons behind these flows of scrap is that large scrap suppliers have their own logistics systems where scrap from different parts of Europe are consolidated to one or several North sea ports, which they supply their customers from (EMR, 2022). The UK is a large exporter because of a lack of its own steel production industry (BIR, 2022).

Regarding scrap supply in Sweden, approximately 2,5 million tonnes is generated annually. About 1-1,5 million tonnes are consumed domestically, and the rest is exported. Prime scrap qualities like E2 and E8 exist in the middle and south of Sweden, nearby Volvo Cars facilities. Smaller volumes of prime scrap are also generated from Volvo AB in Umeå (Stena Recycling, 2022).

Country	Export volume (Mt)
Germany	8,234
UK	7,649
Netherlands	6,310
France	6,135
Belgium	4,067
Czech Republic	2,166
Poland	1,453
Romania	1,305
Austria	1,081
Sweden	0,956
Denmark	0,6
Bulgaria	0,405
Lithuania	0,4
Latvia	0,4
Estonia	0,4

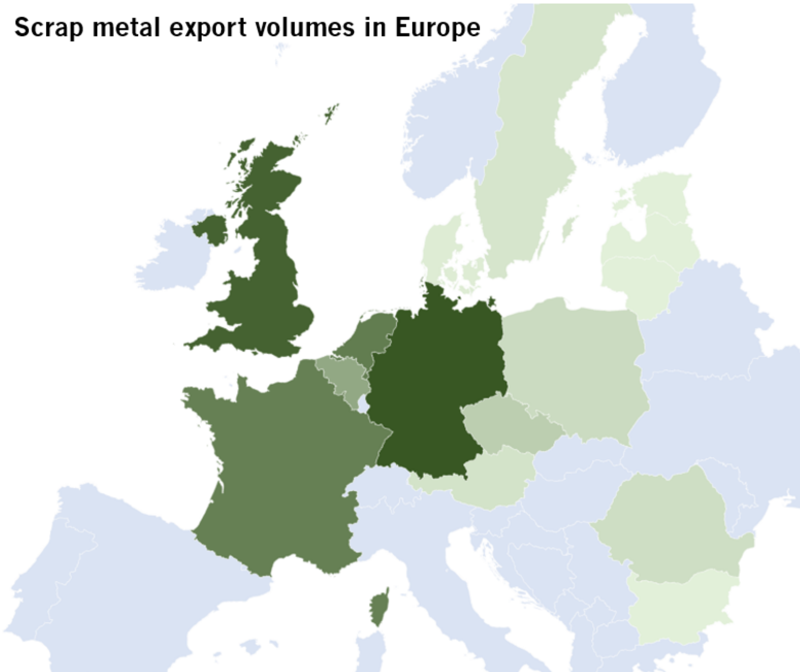

Figure 3.16: Scrap export volumes (Statista, 2020).

Country	Generated scrap volume (Mt)
Germany	20,81
France	16,8475
UK	16,805
Italy	14,8875
Spain	11,8375
Poland	9,4875
Romania	4,8225
Netherlands	4,35
Belgium	2,875
Czech republic	2,675
Sweden	2,5875
Portugal	2,5775
Hungary	2,4375
Austria	2,225
Switzerland	2,15
Bulgaria	1,725
Serbia	1,725
Denmark	1,45
Finland	1,375
Slovakia	1,36475
Norway	1,325
Ireland	1,24875
Croatia	1
Bosnia	0,8
Lithuania	0,7
Slovenia	0,525
Latvia	0,475
Estonia	0,325
Montenegro	0,155

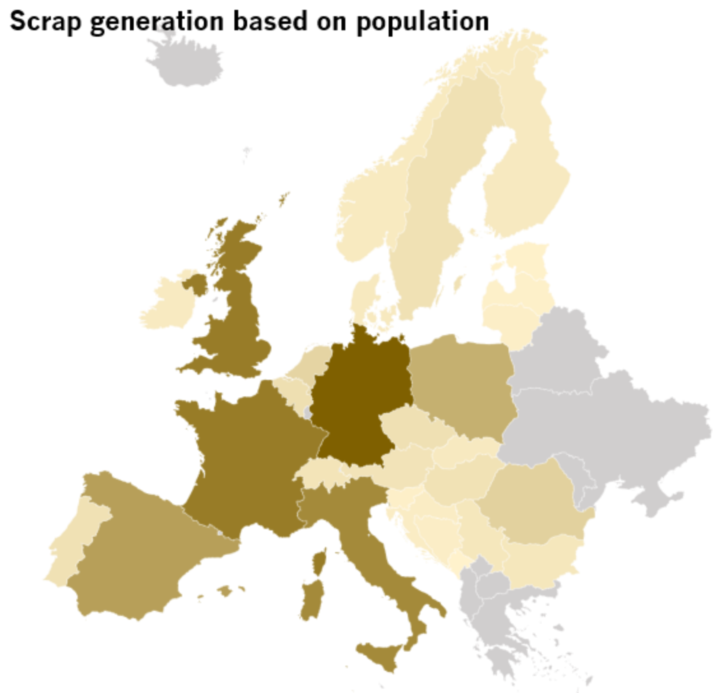

Figure 3.17: Scrap generation based on population (Stena Recycling, 2022).

Scrap yields

Scrap yields, as explained previously, is the amount of new or prompt scrap generated in the production of steel products. This type of scrap is called E2 and E8 and is a premium material especially attractive for steel manufacturers. Understanding the scrap yield for the different steel consuming sectors is therefore relevant to know where to source the E2 and E8. The European Steel Association EUROFER's projected scrap yield rates for 2030 range from 2% in the construction sector to 25% in the automotive sector. However, the scrap yield for the construction sector is expected to decline towards 0% by 2050, while the yield stays constant for other sectors (EUROFER, 2019). According to a material flow analysis of steel and iron, prompt scrap rates in 2000 vary from 5% in construction to 17% for metal cans, with vehicles at 10% (J. Davis et al., 2006).

As mentioned, the automotive industry is the sector generating the largest volumes of E2 and E8, but estimations of scrap yields vary across industry sources. Values range from 20-25% (Kuusakoski, 2022), 25-30% (World Steel Association, 2022), 10% (TSR, 2022) and 15% (BIR, 2022).

3.3.3 Trading and treatment

As demonstrated in Figure 3.15 with the inverted pyramid structure of the scrap market, large scrap yards or processors treat and often also trade in scrap. A number of operators function only as merchants. These merchants and scrap yards build relationships with both suppliers of scrap and the steel companies, their main customers. The specific steel mills that the scrap company supplies determine what grades and qualities of scrap they produce or deliver (ECSIP, 2013).

Trading and logistics

The scrap yard may not always produce a specific grade themselves but can source it in the market, i.e. function as a trader. This often comes down to the logistics, if it makes more sense to source a specific scrap closer to the client, this is referred to as the Nearby sourcing principle by scrap suppliers, which is further elaborated on in chapter 4.2.1 (JBF, 2022). Logistics is a key part of the scrap yards' value proposal, together with the actual scrap treatment. Scrap yards are often strategically located along waterways or with their own railways. The scrap suppliers arrange consolidation in the collection from smaller suppliers and the final distribution to steel mills. This causes logistical costs to be very significant in the overall cost structure for scrap processors (EMR, 2022; ECSIP, 2013; JBF, 2022). Scrap yards or scrap processors are price takers in general, the cost of the scrap they buy is in some ways dictated by the market. In order to safeguard margins it is very important to continuously work to reduce costs. The main costs vary depending on size, location and business model of the scrap yard but in general include: raw material inputs (scrap), transport and logistics, capital costs, permit and compliance costs, electricity costs and labor costs (ECSIP, 2013).

Treatment

The scrap processors involves some or all of the following steps (BIR, 2020):

- *Sorting*: By using magnetic belts, scrap metal can be separated from other recyclable material such as paper in a recycling facility.
- *Shearing*: Hydraulic machinery (capable of exerting extremely high pressure) cut thick, heavy steel originating from e.g. railway and ship structures. Cutting techniques such as gas or plasma arc torches may occasionally be used.
- *Shredding*: Shredders incorporate rotating magnetic drums to retrieve iron and steel from a mixture of materials. Shredders also "shred" the material into smaller pieces, to make them easier to transport and re-melt in the steel mill.
- *Media separation*: Electrical currents, high-pressure air flows and liquid flotation systems are used to further separate the materials.
- *Baling*: Iron and steel scrap products are compacted into large blocks to facilitate handling and transportation, to make the product more volume and weight efficient.

Visual inspection is also used for further sorting. There is a heavy reliance on visual inspection for quality control, both for recyclers and steelmakers. Hand-held XRFs, x-ray fluorescent analyzers, are sometimes used to check the composition of the sorted steel, which relies on the operator's competence (Hall et al., 2021).

In general, scrap processing refers to shredders and shearers, where shredders are the more advanced equipment that produce E40 scrap. Shearers produce HMS with larger, more irregular scrap pieces and more residuals. All major scrap suppliers in Europe have their own shredding and shearing facilities (EMR, 2022; TSR, 2022; Stena Recycling, 2022).

Relationship

What type of supplier-relationship a steel mill has with a scrap yard is mainly determined by the steel mill. ArcelorMittal, Europe's largest steel producer, buys from an estimated 350 suppliers and offers the same prices to all of these, i.e. there is no differentiation potential for the scrap yard (ECSIP, 2013). Also, ArcelorMittal has integrated vertically and bought scrap suppliers to secure their supply (ArcelorMittal, 2022). However, many other, smaller steel companies have longer term contracts with fewer suppliers or scrap yards, this is especially the case when the steel mill requires specific scrap qualities (ECSIP, 2013).

3.3.4 Pricing of scrap

Scrap prices are global and set daily. The prices are highly competitive due to the many scrap producing countries. The prices are also volatile due to, among other things, short contracts and seasonalities. Global market conditions as well as the regular supply and demand determine scrap prices. Also, financial policies and currency fluctuations, where US dollars is the reference, have an impact. Actions of large buyers have an especially big impact on the scrap pricing (ECSIP, 2013; World Steel Association, 2022).

Supply side scrap price influencers regard the availability of raw materials which in turn is influenced by logistics accessibility (access to storage, transport and ports), as well as duties, quotas and non-tariff barriers, social conflicts, war and weather. Export restrictions from big producing countries can have a big impact as well (ECSIP, 2013; World Steel Association, 2022).

Demand side price influencers are the demand from the steel sector in the largest markets that utilize EAF and rely on scrap for production. The main example of this is Turkey, who buy over 20 million tonnes of scrap per year. Scrap demand in Turkey affects global prices of scrap to the extent that they stop correlating to prices of e.g. iron ore. Scrap purchasing by Turkey, and other similar large import markets, also affects the regional prices. As an example, if Turkey buys a large volume of scrap from Canada, prices in Europe will decline (JBF, 2022; ECSIP, 2013; World Steel Association, 2022).

As explained in the Raw materials for steel production chapter, substitutes for scrap are iron ore and DRI. There is a correlation between iron ore prices and scrap prices in the EU, as they both depend on steel sector demand, but it is not a perfect correlation due to differences in raw material input from BOF and EAF production. Also, because all the scrap qualities produced can not be utilized in all steel production (ECSIP, 2013; Kuusakoski, 2022).

As mentioned, the European scrap market is an export market and scrap qualities HMS and E40 are global commodities. This means that the scrap purchase price will be the same across European countries and regions. However, the prices are volatile and vary from week to week, which can be seen in Figures 3.18-3.21 below (EMR, 2022; BIR, 2022; JBF, 2022). E40 requires shredding which is more capital intensive than the shearing required for HMS, which means suppliers require a price premium to do so and E40 becomes a bit more expensive. For E2 and E8, price levels can vary a bit more across Europe as the pricing is not as transparent and depends on the regional availability (EMR, 2022; World Steel Association, 2022).

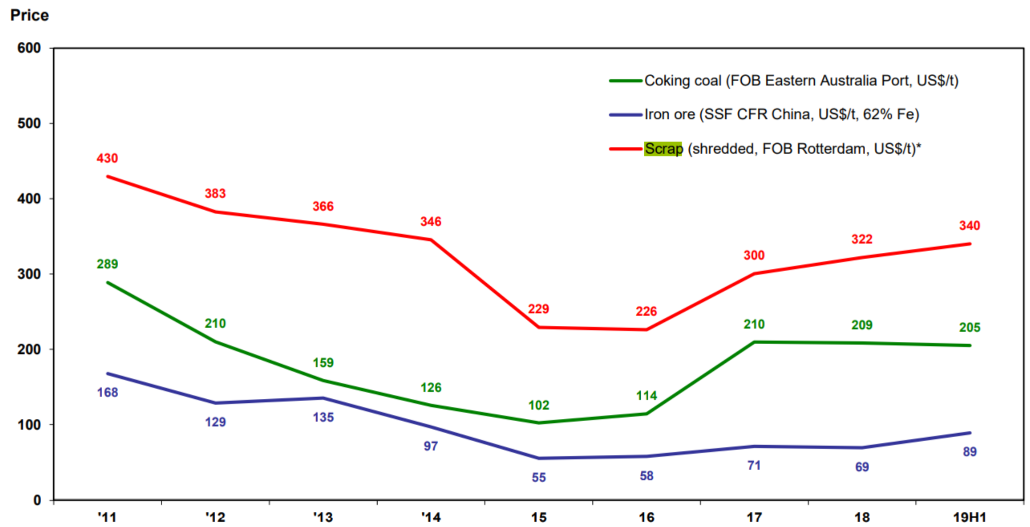

Figure 3.18: Yearly price development shredded scrap compared to Iron ore and coking coal (SteelConsult, 2019).

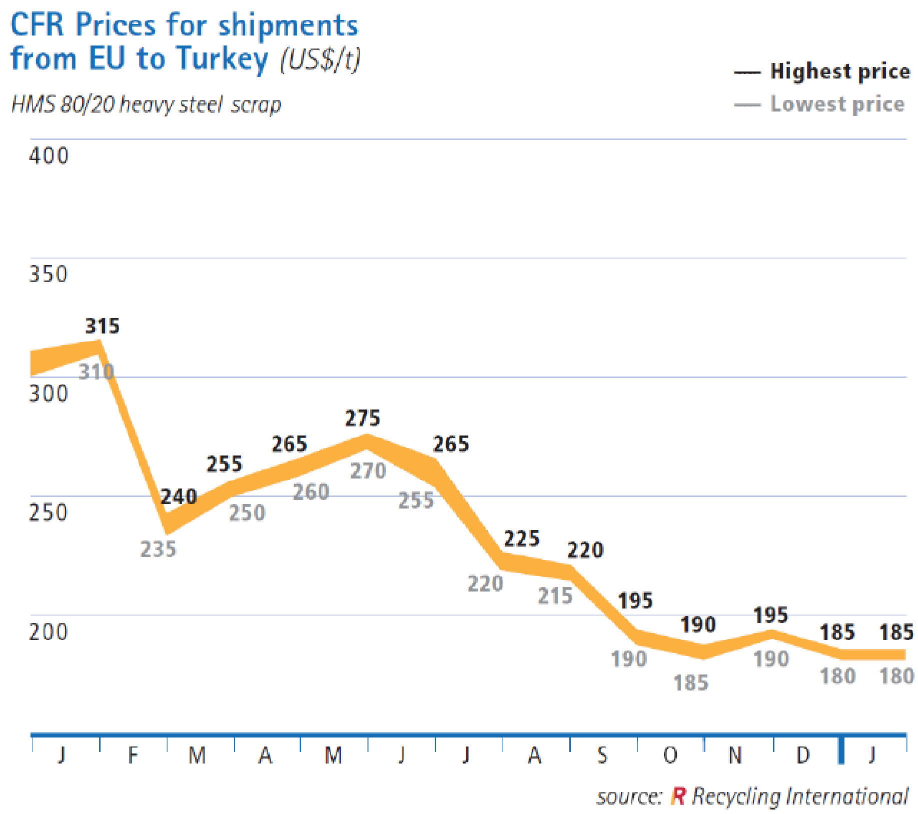

Figure 3.19: Monthly development HMS price to Turkey (BIR, 2016).

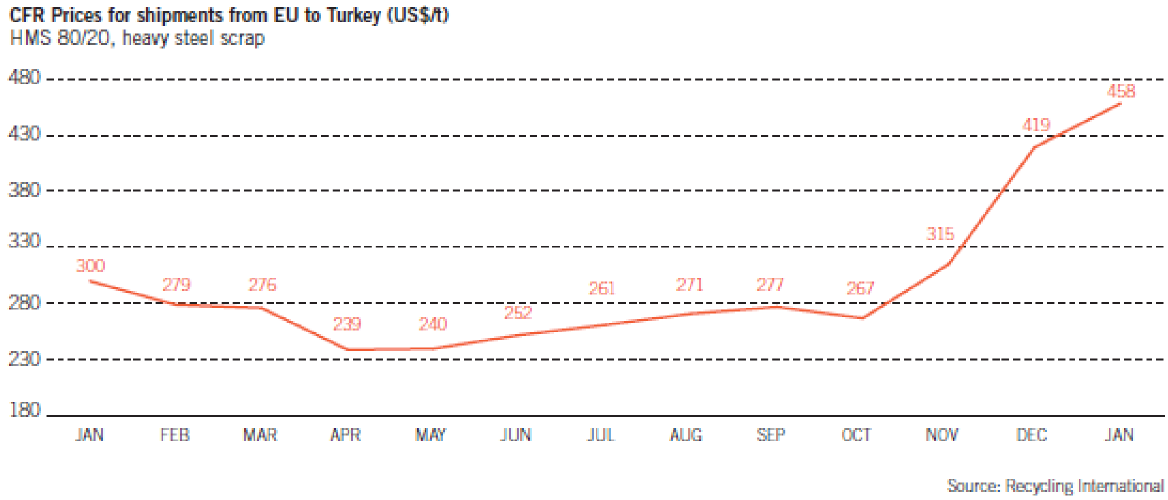

Figure 3.20: Monthly development in 2020 of HMS price from EU to Turkey (BIR, 2021).

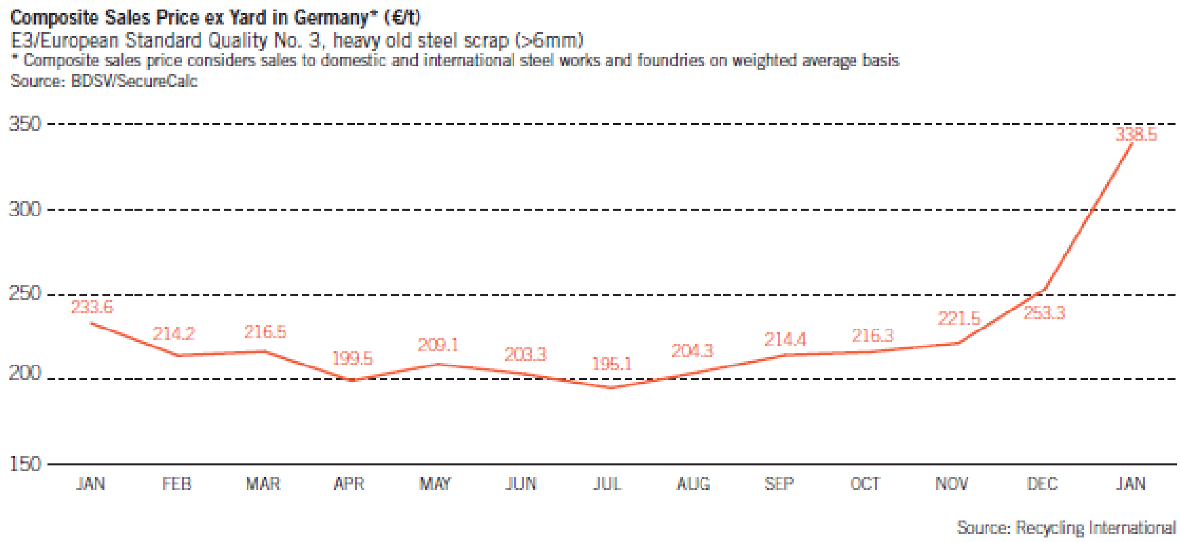

Figure 3.21: E3 (= HMS1) monthly price development in Germany (BIR, 2021).

3.3.5 Future of European scrap market

Future demand

EUROFER estimates that scrap demand will increase as it is part of the EU steel strategy to reduce CO_2 emissions. Demand from both BF/BOF and EAF steel production will increase, with EU strategy further emphasizing EAF production (ESTEP, 2021; EUROFER, 2019). There is consensus from industry sources that demand for scrap will increase dramatically in the coming years (World Steel Association, JBF, EMR, Kuusakoski, 2022). The increase in EAF production, which can utilize 100% scrap compared to BF/BOFs 30%, is one main reason for the increased demand. Simultaneously, the quality of iron ore is getting worse and the extraction process is more energy consuming (BIR, 2022). The decarbonization trend driven by the automotive industry is also a reason for a greater scrap demand since steel produced with a high share of scrap is more environmentally friendly and emits less carbon dioxide than steel produced with iron ore (World Steel Association, 2022).

Future availability and prices

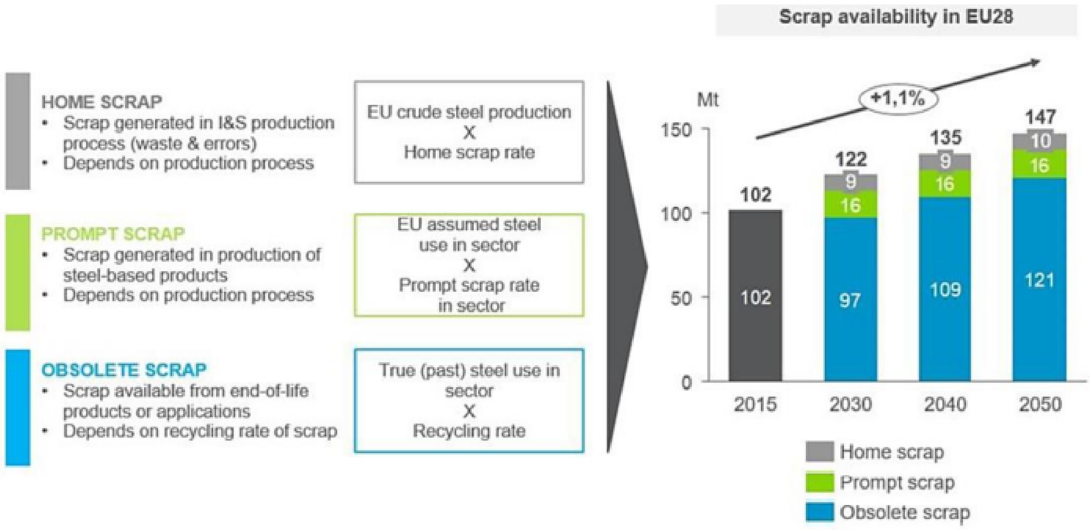

Figure 3.22: Scrap availability in the EU (million tonnes) towards 2050 (EUROFER, 2019).

Scrap availability is expected to grow in the EU towards 2050 with approximately 1.1% annually. The growth is arising mainly from obsolete, old scrap and the forecast is based on the slight production growth forecast of +0.5% per year until 2050 (EUROFER, 2019). In the EUROFER modeled scenarios, as can be seen above in Figure 3.22, home scrap and prompt scrap are expected to maintain their sizes, whereas obsolete scrap is expected to grow slightly, causing the overall availability to increase towards 2050 (EUROFER, 2019).

However, the obsolete scrap characteristics are expected to change drastically for the worse. This is because of the increased complexity and heterogeneity of ferrous materials. Product and material technology have evolved to enable new and more complex materials that make it difficult to separate iron scrap from other scrap or wastes (ESTEP, 2021; EMR, 2022). Examples of this include the combination of steel with plastics and fibers, more complex joints and technical coatings. Also, the repeated recycling causes the quality to worsen. The limited availability and the decreased quality will cause the scrap costs to increase (ESTEP, 2021). Scrap suppliers processing technology has not been developing at the same speed as product and material technology (EMR, 2022). The supply of new scrap will be limited since manufacturers will continue to improve their material efficiency and reduce their waste (Stena Recycling, 2022). Industry experts have stated that Europe will be vacuum cleaned of scrap and European scrap consumers must increase their sourcing radius (Stena Recycling, 2022). ECSIP and OECD findings indicate that globally, scrap availability will increase in emerging economies such as China. In the EU it is expected to stabilize as the stocks near saturation (ECSIP, 2013).

The increased European demand and the decreased availability of scrap as well as higher costs for new processing technology for scrap will lead to increased prices. The scrap prices have historically followed the iron ore prices, but with increasing electricity costs, i.e. higher costs to extract iron ore, and higher scrap demand, this will likely change in the future (Kuusakoski, 2022).

Changes in the industry
ESTEP concludes in their EAF scrap route roadmap that implementing actions are needed for scrap markets, on optimal charge preparation and improved process control. Also, that R&D projects are important to optimize scrap quality through cooperation between stakeholders in the scrap management chain. Moreover, the yield of steelmaking routes can be improved through recovery of metal fractions from residues. By implementing these actions, the expected impact includes decrease of raw material consumption and increased resource efficiency. By securing the quality, the use of low-quality scrap can be increased (ESTEP, 2021).

3.4 Logistics

A main part of this thesis is to create a cost efficient logistics solution for scrap sourcing. Thus, this chapter is introduced with a logistics literature review followed by some key information about scrap logistics.

3.4.1 Cost optimization principles for transport

In a globalized world, reducing transport costs for goods is of great importance. There are several factors determining the total transport costs of a route. By studying and analyzing transport cost determinants, Camisón-Haba and Clemente (2019) found 11 hypotheses that they proved statistically by using data from more than 300 international routes. This resulted in a global model for estimation of transport costs. A number of these hypotheses are presented in the following section, as they provide theoretical and academic legitimacy to comments, hypotheses and assumptions that will be discussed later on in this thesis.

- Hypothesis 1: A firm's transport costs for a particular route have a negative relationship with both the firm's size relative to that of the logistics operator and the number of operators on the route

This means that if a route has high competition between logistics operators, the transport cost will decrease.

- Hypothesis 2: A firm's transport costs on a particular route have a negative relationship with the scale economies generated by both the size of the logistics operator as well as the volume of traffic on the route, exports and the negative trade balance between the origin and destination regions

Indicating that transport costs decrease if the logistics operator is big enough to have scale economies and if the volumes on the route are large, especially going the opposite direction, i.e. if there is a trade imbalance.

- Hypothesis 3: A firm's transport costs on a particular route have a negative relationship with the volume of cargo contracted, the average size per service and its degree of vertical integration

Demonstrating that utilizing scale economies, i.e., transporting larger cargo volumes and with more regularity for the logistics operator, decreases transport costs.

- Hypothesis 4: A firm's transport costs have a positive relationship with the adoption of a lean production system, and the demand for time flexibility and load flexibility

This shows that transport costs decrease if there are storage opportunities and potential to build stock instead of a lean strategy.

- Hypothesis 6: A firm's transport costs have a negative relationship with both transport service frequency and safety, and the number of stops on the route

Implying that transport costs decrease with fewer stops on the route.

- Hypothesis 8: A firm's transport costs have a negative relationship with the quantity and quality of infrastructure on the route

That is, if there are infrastructural bottlenecks or quality issues, transport costs will increase.

- Hypothesis 10: There is a positive relationship between the length of the route and a firm's transport costs, while the relationship between island destination and transport costs is negative

This means that the longer a transport, the higher the transport cost. The hypothesis regarding island destinations was not proved to be statistically significant.

- Hypothesis 12: The rise in transport costs with the increase in distance will be moderated by using rail, maritime and air options, though beyond a certain distance threshold the costs will start to increase exponentially

In other words, transport costs will increase less than linearly with distance when using rail, sea freight and air, up to a certain distance.

As can be noted in the above proven hypotheses about cost minimization for transport, there are many aspects to consider involving the entire supply chain. These hypotheses will be further elaborated on in chapter 5, Analysis and model, and combined with the quantitative results to find the best, cost optimized, sourcing strategy for H2GS.

3.4.2 Scrap logistics

Since the prices of scrap are approximately the same across all European countries, the logistical cost for transporting scrap from a supplier in Europe to Boden is the determining factor for the total purchase cost of scrap. Scrap is also a heavy and voluminous product of relatively low value, which increases the importance of efficient logistics (Kuusakoski, 2022).

Harbors

Harbors are an important factor for the total cost of using sea freight. Even though harbor fees, port structure and the allowed ship sizes may differ slightly between ports, European harbors are similar in many ways, and they can all handle scrap (JBF, 2022). However, the most important factor for a good scrap harbor is how fast it can handle scrap. If the port has a lot of experience of handling scrap as well as good scrap handling equipment, it handles the scrap faster and thus the handling costs will be lower (TSR 2022; Nilsson, 2022; MK Shipping, 2022). From a scrap sourcing perspective, a harbor is also better if there are many suppliers operating in the port (JBF, 2022).

An example of a harbor with efficient scrap handling is Rotterdam, which is among the largest scrap harbors in Europe (Stena Recycling, 2022; BIR, 2022). Rotterdam also has a large number of suppliers in the area, both large and small players, compared to for example Amsterdam where mainly a few larger players are operating (ZHD Stevedore, 2022). The ten largest scrap harbors in northern Europe can be found in Table 3.5. These large export harbors are approximately the same in terms of handling costs (EMR 2022; Nilsson, 2022; MK Shipping, 2022). Regardless of which harbor, it is very expensive to enter a port (Nilsson, 2022).

As mentioned in chapter 3.3.2, most large European scrap suppliers have certain export ports they operate in, and they have scrap yards in the port or nearby as well as an established logistics system to supply the export ports. For example TSR and EMR, European Metal Recycling, both have a number of harbors they supply their customers from, and it is problematic for them to supply scrap through another harbor than these (EMR 2022; TSR, 2022).

Table 3.5: The 10 largest scrap harbors in northern Europe (Stena Recycling, 2022; BIR, 2022).

Harbor	Country
Amsterdam	Netherlands
Rotterdam	Netherlands
Dordrecht	Netherlands
Antwerp	Netherlands
Gdansk	Poland
Hamburg	Germany
Riga	Latvia
Klaipeda	Lithuania
Liverpool	the UK

Tilbury	the UK

Sea freight fares

Sea freight prices are very volatile, they vary weekly and are directly dependent on supply and demand, it is a so-called perfect market (Nilsson, 2022; TSR, 2022). Thus, sea freight fares are very difficult to predict. The prices also vary on the different sea freight markets, which are both geographical markets and ship size dependent markets (Nilsson, 2022).

Consequently, the supply and demand situation at the time has the largest impact on the total sea freight fare. An example of how volatile the sea freight fares are is what happened during the financial crisis 2008. Before Lehman Brothers went bankrupt the daily fare was 200 000 USD. After they announced their bankruptcy the fare decreased to 5 000 USD. That equals a decrease of 97,5%. Smaller but still significant situations occur when there are cyclones in one of the large oceans. Vessels get stuck which affects the supply, and the prices can double from one week to the next (Nilsson, 2022). There are also seasonalities on this market, during winter and July the industrial activity is lower, and hence the demand for vessels is lower (TSR, 2022).

Ice classed vessels

The ice in Luleå is a big potential problem since the availability of ice-classed vessels larger than 20k Deadweight Tonnage, DWT, is limited and significantly lower than regular vessels, which also makes the prices high and volatile (EMR, 2022; Kuusakoski, 2022; JBF, 2022; Nilsson, 2022).

In order to operate in Luleå, you need the highest classification of ice vessels. These vessels can go to any port in Europe, e.g. from Luleå to Italy in the winter, but they prefer to operate in the north since this is where they are needed. Moreover, the supply and demand for them, thus also the prices, are highly dependent on the season. During summer, ice classed vessels compete with “normal” vessels, which have lower operating costs than ice classed vessels, and the margins for them are lower. During winter, the demand is much higher and the prices can rise significantly, closer to 100% than 50% more expensive than ordinary vessels (Nilsson, 2022; Stena Recycling, 2022). The few available ice classed vessels larger than 20k DWT will just give whatever rate they want, without any room for negotiation (World Steel Association, 2022).

Train freight operations

Trains can not compete with large bulk vessels when it comes to cargo of large volumes and low value, since trains can not carry as large volumes and are in general more expensive. However, trains are faster than boats, and also more environmentally friendly (Green Cargo, 2022).

Cargo carried by a train can be limited either due to the maximum weight of the train, the maximum volumes of the wagons or the maximum length of a train (i.e. number of wagons). A single locomotive train has a maximum weight of 2700 tonnes, including the weight of the locomotive itself and the wagons. Hence, the maximum cargo weight is 2000 tonnes. Moreover, topographics have a significant impact on the weight capacity, where flatter routes enable heavier cargo. The maximum volume of a wagon depends on the type of wagon, but one common bulk wagon is 82,4 square meters. Trains in Sweden have a maximum length of 670 meters, which equals around 30 wagons (Green Cargo, 2022).

The train infrastructure in Sweden is broad and connected, but also limited on certain routes. For example, it is possible to drive trains down to Germany and Italy, but no coastal railway exists between Luleå and Umeå. The main railway in Sweden, so-called Stambanan, goes to Boden, but it is limited to only one track north of Gävle. However, as a solution to potential disruption issues, priority on the tracks is given to actors with many and regular train departures (Green Cargo, 2022). Regarding costs, the total fee is based on a fixed cost, e.g. driver and locomotive, and a variable cost, including e.g. electricity and infrastructure (Kuusakoski, 2022). Furthermore, train freight in Sweden does not involve any significant seasonalities for a customer's price (Green Cargo, 2022).

3.5 H2 Green Steel

3.5.1 Steel production and scrap need

H2 Green Steel will produce steel through the EAF route and use a combination of scrap and virgin iron (DRI) as raw material. They will utilize a mix of several scrap grades; their own scrap arising, internal scrap, new scrap, E2 and E8, and old shredded and old sheared scrap, E40 and HMS. The total annual volumes of scrap to be sourced are around 1.7 million tonnes in phase 1 and 3.3 million tonnes in phase 2, when production has been scaled up.

3.5.2 Localization and logistics

The production site of H2 Green Steel will be located in Boden, by the Lule river. The site will have railway connections to Stambanan, and the nearest harbor Port of Luleå will also be reachable by rail. The maximum capacity of arriving trains is three per week. Luleå port is currently undergoing major renovations to be able to receive more cargo and larger vessels (Port of Luleå, 2021). H2GS are participating in port renovation discussions to ensure that the port will have the sufficient capacity and capabilities, but the exact future capacity and limitations are difficult to know at this stage. H2GS will have some storage possibilities in Port of Luleå as well as some storage at the production site where scrap can be stored. The planned storage will be able to cover one to a couple of month’s scrap need. H2GS has planned to use sea freight for the majority of scrap supply, and some volumes by train supply. However, the exact share between the two has not been decided on.

For sea freight, H2 Green Steel is investigating both using a shipping company and the spot market. With a shipping company, H2GS plans to use return logistics, i.e. to unload the finished steel product, the coils, of the vessel and then load scrap onto the vessel in the same port. To improve regularity and economies of scale, a selected couple of ports in northern

Europe are being evaluated. This is because many future customers of H2 Green Steel are located in the northern and central regions of Europe.

The Boden-localization means that H2GS has proximity to several other large industrial players in Sweden such as SSAB, who are building a new green steel plant in Luleå, LKAB and Boliden.

3.6 Summary of context description

The context description has been an extensive chapter describing the background empirical data to the thesis research.

Steel is a critical raw material whose demand is not likely to decrease. Instead, with the decarbonization trend, the demand for green steel is increasing. Green steel can be produced with hydrogen-reduced DRI and the EAF production route, which can utilize scrap and thus saves even more energy and resources. Scrap can be divided into new and old scrap where new scrap is generated in the steel mill or from the manufacturing of steel products and old scrap comes from end-of-life products and structures. Old scrap is a commodity and is generated, processed by scrap suppliers, and exported in large volumes every year. Old scrap can be divided into shredded (E40) and sheared (HMS), depending on how it has been treated. Quality of scrap is an issue due to the (increasing) levels of residual elements that can hamper the steel production and quality of the steel produced.

In Europe, the main scrap generating countries are the UK and Germany, and most exports go from the Benelux harbors as well as from the UK. There are well-established flows of scrap within Europe. The pricing is the same across Europe, but volatile and is greatly impacted by the actions of large buyers, such as Turkey. Since scrap purchasing price is the same, the total cost is highly impacted by the logistical cost of handling and transporting scrap from the origin to the steel mill. Scrap suppliers have established logistics operations often including having their own terminals in the ports as well as railway connections.

The choice of harbor can have a significant impact on the scrap operations and costs. European harbors are generally quite similar, but efficient handling is what makes one harbor better than another since that can enable cheaper harbor fees. Rotterdam is an example of a port with considerable scrap experience and thus efficient scrap handling. Although harbor costs are affecting the total cost of using sea freight, the sea freight fares are undoubtedly the largest impacting factor since they are extremely volatile and can change drastically from week to week, fully dependent on supply and demand. The fares for ice classed vessels are also very volatile, and during winter they are often very expensive due to high demand and limited supply. Regarding train freight, the fares are more stable. Train freight is however limited by the maximum weight and volume capacity, which compared to sea freight is small. Train freight is also highly dependent on the railway infrastructure.

H2 Green Steel will produce steel through the EAF route and have an annual scrap need of 1,7 million tonnes in phase 1. Due to their location in Boden, the scrap will have to be transported long distances, using a combination of sea freight and train freight.

4. MANAGERIAL PERSPECTIVES

This chapter contains important topics of which the industry experts used in this study have partly varying or contradictory opinions. The purpose of the chapter is to highlight the subjectivity in the scrap industry by demonstrating the different perspectives.

4.1 Scrap market

There are different opinions among the industry experts regarding the scrap market and its scrap supply. Below, a few key subjects are discussed.

4.1.1 What affects availability of scrap

According to the World Steel Association (2022), there is a logical reason behind the variations in scrap availability; when the cost of collecting scrap is high, i.e the logistical costs, the availability declines, and when it is cheap to collect scrap, the availability increases. The source also explains how the scrap availability is dependent on scrap price. The higher the price, the greater the scrap collection and hence larger available volumes. BIR (2022) partly agrees with this statement, in particular about how higher scrap prices attract more collectors.

Furthermore, TSR (2022) describes how the availability of scrap is dependent on seasonality. During the winter season there is less production and construction, thus less scrap is generated. Even though the southern parts of Europe are not as affected by winter as the northern parts, Christmas holidays still have an impact. BIR (2022) highly stresses the impact of seasonality, and estimates the scrap generation during winter is only 50% of the generation during summer. Moreover, according to the World Steel Association (2022), seasonality of scrap import in Turkey, and thereby scrap export from Europe, is existing but not significant. An example is the Ramadan period which might lead to lower demand, and during spring and thus high construction activity, the demand might be higher. JBF (2022), which has a Nordic perspective of the scrap market, continues and says there are seasonalities on the scrap market which are mainly weather dependent. During winter, for example, freight is more complex and expensive.

Subjectiveness of scrap availability
As mentioned, Rotterdam and Amsterdam are two of the largest scrap harbors in Europe, see Table 3.5. Port of Rotterdam (2022) says the total export volumes from Rotterdam is approximately 2.5-3 million tonnes per year, and the total volumes from Amsterdam is around 4-5 million tonnes per year. Thus, this source suggests Amsterdam has a larger scrap supply than Rotterdam. TSR (2022) on the contrary implies the volumes from Rotterdam are significantly larger than those from Amsterdam, and that Amsterdam only exports around 900 000 tonnes annually. ZHD Stevedore (2022) agrees Rotterdam is larger than Amsterdam, but the difference is small. Rotterdam exports around 2-2,5 million tonnes annually, and Amsterdam exports around 1,8-2 million tonnes annually. In conclusion, three industry

sources with many years of experience have remarkably contrasting views of scrap volumes in these two ports.

4.1.2 Scrap qualities

As mentioned in chapter 3, the quality of scrap is varying and subjective and dependent on, among others, the geographical market. According to Stena Recycling (2022), the scrap in Rotterdam has bad quality. EMR (2022) claims the quality of scrap in Benelux and northern France is similar to the UK, and that this scrap contains a relatively large share of residual elements such as copper.

Moreover, BIR (2022) argues countries that export large volumes to Turkey usually have a lower quality of the E40. This is for example the Baltics, south of Europe, and some suppliers in the UK. However, that does not mean Turkey is a "dumping market", they also use high quality scrap. The World Steel Association (2022) on the other hand, says Turkey does not buy that much E2 and E8, they buy less premium qualities. EMR (2022) agrees, and says Turkey is not as picky with the quality as other scrap consumers are. Further, for Kuusakoski (2022), the production cost for scrap that is exported to Turkey is 25% lower, which indicates a lower scrap quality. Unlike Turkey, Sweden has strict specifications of the copper content and historically, lower quality scrap is exported from Sweden, not consumed. Germany and the Nordics have in general good scrap quality and scrap quality control (Kuusakoski, 2022).

4.1.3 Scrap suppliers

The European scrap supplier market includes both smaller players and large established players with million tonnes of scrap sold every year. In this chapter some of these suppliers are described more in detail. The scrap suppliers that are further investigated are the ones deemed most relevant for H2GS, due to either their volumes or their geographical markets. Key information about these players are summarized in Table 4.1.

Table 4.1: Summary of scrap suppliers (EMR, 2022; Kuusakoski, 2022; TSR, 2022; Stena Recycling, 2022).

Scrap supplier	Geography	Volumes	Qualities	Other
EMR (European Metal Recycling)	The UK, western Germany, ports in the Netherlands	4 million tonnes generated annually in the UK, 2 million tonnes in northern Europe	10% E2 and E8, 50% HMS and 40% E40	The only scrap exporter from Tilbury (London)
TSR	UK, Germany, Belgium, Poland, Czech Republic,	7,5 million tonnes generated	60% HMS, 40% E40. E2/E8 is sold locally, not	The export ports are located in northern

	Netherlands, Slovakia, Russia, Sweden, Denmark, Austria	annually in total, of which 2.5 million tonnes is exported	exported	germany or in the Netherlands, Amsterdam is their largest port
Stena Recycling	5 main countries; Sweden, Norway, Denmark, Finland and Poland	2 million tonnes generated in total on their different markets	All, but mostly fragmented	Sweden is their largest market. No export from Poland
Kuusakoski	Estonia, Finland and Sweden	700 000 tonnes generated annually, of which 200 000 tonnes is exported	Stable availability of E40 and HMS, HMS Bonus varies	24 out of 40 sites are located in finland

Moreover, Figure 4.1 shows the key suppliers in Table 4.1 as well as 8 other suppliers and their scrap yard locations in circles of different colors and sizes. The larger the circle is, the more scrap yards exist in that area. The black squares symbolizes clusters of automotive assembly plants, i.e locations where new scrap, E2 and E8, is generated. As for the supplier scrap yards, the larger the square is, the more assembly plants exist in that area. Thereby, areas with large or many circles and squares indicate a larger supply of scrap.

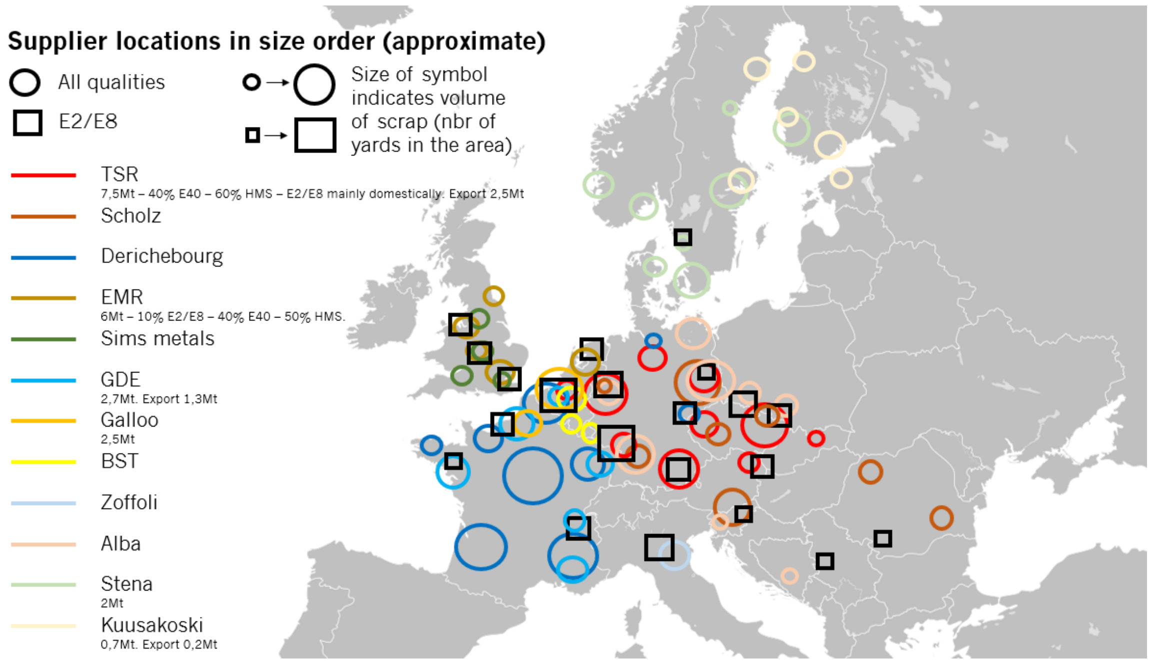

Figure 4.1: Suppliers, assembly plants and scrap yard locations (ACEA, 2022; TSR, 2022; EMR, 2022; Kuusakoski, 2022; Stena Recycling, 2022; Galloo, 2022; GDE, 2019).

4.1.4 Scrap sourcing relationships

According to industry sources, there are several ways of sourcing scrap. The most common way is to buy from a scrap supplier, which in turn sources from a scrap collector or directly from a steel consuming manufacturer. However, which strategy and relationship is best depends on the buyer's business and priorities.

JBF (2022) claims a contract with a supplier is a good idea if the volumes are large and flows are regular. However, since the scrap metal prices vary every week, it is not possible to tie a price to a contract, the contract will follow a price index. Moreover, a level of precaution is wise to have when doing business at the scrap market since some suppliers are not serious, the small ones in particular. The large European suppliers however are reliable. Further, JBF (2022) explains how this is also connected to storage capacity, if a buyer has a large storage, more supply risk might be acceptable compared to a buyer with little or no storage.

MK Shipping (2022) indicates a geographical perspective to scrap supply, and says that suppliers in Spain and Italy sell to Turkey, and not to a company in the Nordics. Companies in the Nordics should instead buy from Balticum, Germany, or other nearby markets.

The World Steel Association (2022) stresses the importance of having relationships and contracts with automotive manufacturers and other steel consumers, and explains how those relationships can open up a different market since it can enable a purchase of new scrap directly from the generator, without additional fees from a middleman. It is a key activity for steel producers. JBF (2022) agrees with the importance of relationships with manufacturers or key suppliers. JBF also adds that H2 Green Steel is early to the market, and that the company should use that "first mover advantage" and build relationships with suppliers.

Stena Recycling (2022) is not very positive towards the idea to establish partnerships with manufacturers or buy back scrap from steel consuming customers. They think it is too complicated since for example a car manufacturer will use several suppliers, but only get "one package" of scrap, and they will not want to divide that based on which supplier sold them which scrap.

Finally, since many European steel producers are changing to EAF, the demand for all scrap qualities will grow significantly in the next couple of years, and it will be even tougher to get E2 and E8 in particular since the supply of prime scrap is already very limited. JBF (2022) stresses how the car industry thereby is where it is important to build relationships, and that H2 Green Steel should use that some of their customers are automotive producers.

4.2 Scrap industry logistics

How to efficiently transport scrap is a complex problem and since the industry sources have contrasting ideas, one perfect solution does not seem to exist. Instead, scrap logistics can be efficient in different ways and with different strategies. In this chapter, scrap logistics topics are discussed in detail.

4.2.1 Nearby sourcing principle

As mentioned, scrap metal is a low value product and transport intensive. Thus, the transportation costs and the transport distances should be minimized. According to JBF (2022) there is a "nearby sourcing principle", which means one should always choose to source as locally as possible. For example, for a company operating in Sweden, scrap is cheaper to buy in Sweden since long transport distances increase the total cost of buying scrap, thus it is always more expensive to import. Stena Recycling (2022), BIR (2022), Nilsson (2022) and the World Steel Association (2022) agree that in general, the shorter the distance the less logistical costs you will have. However, that is not always possible due to limitations of supply, which is why for example Turkey sources from all over the world (Stena Recycling, 2022). Furthermore, the World Steel Association (2022) adds that Turkey's steel business is more profitable than in other countries, hence they can afford to transport longer distances. This is actually applicable to more buyers than Turkey. Scrap is moving around globally, despite high transport costs.

4.2.2 Sea freight

The question of mode of transport for scrap is widely discussed. Most of the industry sources agree that transporting in bulk vessels directly from northern Europe to Boden is the cheapest option, but not always the most practical, and there are other aspects than costs to be considered.

Sea freight strategies

The most common practice on the scrap market is that the supplier has responsibility for the transport, due to the convenience it implies for the buyer (JBF, 2022; TSR, 2022). However, if you have large volumes, it is cheaper to rent vessels yourself and control your freight. Though, this requires more work and employees. Outsourcing the transport to the supplier gives the buyer less control, so if a buyer has certain standards, for example sustainability requirements such as energy efficiency or CO_2 emissions, the buyer must communicate this to the supplier clearly. Overall, this comes down to a question of control, price and convenience (JBF, 2022).

Whether the buyer or the supplier has control of the transportation also depends on the buyer's storage capacity**.** With low stock, the shipments must be on time, thus better control of the transport is necessary and outsourcing may involve too much risk (JBF, 2022). Generally steel producers do not prefer to have too large stocks; 30-40 days consumption is common, and 1-2 months is maximum (Kuusakoski, 2022).

If a company decides to control the freight themselves, there are two types of sea freight strategies; using a shipping company or using a broker on the charter spot market. Most of the industry sources agree that if a business has large volumes and regularity, it is better to use a shipping company and have a long term contract. However, this option can come with a higher cost as well as some other disadvantages.

As mentioned, long term contracts with a shipping company is a good idea for companies with large and regular volumes. In these cases there is no point in using the spot market. Additionally, in order to save money on the spot market, you have to be very active and monitor the market constantly (Nilsson, 2022). Boliden (2022) agrees that you need to have large and regular flows of products to use a shipping company, but you also take on the risks induced by a long-term contract with this option. Thus, spot- and time chartered boats are better. In addition, chartering a boat on the spot market is the best option for one way sea transport, since the broker is responsible for chartering the boat on the way back. According to MK Shipping (2022), chartering one way at the time is the most economical alternative. TSR (2022) says chartering vessels on the spot market enables you to act when the prices are low and it gives you flexibility.

The difference between these two sea freight strategies is when using a shipping company, all costs are included in the fare except handling costs in the departure- and arrival port. Hence, for example port fares, distance and fuel are all included in the total fare even if some of them are variable. With a long term contract, the fuel price will follow an index. The daily rent will be more expensive the longer the distance is (Nilsson, 2022). Chartering a boat on the spot market is comparable to leasing a car, there is a fixed charter rate, but the buyer still needs to pay for fuel and parking, i.e port fees etc. Thus, to really minimize costs on the spot market, you also need to monitor the fuel prices (MK Shipping, 2022).

Bulk or container

The industry sources used in this study are not in complete agreement when it comes to whether bulk or container is the most efficient way to transport scrap. Bulk is more common and usually cheapest, but containers can be more suitable for prime scrap as well as for transports to Asia.

Kuusakoski (2022) and MK Shipping (2022) claim it is most common to transport scrap in bulk since it is more efficient and cheaper than transporting with containers. More detailedly, bulk is the best way to transport scrap since the containers themselves weigh too much to make the handling cost savings worth it (Nilsson, 2022). Handling costs are saved since the containers are easier to handle, thus faster. Nilsson (2022) estimates 15 tonnes per grab with containers compared to 1-2 tonnes per grab for bulk. The containers also have to be transported back in most cases. Nilsson (2022) does not know of any operator who transports scrap in containers.

Scrap has been transported in bulk historically, but it is difficult to say if bulk or containers are cheaper according to Stena Recycling (2022). It depends on the distance and on which markets the scrap is going to and from. Stena uses bulk to southern Europe, but for longer distances like to Asia, they use container vessels. This is because the large flows of containers from Asia to Europe must be transported back, and contributing to that return flow entails a significant cost benefit. EMR (2022) agrees and says E40 and HMS are normally transported in bulk, except for transports to Asia, where containers are more common since they are highly used there. Furthermore, Stena Recycling (2022) mentions E2 and E8 is not volume- and weight efficient in a container since it reaches the maximum weight long before it reaches full volume. E40 is more volume efficient.

Kuusakoski (2022) states all qualities of scrap are weight efficient, i.e they will reach the maximum weight capacity of a container. The density is not an issue. Thus, in regards to the weight efficiency factor, it does not matter if you transport with bulk or container. However, E2 and E8 are more common to transport in containers since they are premium products with high demand.

According to MK Shipping (2022), the question if bulk or container is the smartest way of transport depends on the volumes bought. If a buyer buys large volumes, the buyer competes with the Spanish, Turkish, and the US market, and transport in bulk. If a buyer buys small volumes, the buyer uses containers. It is about economics of scale. Also, scrap qualities can be combined on bulk vessels, but when you take it off the vessel, you want the qualities to be divided which can require some more handling.

Vessel size

Vessel sizes is another area where there are many differing ideas regarding the most efficient option. The industry sources used in this study suggest vessel sizes from 5k DWT up to 60k DWT, but several declare 20k DWT as a good general option.

MK Shipping (2022) means it is not possible to fill the larger sized vessel with scrap in one port, instead one must stop in several ports to add up to a full boat. Stena Recycling (2022) adds that it is very costly to transport scrap long distances on land in order to collect enough scrap to fill a boat in a port, but it is also very expensive to enter several ports as well as going with half-empty vessels. It is thus better to use smaller vessels, in order to be able to fill them up in one port only.

Nilsson (2022) agrees with the fact that it is very expensive to enter a port. Moreover, the main port fee depends on ship size, and not cargo weight. Hence, that fee will be the same regardless of how much cargo is added to the ship. Thus, even if the cargo is just added up with a few hundred tonnes, the full main port fee still has to be paid. Consequently, entering several ports to collect scrap is a bad idea. Furthermore, the unloading time per tonne and the time it takes for the vessel to go in and out of the port is the same regardless of how large the vessel is. Thus, for a smaller vessel, a larger share of the total time is going in and out. The total time in port per tonne is thereby shorter the larger the boat is.

Benchmarking sea freight strategies

JBF used to control their own transport, but outsources logistics today. They transport according to their needs regardless of season, i.e. they do not transport less during winter despite weather implications. On the contrary, they intentionally buy some material during winter, for example coal, since there is less boat traffic as a result of the ice (JBF, 2022).

Stena Recycling uses sea freight for markets in southern Europe. Stena does not own any vessels, since it is very complicated and time consuming to plan sea logistics. Stena does not believe many steel producers control or own their logistics. The core activity of Stena, nor for steel producers, is not transport logistics, which is why they outsource it. Stena uses a broker, and they charter ships on the spot market. They do not have large and regular flows enough to have long term contracts with a shipping company. In general, Stena's strategy involves owning as few vehicles as possible since it is more beneficial for them to rent according to their needs (Stena Recycling, 2022). TSR uses a broker and charter vessels on the spot market in order to be flexible. The main logistical cost is freight weight and type, since this varies. Other costs might be fixed (TSR, 2022).

The large industrial companies in the north of Sweden, like LKAB, SSAB and SCA, have designed a transportation strategy using a long term contract which is usually cheapest, however this includes risk mitigation for potential supply chain problems. For example, pay for delays caused by ice during winter (Nilsson, 2022).

4.2.3 Train freight

Train limitations

The use of train freight is naturally limited by the railway infrastructure. Boliden (2022) explains how the main railway in Sweden (Stambanan) goes to Boden, but there is only one track north of Gävle. If there is a problem on this track, it can cause delays for a week, and this is a major issue with using Stambanan. The source stresses safety stock is necessary if using this railway due to the significant risk of disruption. Green Cargo (2022) disagrees and does not think Stambanan will be a bottleneck, since companies will get priority on the railway if they have train transports often enough.

Another limitation for train freight is the use of bulk wagons. Scrap on trains is usually transported in bulk. A problem is that the handling, i.e. utilizing a bulk handling grab to collect scrap from each wagon, is quite slow and hence expensive. A technology is in development which enables scrap handling to be easier, by turning the wagons upside down. A problem left to solve is how to make the wagon strong and solid enough to carry the scrap (Green Cargo, 2022).

Containers are easier to load and unload to the train, however, the handling of getting the scrap out of the container can be time consuming. In addition, today there is no depot in the north of Sweden where Boliden is located, which means the train containers must be transported back to the south of Sweden, empty or not. However, Northvolt may create a container hub in the north of Sweden when their production facility is up and running (Boliden, 2022).

Moreover, a final major limitation with train freight is that efficient train freight requires freight in both directions. According to both Boliden (2022) and Green Cargo (2022), one way train freight is remarkably more expensive than using return freight due to the train fare structure. It is possible to combine scrap and coils on the same train, but it might require different wagons. It is also possible to share a train with another company with similar transport needs (Green Cargo, 2022).

Except for the potential limitations, Boliden (2022) is positive towards train freight. Boliden has built a system for train freight in Sweden, and implies that once the resources are in place for train freight, i.e wagons, drivers etc., the number of departures might as well be increased since most of the fixed costs are paid already. It is relatively cheap to increase the number of departures once a system is established.

The World Steel Association (2022) and Kuusakoski (2022) stresses the importance of using both train, boat and truck freight, and not rely fully on one transport mode. Trains are good in Sweden, and trucks are good in Norway and Finland (Kuusakoski, 2022). Finally, according to Green Cargo (2022), in order to minimize costs in train freight, volumes and capacity should be maximized.

Train vs truck

When it comes to whether train or truck is the cheapest mode of transport, a rule of thumb is if the distance is less than 50 km, truck is cheaper. On the contrary, long haul transports are cheaper with train. Though, railway does not exist everywhere, which is a significant limitation. Trucks are always more flexible (Nilsson, 2022).

Benchmarking train freight

Boliden (2022) explains how they chose to use trains due to the smaller volumes and faster transport compared to bulk vessels, and thus less tied up capital. Trains can take less cargo per departure, and thus the departures are more frequent. Boats can depart more rarely, but with much larger volumes. Thus, trains are a better fit if you want to transport lower volumes at the time but more continuous. However, Bolidens products are of high value while the value of scrap is relatively low. Furthermore, Boliden uses all modes of transport. They control the logistics within their own sites, but they buy transport for import and export to and from the sites. Since Boliden’s products are of high value, they can not use too large volumes in transport since that results in too much tied up capital. They use boats and trucks, but small sizes. They can not have too large storages either due to this. They use Helsingborg as a reloading hub as there is a depot of containers there. They have a thorough planning system to make sure no trains are empty or standing waiting. Boliden are also speditours, i.e other companies can rent wagons from them.

Stena Recycling has their own train wagons. This way of train transportation is economical, however, train as a transport mode is not very flexible due to e.g the limitations of the railway network. They use train in Sweden and other nearby markets. For longer distances they use sea freight (Stena Recycling, 2022).

4.2.4 Intermodal transport solution

An alternative to transport by boat from Europe all the way to Luleå is to stop at a port in the south of Sweden, Malmö, Helsingborg or Göteborg, and then transport the scrap by train to Boden. The main argument for this solution is that Luleå port will be a bottleneck, especially during winter when there is ice in Bottenviken, and by transporting by train from the south of Sweden, that bottleneck can be avoided. The main refutation is cost. It is cheaper to transport in bulk vessels all the way to Luleå, and thus avoid extra handling costs for moving the cargo from boat to train, as well as the more expensive train freight fares.

Nilsson (2022) is positive towards the train solution since he is certain Luleå port will become a bottleneck. For example, SSAB does not ship to Luleå, they use boat transport from south of Sweden only and use trains through Sweden. He also thinks it is a good idea to look into train transport all the way from Germany, especially if there are trains with coils already going that way, and thereby use the trains as return freight. Nevertheless, he believes it is cheaper to transport to Luleå by boat, but it may not be the most practical solution. Further, Helsingborg might have more experience with handling scrap than Luleå, but he does not think the cost difference will be significant. Another aspect here is winter. It might be clever to use Luleå port during summer, when there is no ice, and use Helsingborg during the winter. But again that has to be compared to train all the way, since e.g. Rotterdam to Helsingborg is a rather short trip.

Kuusakoski (2022) vouches for a hub in the south of Sweden as well, and to transport scrap up and coils down. This is a good idea since Luleå will become a bottleneck and thus it is not wise to put 100% of the cargo there.

4.2.5 Return flows

According to industry sources, several benefits come with using return freight. One of them is the imbalance in Sweden, with much more inbound than outbound cargo. According to Boliden (2022) this implies an opportunity to utilize the train return transports going back to Europe. A partner shipping company confirms it applies to sea freight as well, and explains how there is more cargo going to Bottenviken than from Bottenviken. Other benefits and limitations slightly differ between sea- and train freight, thereby they are discussed separately below.

Sea freight

Using return flows when transporting coils and scrap on sea vessels, i.e to transport coils from Boden to Europe, and then load the vessel with scrap and take it back to Boden, is not very common today according to the Port of Rotterdam (2022). Many industry sources perceive the idea as something new and innovative, but probably possible. Other industry sources think it might be problematic in practice. Thus, whether return flows is a good idea for scrap and coils or not is arguable.

The most important aspect of return flows is whether it is possible to transport coils and scrap on the same vessel, since the materials are very different. According to several industry sources, it is possible, it is just a matter of how to design and optimize the cargo (World Steel Association, 2022; Nilsson, 2022; MK Shipping, 2022; EMR, 2022).

Stena Recycling (2022) believes return flows are most likely possible, but they are skeptical since the coil and the scrap may have different flow speed and volumes. There is probably a regular flow of finished products, but less regular gathering of scrap. Additionally, it may not be possible to unload and load the vessel at the same spot in the harbor, since it is rare that coils and scrap is handled at the same spot. Coils should be weather protected, while scrap usually just lays in piles on the ground. Thus, switching docks in port might be necessary which involves extra fares. A commercial manager at Port of Rotterdam (2022) confirms this theory, and explains how coils and scrap are loaded in different terminals in the port which requires a switch if return flows are to be used. He adds that switching docks with large vessels is a security issue in the port, since the space is limited and there is a lot of traffic. Thereby the port tries to minimize dock changes.

Moreover, MK Shipping (2022) is positive towards return freight, but as revealed in chapter 4.2.2, implies in some cases it can be cheaper to charter a boat one way, and then charter the return boat on the spot market, instead of charter one boat two ways. This is due to the varying sea freight prices. Nilsson (2022) is responding to this argument by stressing the importance of understanding return flows from a broker's perspective versus a shipping company's perspective. There is a tendency for sea freight brokers to vouch for the spot market, since they get commission for every ship that is rented using them as a service. Thus with return freight they suggest renting one boat on the way down and another boat on the way back. For a shipping company however, they prefer to get a two-way contract in order to avoid empty vessels. He believes it is difficult to say what type of contract is cheaper long term, but if the business involves regularity, predictability of costs is most likely preferred, which is achieved to a larger extent by signing a longer contract with a shipping company. How economically beneficial that contract will become is solidly dependent on how the market will vary. Still, he believes it is more safe than using a broker and monitoring and acting based on the spot market. In general, he is positive towards the idea of using return flows.

According to JBF (2022), return flows are a smart way to lower costs and emissions by supplying scrap from those harbors you are shipping to anyway. It is also an enabler for buying scrap from customers. Kuusakoski (2022) agrees that return flows are a good idea, and adds the importance of trying to buy scrap from customers since it means the quality of the scrap will be fully secured.

Train freight

As explained in chapter 4.2.3, train freight requires return freight in order to be economical and efficient, and if utilizing the return fully the prices can become relatively low. Only infrastructure costs will be added for the return, hence there is barely a cost difference between full and empty return wagons (Green Cargo, 2022). Based on statements from MK Shipping (2022) and Green Cargo (2022), return freight is more essential for train freight than it is for sea freight.

4.2.6 How to minimize logistical costs

According to several industry sources, there are a few key factors in order to minimize logistical costs. These are to minimize the number of steps in the supply chain, maximize capacity, use economies of scale, create partnerships and contracts with suppliers and steel consumers, and minimize distance.

Minimizing the number of steps in the supply chain is crucial since stopping in another harbor or changing mode of transport involves handling, and handling involves costs (EMR, 2022). Maximizing the capacity is important to avoid paying for something that is not fully used. Further, economies of scale is an important factor for scrap logistics, and it is beneficial to transport large volumes. Establishing relationships with the right manufacturers is a key activity in order to secure scrap supply, especially of new scrap, and in order to get the right prices (World Steel Association, 2022). Also, if the volumes are large, the business is regular and the products are of low value, it is a good idea to have a contract with a shipping company (Nilsson, 2022).

Furthermore, EMR (2022) argues in order to minimize logistical costs, density must be investigated. The density before shredding is very low. That is why shredders are close to the population, transporting unshredded scrap is unfavorable since it is not weight and volume efficient. Scrap is really a logistic business more than anything else. MK Shipping (2022) adds the time in port is essential to minimize port costs, the shorter the better, since some charges are time based.

5. ANALYSIS AND MODEL

In this chapter, the research that has been gathered in the chapters above are analyzed. Firstly, qualitative hypotheses about which sourcing routes are most suitable is developed in order to create the basis for the quantitative model. Then, in this model, the most promising sourcing routes and transport modes are evaluated and total costs are calculated. Once the results from the quantitative model are final, those results are discussed and compared to more qualitative arguments to eventually head towards a recommendation.

5.1 Qualitative hypotheses

5.1.1 Areas with scrap supply

In chapter 3.3.2, under *geographical spread of supply,* information about the scrap market and scrap supply have been summarized in maps, see Figure 3.16 and 3.17, from which conclusions can be drawn about suitable areas for sourcing. As stated in this chapter, the countries with the largest scrap generation are Germany, France and the UK, but the areas which export a lot of scrap are slightly different due to the large flows of scrap from central- and eastern Europe to steel hubs in Germany and to export ports in Belgium and the Netherlands. Thus, the largest export areas are Benelux, Germany and the UK.

The map of supplier locations, Figure 4.1, in chapter 4.1.3 confirms this by demonstrating the scrap yard locations of large European suppliers, and how these locations match with the large export areas. Thereupon, the largest scrap supply can be found in the Benelux area, western Germany and the south of the UK. France and central Europe have good supply too. Northern Europe has a relatively small supply. Additionally, since old scrap exists where people and industry are, and new prime scrap is generated around automotive plants or other large steel product clusters like western Germany, these areas have supply of all scrap qualities. Moreover, Turkey buys a lot from these regions which is a major indicator for scrap availability.

In conclusion, in order for H2 Green Steel to source sufficient volumes of scrap, further analysis of transport routes from Benelux, Germany and the UK should be conducted.

5.1.2 Transportation options

Now that the best scrap supply areas are established, the next step is to decide how to transport scrap from those areas to H2 Green Steel's production plant in Boden.

The two main alternatives to choose from are sea freight only or sea freight and train freight. This is due to the volume limitations of train freight. As explained in chapter 3.4.2, under *train freight operations,* the maximum cargo weight of a train is 2000 tonnes. In the next chapter, 3.5, it is described how H2GS requires 1.7 million tonnes of scrap during phase 1, and that the current train freight capacity is three train arrivals per week. Hence, the maximum volumes that can be transported by train per year is:

$$2000 * 3 * 52 = 312000\ tonnes/year$$

Since H2GS requires 1.7 million tonnes annually, it is clear that train freight alone will not be able to provide sufficient volumes. Thus, at least 1.388 million tonnes will have to be transported with sea freight. Sea freight is in general better suited for large volumes of bulky, low value products, just like scrap metal. For example, a 35k DWT vessel can carry around 30 thousand tonnes of cargo, compared to a train that can only carry 6,7% of that (2000 tonnes).

Another benefit with sea freight in bulk vessels is the fact that it is cheaper over longer distances. The main disadvantage with using sea freight to transport scrap to Boden is the ice in Bottenviken during winter, and this requires ice classed vessels which are very expensive during the winter months. They are also difficult to get a hold of in sizes larger than 20k DWT. Other disadvantages are the varying sea freight fares and the use of Luleå Port which according to several industry sources will be a bottleneck.

An essential argument for using train freight is the environmental factor, where trains fueled by renewable energy sources emit significantly less carbon dioxide than bulk vessels fueled by bunker fuel. Other arguments for using train freight is to avoid the potential bottleneck in Luleå port and to avoid the issues caused by winter weather. Train freight is not affected by winter in the way sea freight is. In addition, train freight fares are considerably more stable than sea freight fares. The main disadvantage with train freight is the very limited cargo volumes compared to a bulk vessel. Furthermore, since scrap metal is a low value product, the capital tied up during transit is not very significant, which lowers the importance of a fast transport mode. Thereby this is a central benefit of train freight that is not really valued in this case. Besides, train freight has a risk of being limited by the infrastructure, which in Sweden can be inadequate for certain distances.

Nevertheless, since this thesis is primarily aiming at minimizing costs in the scrap supply chain, and sea freight is the cheapest alternative, sea freight will be the main transport option to look at in further analysis. Thus a larger focus will be put on sea freight in the model. However, train routes will be included in the model as well. Since several industry sources have indicated good railway infrastructure and favorable fares all the way down to Germany, one route down the Ruhr area is included. In addition, the cost of train freight is very dependent on the use of return flows, which in relative terms, sea freight is not. Hence, train return flows will be evaluated in the model. Finally, the model will also include a combination of sea- and train freight, where ships are used from the North sea to south of Sweden, and then trains are used through Sweden. This alternative aims at utilizing the benefits of sea freight, but still avoiding the potential bottleneck in Luleå port as well as the ice during winter.

Regarding vessel sizes, the model will include three sizes, 16k DWT, 25k DWT and 35k DWT. Out of the vessel sizes mentioned by industry sources, ranging from 5k DWT to 60k

DWT, 5k DWT is excluded since it is too small and thereby not economically beneficial, and 60k DWT is excluded since it will be difficult to fully utilize the cargo capacity without making several stops on the route, which is very expensive. Also, some ports do not allow vessels of such large sizes due to depth limitations. Hence, the relevant interval is approximately between 10k DWT and 40k DWT. Further, 35k DWT and 25k DWT were suggested by a partner shipping company and thus included. Lastly, 16k DWT was added to offer a slightly smaller vessel for the harbors with smaller scrap availability.

5.1.3 Suitable harbors

With sea freight considered to be the main transportation method for a majority of the scrap supply, the origin ports need to be decided in order to compare transportation and handling costs for the different routes.

A good scrap port has scrap experience, good scrap equipment, and multiple scrap suppliers with their own terminal in the port. With sufficient scrap experience, port turnaround times are lower which decreases cost and increases the overall transportation and logistical efficiency. Scrap handling depends on the stevedore companies in the port, and whether they utilize one or two cranes to load the vessel. The ports with deemed good scrap experience are the ports that have been frequently mentioned as good scrap harbors from industry sources, where many scrap suppliers are located and have their own terminals or scrap yards, and where large volumes of scrap are exported with regularity.

The ports exporting much of Europe's total scrap export volumes are the so-called ARAGT ports, ports in the UK (eastern, southern and western), and a few northern German ports such as Hamburg and Bremen. The 10 most relevant scrap handling and exporting harbors in northern Europe are presented in Table 3.5 in chapter 3.4.2 *Harbors* and consist of:

- Amsterdam
- Antwerp
- Dordrecht
- Rotterdam
- Gdansk
- Hamburg
- Riga
- Klaipeda
- Liverpool
- Tilbury

Port of Rotterdam is the most frequently mentioned port during interviews with industry sources. The port is described as having a specialized scrap business. The Port of Amsterdam is the second most mentioned scrap port. Dordrecht is closely linked to the Port of Rotterdam, and together with Amsterdam and Antwerp they are part of the ARAGT-cluster (also including Genth and Terneuzen). The Port of Antwerp is an expensive harbor and never mentioned in interviews, which is why it will be disregarded as a potential suitable harbor.

In the UK, Liverpool and Tilbury appear to have similar export volumes, as they have been given similar attention during interviews, have similar industrial and societal surroundings and scrap suppliers present in the port. Since Liverpool is on the west coast of the UK, a sea freight journey will be approximately 4 days longer, making this option disregarded. Port of Immingham is the scrap exporting port closest to the Nordics, on the east coast of the UK, and will therefore also be considered in the model.

Many sources have indicated that for larger volumes and larger ships, the Baltic ports will not suffice. The reason is mainly the limited supply of scrap in the area and because many of the ports have drought restrictions. This causes the scrap exported and transported from the Baltic countries and in the Baltic sea to do so in smaller vessels, 5-10k DWT. This excludes the above-mentioned ports Riga and Klaipeda. Poland is one of the main exporters of scrap within the EU, to Germany and Czech Republic (as can be seen in Figure 3.14) i.e. their scrap flows are not as linked to specific ports. However, since the geographical location of Gdansk is beneficial and it is considered one of the top ten scrap handling and exporting harbors in northern Europe it will be investigated in the model.

To conclude, the ports to further investigate with the quantitative model include Port of Rotterdam, Port of Amsterdam, Tilbury Docks, Port of Immingham and Port of Gdansk.

5.1.4 Return logistics

H2GS have a plan to utilize return logistics from their outbound shipments in a northern European system logistics set-up. Coils will be delivered to European customers through (probably) two main ports, and from these ports the scrap will be loaded and transported back to Boden. Based on the H2GS customer locations, a partner shipping company suggested Port of Rotterdam and Port of Rostock, a Baltic port in northern Germany. Due to this, Port of Rostock has been added as a potential scrap harbor to quantitatively investigate.

Interviewees have been negative towards the Port of Rostock, as it is not connected to any barges or river systems where scrap can be transported easily. Neither is there much scrap generation in the region due to a lack of industry and cities (TSR, 2022; Europort Rostock, 2022). However, being the innovative company that H2GS is, the potential to set up new flows in the scrap supply chain is not intimidating. Rostock will therefore be investigated despite the current situation of scrap exports. Gdansk is the Baltic harbor mentioned in the previous list that is closest to Rostock. It could be an interesting option to change Rostock to Gdansk, keeping one Baltic harbor and one North sea harbor. However, this depends on the final locations of H2GS customers that have not been set in stone, right now Rostock appears the better alternative. It is likely to be more expensive at first to supply scrap from Rostock, before a new supply chain and flow is in order. However, the option to not utilize return freight, i.e. take the ship ballast from Rostock to Luleå and hire another ship on the spot market from another harbor for scrap supply may be more expensive, and does not make sense logistically.

As described in chapter 4.2.5, return flows with train freight are highly beneficial. The cost increase for transporting goods on the return trip is very incremental, around 10%, and it only includes some additional costs for infrastructure with the heavier cargo load. However, it is not always easy to find suitable return bulk cargo going south from Boden. Today, coils and scrap require very different types of wagons. There is research being done for the potential of using combo wagons, but these initiatives require time and partnerships between the parties, i.e. the wagon manufacturer, railway and train provider, steel or cargo-providing company. The bulk wagons that are most commonly used today to transport scrap do not have any obvious cargo that can utilize the return freight, making the cost per tonnes much more expensive. Through collaboration with other industrial players across sectors in northern Sweden (such as LKAB, SSAB and Boliden), industrial sources have confirmed it may be possible to fill up the return freight of bulk cargo (Green Cargo, 2022; Boliden, 2022). Due to this the quantitative cost analysis will include both train freight with return cargo and train freight without return cargo.

5.1.5 Conclusion of hypotheses

Based on the arguments above, in total 30 routes have been developed, as shown in Figure 5.1. Most of the routes are sea freight routes, with vessel sizes 16k-, 25k-, or 35k DWT. Train routes to both Germany and within Sweden are also included, as well as 3 intermodal routes. There are several sourcing origins, mainly based on where there is scrap supply and quality of the ports, but also considering return flow possibility.

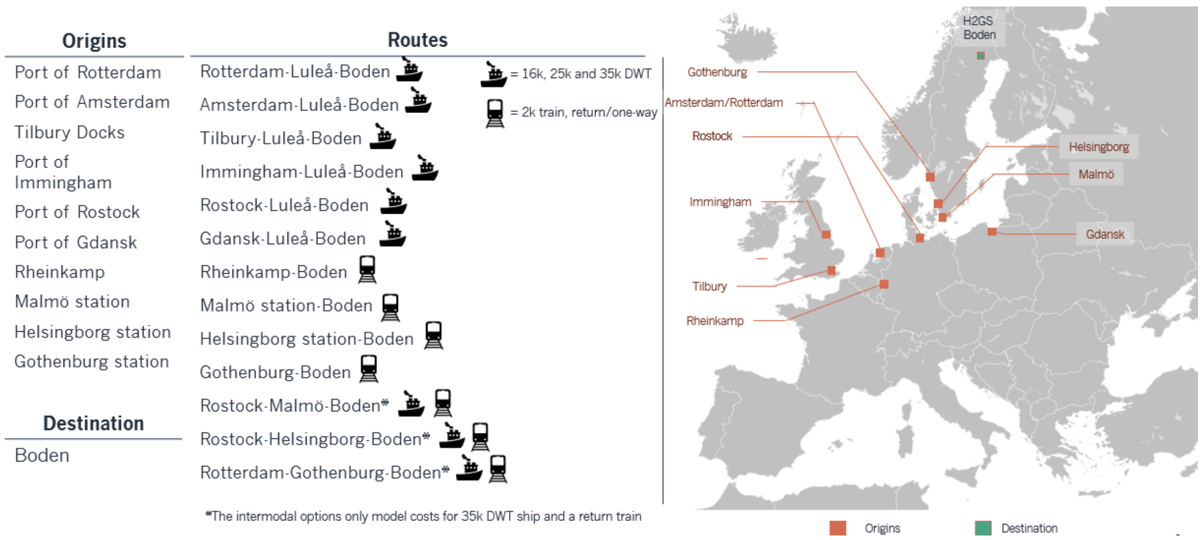

Figure 5.1: Evaluated routes.

5.2 Model

Screenshots from the model can be found in Appendix 1. It is built based on the arguments and hypothesis above, and includes two modes of transport and one combination alternative.

For each transport mode, several routes are investigated. The model also investigates the scrap availability in the origin region. The results of the model will be a cost- and scrap availability ranking for all the routes.

5.2.1 Quantitative data

The data in the model is gathered from a number of different sources. Most of the raw data is collected from interviews with industry experts, such as employees at scrap supplying companies, stevedoring companies and shipping companies. Further, a significant amount of data is derived from similar data sourced from a senior logistics consultant, and applied to raw data from interviews. Some of the data comes from internal H2GS sources as well. A summary of the data collection is demonstrated in Table 5.1 below.

The data collection process for this project has been complex for a few main reasons. Firstly, a considerable amount of data had to be collected in order to understand what further data was necessary. Thus, the data has been gathered successively throughout the whole project, which in some cases have impeded the progress as well as caused collection of irrelevant data. Secondly, roughly all data regarding scrap logistics is hardly reachable since it is not public and accessible online. In order to collect the data, contact with an industry source is practically crucial. Additionally, since little to no research has been conducted previously on this topic, a collection or summary of this type of data is hard to find. Thirdly, some of the data is subjective, and sources can claim different numbers on the same cost. Thereby, some data had to be checked with a third or fourth source, and in some cases an average had to be estimated.

Table 5.1: Data collection for model summary.

Type of data	Source	Comment
Handling costs	Interviews with stevedoring companies	Stevedoring companies are controlling cargo handling in ports
Logistical costs in different geographies	Senior partner consultant	Used to derive costs
Sea freight rate estimates	Partner shipping company	
Bunker fuel costs	Partner shipping company and industry experts	
Days in transit and in port	Partner shipping company	
Switching docks fee	Port of Rotterdam	Switching docks is necessary after discharging coils before loading scrap
Harbor fees	Interviews with Port of Rotterdam, Port of Rostock	

	and Port of Immingham, and partner shipping company	
Train freight rate estimates	Green Cargo	
Scrap availability in port areas	Interviews with scrap suppliers, Stevedoring companies, Port officers	

5.2.2 Model purpose and structure

As mentioned, the purpose of the model is to contribute with the quantitative output needed as a basis for the scrap sourcing recommendation. The model calculates the total cost of transporting scrap from a certain location, with a certain transport mode. It contains total cost calculations for 6 different sea freight routes, and 3 different ship sizes per route. It also contains total cost calculations for 4 different train freight routes, both one way and return, as well as 3 intermodal alternatives. In addition to the transport cost calculations, the model includes a scrap availability analysis in which the export volumes are stated for the relevant ports. This analysis is valuable since the scrap availability in the area around a port is a key factor for the potential sourcing volume from that port, which must be considered together with the logistical costs.

The model is divided into two main parts, output and input. The input sheets contain all raw data, calculations and approximations. The output sheets are only compilations and summations of the data in the input sheets, with the purpose of demonstrating the results clearly.

Moreover, the model is not only built for its current use, but also to enable future expansion. More transport routes and modes can easily be included and more data sheets as well since the cells are linked appropriately. Since H2GS are not starting steel production until 2025, some room for changes and development is valuable.

5.2.3 Quantitative results

Evaluation criteria

In the model, all the potential routes mentioned in 5.1.5 are included. In order to evaluate all of these routes, certain evaluation criteria were used, described in Figure 5.2.

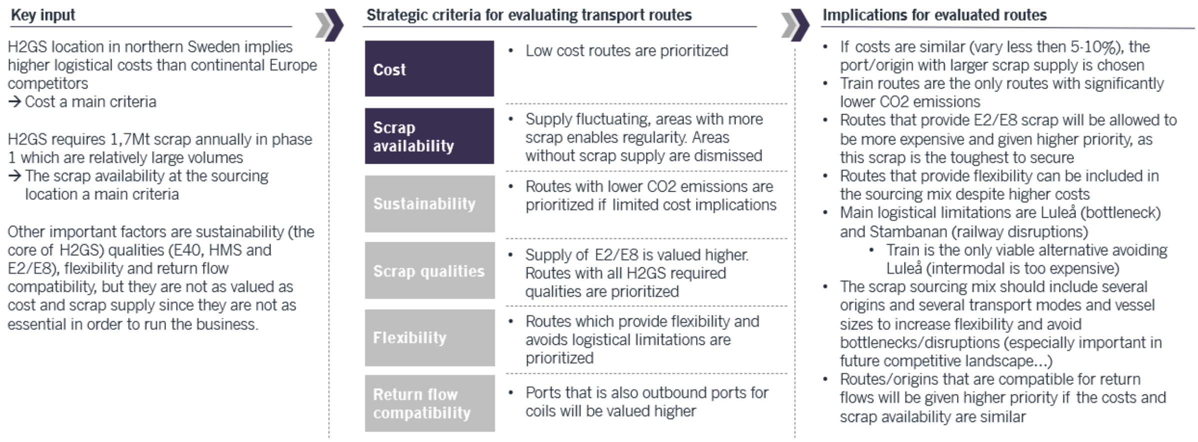

Figure 5.2: Evaluation criteria for sourcing routes.

Logistic costs and scrap availability are the aspects with highest strategic priority for scrap sourcing for H2GS. The reason for this is because H2GS is located far north in Sweden and already has higher logistics cost than their continental European competitors. Hence, H2GS needs to develop and use cost efficient solutions. Scrap availability is paramount considering the volumes H2GS plan to source. Also, when taking into account the increasing demand of scrap and the already very fluctuating availability, regions with larger volumes are more safe to have sufficient scrap supply available at the right time.

Besides cost and scrap availability, there are several other aspects that need to be considered when evaluating scrap sourcing routes, as can be seen in Figure 5.2. These are:

- Sustainability - Lowering CO_2 is core to H2GS and should penetrate logistics
- Scrap qualities - Supply of E2 and E8 is valued higher. Good if there is supply of all H2GS required qualities
- Flexibility - To avoid logistical limitations, e.g bottlenecks (Luleå port) or railway disruptions (Stambanan)
- Return flow compatibility - Ports that is also outbound ports for coils will be valued higher due to the potential of return flows

Results

Out of these 30 routes, 10 were decided to be the most relevant based on the evaluation criteria. In the sheet *Ranking* in the model, included in Appendix 1, all routes are sorted based on total cost and more detailed comments are provided for each route. In this sheet, the scrap availability is also stated. The chosen 10 routes will be presented in the following two tables, in Table 5.2 where they are ranked based on the logistical cost and in Table 5.3 where they are ranked on the scrap availability of the origin. The other factors' influence on the chosen routes are then discussed. Note that the logistical costs have been scaled to protect confidentiality.

Table 5.2: Ranking of top 10 scrap sourcing routes based on costs.

Route	Type of shipment	Costs (Euros/tonnes)

Gdansk - Boden	35k DWT vessel	40,20
Gdansk - Boden	16k DWT vessel	40,66
Rostock - Boden	16k DWT vessel	43,39 (indication of scrap price increase 30-40 euros/tonnes for transport to Rostock compared to other ports)
Immingham - Boden	35k DWT vessel	45,91
Tilbury - Boden	35k DWT vessel	46,42
Amsterdam - Boden	35k DWT vessel	46,76
Rotterdam - Boden	35k DWT vessel	47,04
Göteborg - Boden	Return train	52,98
Rheinkamp - Boden	Return train	66,79
Rotterdam - Göteborg - Boden	35k DWT vessel + return train	84,74

Table 5.3: Ranking of top 10 scrap sourcing routes based on scrap availability.

Route	Type of shipment	Scrap availability
Rheinkamp - Boden	Return train	~3 million tonnes
Rotterdam - Boden	35k DWT vessel	3 million tonnes export/year
Rotterdam - Göteborg - Boden	35k DWT vessel	3 million tonnes export/year
Amsterdam - Boden	16k DWT vessel	2,5 million tonnes export/year
Tilbury - Boden	35k DWT vessel	1 million tonnes export/year
Gdansk - Boden	35k DWT vessel	0,6 million tonnes export/year
Gdansk - Boden	16k DWT vessel	0,6 million tonnes export/year
Immingham - Boden	35k DWT vessel	0,3 million tonnes export/year
Göteborg - Boden	Return train	-
Rostock - Boden	16k DWT vessel	<0,1 million tonnes export/year

By combining the results in the two tables above, all routes can be plotted according to the cost and scrap availability as seen in Figure 5.3. The best options will have the lowest cost and the highest scrap availability, i.e., in the top left corner of the graph. These routes are in the inner, dark green, marked area of the graph. The next best options are included in the larger, light green area.

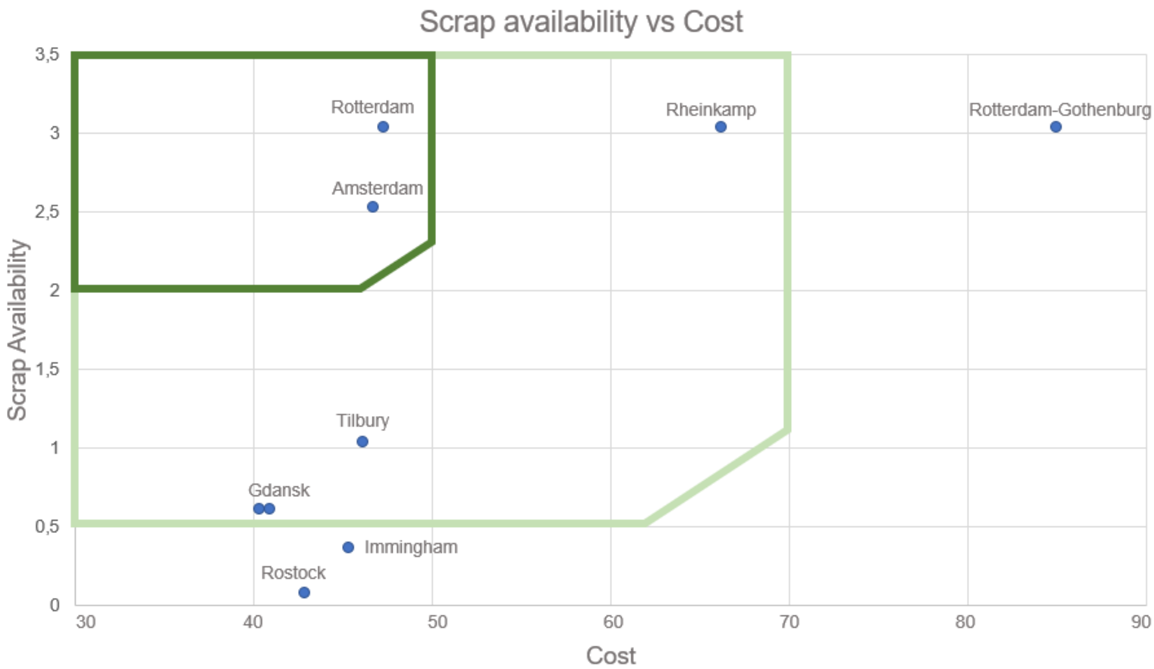

Figure 5.3: Routes plotted according to scrap availability and cost.

When including the remaining evaluation criteria, sustainability, scrap qualities, flexibility and return flow compatibility, several of the routes become more favorable. Train freight is better from an environmental perspective with less CO_2 emissions per transported tonne and km.

Flexibility is improved by using (return) trains, i.e. from Rheinkamp or Gothenburg or the intermodal option with a vessel from Rotterdam and then return trains from Gothenburg. This is because using railway shipping limits the bottleneck of Luleå Hamn. Flexibility is also improved by using a mix of harbors and a mix of ship sizes, to limit dependencies on a single harbor or certain available scrap volumes.

The origin area Ruhr, Rheinkamp, has a large supply of E2 and E8 scrap due to the automotive industry. This makes the Ruhr-train sourcing route a better option, since E2 and E8 scrap is often difficult to source. Rotterdam and Amsterdam are the largest export harbors and they have large scrap supply of all qualities.

By using shipping routes from Rotterdam or Rostock, there is return flow compatibility with current H2GS planned outbound coil flow. This is an environmental benefit that reduces the risk of a vessel going “ballast” i.e. without cargo, and potential cost benefit if a system logistics solution is set up with a shipping company. Return flows also eases sourcing new scrap from H2GS’s own customers, as it will be the same destination and origin of the transported goods. However, the potential to utilize return flows from Rostock are limited due to the limited scrap availability. A sales manager at TSR indicated a cost addition of 30-40 euros per tonnes in order to transport the scrap to Rostock (TSR, 2022).

5.3 Discussion

5.3.1 Key takeaways from model

By studying the quantitative results of the model, several key takeaways can be made.

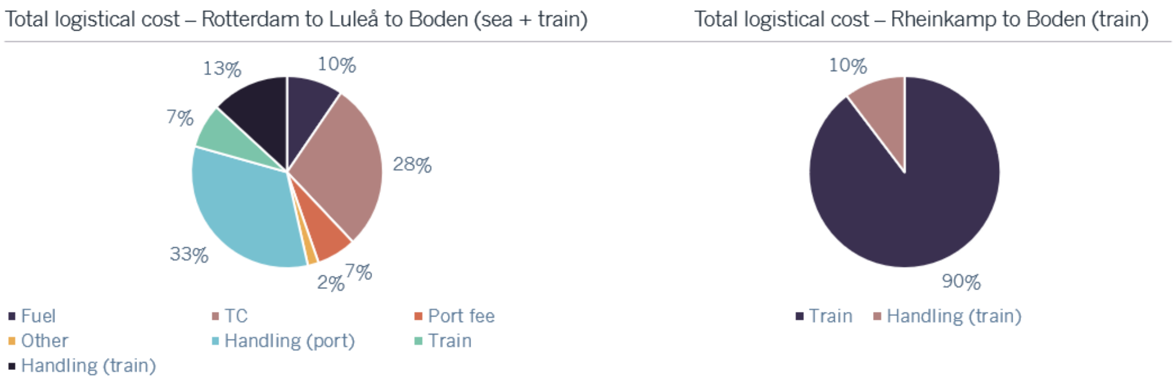

Figure 5.4: Logistical cost breakdown.

Handling costs are major

As can be seen in the example cost breakdown in Figure 5.4 above, handling costs constitutes the largest share of the total sea freight scrap transportation costs. Handling costs differ depending on the experience of the Stevedore-company and the labor rates in the country among other things. The handling cost will also influence the sea freight fares as the loading- and unloading rate determines the amount of time a ship will stay in the port, i.e. the number of days the ship is chartered. This means that in order to reduce logistical costs, it is important that the port has efficient and cheap stevedore operations that can ensure fast loading and unloading.

Shorter distance is cheaper

The results show that Gdansk is the cheapest option, followed by Rostock. These origin ports have the two shortest geographical distances to Luleå. A shorter distance means fewer days at sea, i.e. less time charter day-rates, as well as less fuel consumption. All three ship sizes from Gdansk are the cheapest followed by all three ship sizes from Rostock. After these routes the 35k DWT vessels from the remaining origin ports are ranked as cheapest. Immingham and Tilbury are then the cheapest options, both of which have a larger geographical distance to Luleå compared to Rotterdam and Amsterdam. The reason for this is because the handling costs in the port are cheaper in the UK compared to the Netherlands. Immingham and Tilbury have the same handling costs and between them, Immingham is cheaper due to the shorter distance. The same argument applies to Amsterdam and Rotterdam, where Amsterdam is somewhat cheaper due to the somewhat shorter distance to Luleå. The time-charter rate is paid per day, meaning that if one journey is only a few hours longer, the total time charter rate will be the same. However, fuel costs increase with larger distances.

To conclude, a significantly shorter sea freight journey is always cheaper, due to fewer charter days. With similar handling costs and similar distances, i.e. same days at sea, the shortest distance will be the cheapest option due to less fuel consumption.

Return trains can be cost competitive, when including the Luleå-Boden rail freight
One-way trains are very expensive, around twice as expensive as the average sea freight option and they are therefore excluded from the top 10 results. With cargo on the return trip however, i.e. a return train, the cost per ton is lower and can be cost competitive. The cost increase for a one-way train compared to a return train is 68%, i.e. return cargo is critical for efficient rail freight. In the comparison of all the investigated routes, the cost difference between return rail freight and sea freight becomes quite small, after adding the additional train transport and handling required between Port of Luleå and Boden for all sea freight routes. The rail journeys are around 10-20 euros more expensive per tonne.

Intermodal options expensive due to loss of economies of scale for short sea distances and increased handling
The most expensive scrap sourcing routes are the intermodal options, i.e., when utilizing both bulk vessels and bulk trains. All sea freight routes are in fact intermodal as they depend on railway transport between the port of Luleå and Boden, however this train transport is very short, and have not been considered as the intermodal options. The investigated intermodal routes are Rotterdam-Gothenburg-Boden, Rostock-Malmö-Boden and Rostock-Helsingborg-Boden. The reasons these routes become very expensive are due to the loss of scale economies with sea freight short distances and longer distance with the more expensive railway transport. Handling cost in ports (and days still in port) and port disbursement costs are dependent on the vessel size and cargo volume and will stay the same unrelated to the distance traveled, i.e. days in transit. For Rostock-Malmö and Rostock-Helsingborg, the days in transit are only one and the days still in port (for loading and unloading) are six. For Rotterdam-Gothenburg the relationship is three to six, i.e. the port days extend the days in transit.

Rail handling costs are cheaper than port handling, but rail transportation is much more expensive. The intermodal option is calculated with return trains, i.e. the cost is split between cargo in both directions, yet rail transport cost accounts for more than 50% of the total logistical cost for all intermodal options. Further, an aspect that was not accounted for in the model is the additional cost of storage for scrap transported with bulk vessels to be loaded onto bulk train wagons. Bulk trains have a weight restraint of 2000 tonnes, and maximum number of departures are three times a week, meaning that the scrap transported with bulk vessels to Gothenburg, Malmö or Helsingborg would need to be stored for weeks.

Scrap availability is the determining factor
The total logistical costs are quite similar between ports. However, scrap availability differs a lot. This means that the lowest cost is not always the best option, as there may not be sufficient scrap volumes to maximize the supply from that port. As can be seen in Table 5.2 in 5.2.3 *Quantitative results*, the total logistical cost to Boden varies with only 1,13 euros

(45,91-47,04) from origin ports Rotterdam, Amsterdam, Tilbury and Immingham. Immingham is the cheapest, followed by Tilbury, Amsterdam and finally Rotterdam. The inverse order is true in terms of largest volumes of scrap exports, which can be seen in Table 5.3 in 5.2.3 *Quantitative results*. Rostock has the lowest scrap volumes, and the largest German scrap supplier TSR indicated a scrap price increase of 30-40 euros per tonnes to export it from Rostock. In other words, if there are not enough volumes in the port, getting a scrap supplier to increase the volumes to the port is likely much more expensive than switching to a port with slightly higher logistical costs.

5.3.2 Qualitative and quantitative route evaluation

The results from the model highlights 10 routes as the most suitable for H2GS scrap sourcing based on certain criteria. The route with a 35k DWT vessel Gdansk-Boden is the cheapest route, but since the scrap availability is lower in Gdansk, a 35k DWT vessel might be difficult to fill with scrap. Thus, a 16k DWT vessel is a better fit in order to maximize capacity. The 16k DWT route from Gdansk-Boden is also the second cheapest route and the cost difference is very small. Generally, Gdansk is an efficient scrap harbor and a good sourcing origin, but there is limited supply of scrap due to large flows of scrap transported inland to for example Germany. Less scrap is thus exported through ports. Also, no large scrap suppliers operate in the area, instead there are smaller, more local players. Nevertheless, Gdansk is within the larger green circle in Figure 5.3, which indicates it is still a good choice.

The third cheapest route is Rostock-Boden with a 16k DWT vessel. However, Rostock has no scrap export currently, hence no scrap handling experience, and there are no significant suppliers in the area. Rostock is also not connected to the German inland barge system. Thus, Rostock is not suitable for scrap sourcing. This is also demonstrated in Figure 5.3 where Rostock is not included in any of the circles. As mentioned, it is possible for TSR to transport scrap from Hamburg to Rostock, but for a cost of approximately 30-40 EUR per tonnes. The only benefit of using Rostock is the potential for return freight.

Immingham-Boden with a 35k DWT vessel is also a relatively cheap route, but the scrap availability is low. Tilbury-Boden with a 35k DWT vessel is similar in terms of costs but the scrap availability is significantly larger. 35k DWT is the chosen vessel size since it is the cheapest alternative, and the scrap volumes are large enough to fully utilize the capacity. One negative aspect with Tilbury is the fact that there is only one supplier operating there (EMR). The UK in general has large export volumes due to a small steel producing industry, thereby they also export some volumes of prime scrap like E2 and E8. In Figure 5.3, Tilbury is included in the larger circle due to the relatively high scrap supply, while Immingam is not included since the scrap availability is too low.

Amsterdam-Boden and Rotterdam-Boden with 35k DWT vessels are outstanding routes in terms of scrap supply, both of them export around 2-3 million tonnes every year and all qualities required by H2GS are available. Both these routes are included in the top left circle in Figure 5.3, indicating routes with high scrap supply and low enough cost. In addition, Rotterdam, and potentially also Amsterdam, are possible to use for return freight. They are established scrap harbors with efficient handling and many suppliers in the area. However, Rotterdam has a larger number of suppliers as well as both small and large players, while Amsterdam mainly has a few large suppliers. 35k DWT is the chosen vessel size since it is the cheapest alternative, and the scrap volumes are large enough to fully utilize the capacity. A negative factor is the high competition, for example Turkey tends to buy large volumes from these ports.

The train freight route Göteborg-Boden is a good alternative for transport within Sweden. It is the cheapest train alternative and Göteborg is a city with relatively high industrial activity. However, the scrap volumes are still too low, and compared to sea freight routes it is expensive. Thus, this route is not included in a circle in Figure 5.3. Rheinhamp-Boden is more expensive, but the scrap supply is very large in this area, in particular this region generates large volumes of E2 and E8 due to the many automotive manufacturers. Hence, this route is included in the larger green circle in Figure 5.3. Train freight is the most environmentally friendly alternative, especially in Sweden where the energy is renewable. These routes will also avoid the potential bottleneck in Luleå, but they may imply issues on Stambanan. Moreover, to mix sea freight with train freight, especially to transport by train from a major scrap area like Ruhr, will give the total supply chain more flexibility and margins for potential logistics- or supply disruptions. In summary, increased flexibility, sustainability and securing the right qualities justifies the slightly higher cost on this route.

The last route is the intermodal route Rotterdam-Göteborg-Boden. This route is very expensive, thus not included in any circle in Figure 5.3, but it is the cheapest intermodal alternative. This route originates from a port with a large scrap supply, and it avoids Luleå, but these benefits will not outweigh the high cost.

Furthermore, there are some important factors that can be applied to several of the mentioned routes. Firstly, by using a 35k DWT vessel, the vessel can be loaded with two cranes in the port, which enables twice as fast loading. This is only possible for vessels larger than 20k DWT since the cranes can collide and thereby lose their efficiency if the vessels are smaller. Hence, all routes with 35k DWT vessels enable faster handling in port. Secondly, according to hypothesis 3 in chapter 3.4.1, larger volumes per route and regularity of transports decreases the logistical costs. This speaks in favor of using the 35k DWT vessel as it is the largest vessel option. It also suggests Rotterdam or Amsterdam as the best sourcing origin, as these are the areas with largest scrap supply and thus largest potential for both large volumes and regularity. Thirdly, hypothesis 6 in the same chapter (3.4.1) advises to minimize the number of steps on a route. This advocates usage of smaller vessels to areas with smaller scrap supply, such as using 16k DWT to Gdansk, instead of passing several harbors to fill up the vessel. Finally, as mentioned earlier in the analysis, return freight is essential for all train routes due to the cost structure of train freight where few costs are added on the way back. There is approximately a 68% cost increase if using one way freight. This stresses the importance of finding cargo to fill up the train on the way down to Ruhr, which can become a challenge. In addition, to avoid potential disruptions on Stambanan due to only one track north of Gävle, many and regular train departures may become a requirement in order to get enough priority on the railway.

In conclusion, as the model results also demonstrated, sea freight is the cheapest and most feasible option for the large volumes of scrap that H2GS requires. The most suitable sea freight routes based on the arguments above are Gdansk to Boden with a 16k DWT vessel, Rotterdam or Amsterdam to Boden with a 35k DWT vessel, and Tilbury to Boden with a 35k DWT vessel. In order to increase the flexibility, lower CO_2 emissions and secure E2 and E8 scrap supply, the train route from Rhur to Boden is a good complementary option.

5.3.3 Other qualitative aspects to improve scrap sourcing strategy

Increase sourcing volumes during summer

Even though sea freight in bulk is the best way of transporting scrap, it comes with certain issues. In this case, the major issue is the ice in Bottenviken during winter, and the requirement for ice classed vessels it entails. As mentioned, ice classed vessels are closer to 100% than 50% more expensive than normal vessels during winter, and they are very difficult to get a hold of in sizes larger than 20k DWT. This is corresponding to hypothesis 1 in chapter 3.4.1, implying it is more expensive to use a route with fewer operators, which is the case with ice classed vessels during winter in Bottenviken. Train freight on the other hand, is not significantly affected by winter, and it avoids Luleå port. Furthermore, scrap availability and logistics in general is highly affected by seasonality. The scrap generation during winter is lower, one source estimated it is only 50% of the generation during summer, which also affects the scrap prices. This is shown in Figures 3.18-3.21 in chapter 3.3.4, where the price peaks are in January. The sea freight is more expensive during winter due to weather conditions. Consequently, it is advisable to source larger volumes of scrap during sommer, when the scrap availability is higher, the scrap prices lower and the cost of freight is lower. Also, sea freight should be maximized during summer, and minimized during winter in order to avoid the need of expensive ice classed vessels. Instead, train freight should be maximized during winter, but not used as much during summer, to lower the costs. Below is a calculation example of this solution, assuming full capacity of train freight and no sea freight during December to February, and larger volumes sourced during April to September to compensate for the smaller volumes during winter.

Maximum volume with train freight December to February:

$$3 * 3 * 4 * 2000 = 72\,000\ tonnes$$

H2GS required volumes December to February:

$$1700000/12 * 3 = 425000\ tonnes$$

Volume left to source:

$$425000 - 72000 = 353000\ tonnes$$

Spreading these volumes over summer months (April to September):

$353000/6 = 58834\ tonnes$

Increase of volumes per summer month:
$1700000/12 = 141667\ tonnes/month$
$(141677 + 58834)/141667 = 41,5\%$

In summary, with this solution, 353000 tonnes of scrap is lacking during the winter months, and must instead be sourced during summer and stored. If spreading the lacking volumes over April to September, 41,5% more scrap must be sourced each month during this period. In chapter 3.5.2, it is stated that the planned storage will be able to cover one to a couple of month's scrap need. The volumes requiring storage equals approximately 2,5 month's scrap need (353000/141667). Thus, this might be possible to implement depending on what the exact storage capacity will be. The best train route to maximize during these winter months is Ruhr to Boden. An intermodal solution could also fulfill the same purpose, but intermodal solutions are very expensive.

Additional logistics advice

Hypothesis 4 in chapter 3.4.1 explains how the transport costs are lower if the business is less Lean, i.e larger volumes per route and less frequent transport rather than smaller volumes per route and more frequent transports. This speaks for using larger vessels as much as possible, in this case using 35k DWT vessels if the scrap supply allows. In general, since the prices and supply are very fluctuating on the scrap market, being Lean is difficult, and in particular expensive. The subjectiveness in the scrap market involves further implications regarding this, since the scrap prices and the available volumes are hard to predict and often not fully transparent, thus different sources can give significantly different numbers. This means a buyer must be flexible in terms of volumes and sourcing locations.

Another relevant hypothesis in chapter 3.4.1 is hypothesis 8, stating that the transport costs will increase if the quality of the infrastructure is low. This is mainly applicable to the mentioned potential disruption issues with Stambanan and Luleå Port, and it stresses the importance of having several transport modes in the supply chain and to avoid Luleå by using trains and avoid Stambanan by using ships.

Regarding sea freight, it has been mentioned earlier that the sea freight fares are very volatile, and the rates can increase 100-1000% simply by a storm or another external factor causing vessels to be unavailable. This entails a risk of high unexpected costs when using sea freight, as well as another reason to increase the number of transport modes. As can be seen in Table 5.2 in 5.2.3 *Quantitative results*, the logistics costs for the chosen train freight routes are around 10-20 euros more expensive per tonnes (i.e. 30-40% cost increase). Considering the volatility of sea freight fares, it is likely that the train freight will be cheaper many times, as these costs are more stable.

6. RECOMMENDATION - SCRAP SOURCING STRATEGY

This chapter will describe the recommended scrap sourcing strategy for H2GS, including the recommended routes as well as other logistics and scrap sourcing recommendations. The recommendations are based on quantitative and qualitative research and analysis.

6.1 Recommended sourcing routes

The recommended sourcing routes are stated in Table 6.1.

Table 6.1: Recommended sourcing routes.

Route	Details	Total log. cost (€/tonnes)	Annual scrap volumes (Mt)	Main rationale
Gdansk-Boden	16k DWT	40,66	0,6	Cheapest, medium scrap supply
Tilbury-Boden	35k DWT	46,42	1	Low cost, medium/high scrap supply
Rotterdam/ Amsterdam-Boden	35k DWT	46,76	3+2,5	Low cost, high scrap supply, return flow potential
Ruhr-Boden	2k tonnes return train	66,79	1-3	Low CO_2 emissions, E2/E8 supply, avoids bottleneck in Luleå

The evaluation criteria, the results from the model and the qualitative arguments in the section above clearly points at these 4 route alternatives. Together, these routes will secure sufficient volumes at a low cost, as well as increase flexibility and reduce risk of supply disruptions by using several transport modes and sourcing origins. Additionally, the train freight route will contribute to lowering the CO_2 emissions.

The scrap volumes to source from each origin is not specified in this recommendation since the scrap supply is very fluctuating, and a certain volume may not always be available at a certain location. In addition, the offers from scrap suppliers regarding volumes and prices can be unpredictable, and the pick up location can be in one harbor one week and another harbor the next. Thus, H2GS as a buyer has to be flexible to some degree.

In Figure 6.1, the routes are mapped, and a few suggested suppliers for every origin is included. The suppliers in Gdansk are smaller, more local players. EMR and TSR are large European suppliers, and as demonstrated in Table 4.1 in chapter 4.1.3, they export large volumes of scrap.

Figure 6.1: Recommended sourcing routes.

6.2 Other scrap sourcing recommendations

Below, recommendations beyond the sourcing routes are summarized.

6.2.1 Supplier relations

The demand for scrap is increasing in the coming years, with many European steel producers switching to EAF, which is scrap-based steel production. Even though Europe currently is the largest exporter of scrap, it is projected to become an importer in the future, as the generated scrap volumes are not projected to increase in any substantial way. In order to secure sufficient volumes, it is important to build supplier relations and plan for the future. By acting now, H2GS can have a first-mover-advantage and secure volumes before their competitors have switched to EAF. Another threat regarding this and a reason to create partnerships with suppliers is ArcelorMittal, a large German steel producer, who is vertically integrating and buys scrap suppliers.

Good supplier relations is also the main way to ensure the quality and content of the delivered scrap. Residual elements in the scrap damage the steel production and prevent the production of higher quality steel products. As different scrap customers, i.e steel producers, have different preferences, a good supplier relationship with trust and cooperation is necessary to ensure that H2GS receive scrap with the quality they need. In the future it might be necessary to jointly develop new scrap processing technology, as this development has been slow, and not aligned with the developing and increasing complexity of product materials.

Lastly, H2GS has an opportunity to utilize their customers, build strong relationships and buy back new scrap from them. With a decarbonization trend growing, driven by the automotive industry, H2GS can use their offering of green steel as leverage to buy back as much high quality E2 and E8 scrap as possible.

6.2.2 Sourcing during summer

Transporting scrap during the winter months with ice-classed vessels is significantly more expensive. This is especially true for the larger 35k DWT vessel, as the market supply of the larger ice-classed vessel is very limited, and the shipping market is a perfect supply-and-demand priced market. Scrap availability also follows seasonalities, with prices often peaking during January and sometimes only 50% of summer volumes available during winter, due to less industrial activity and less collecting activity. H2GS will have some storage both in Luleå Hamn and at their site in Boden. The recommendation is therefore to maximize the volumes in these warehouses before the winter begins. By sourcing more scrap during summer, spring and fall months and limiting the scrap inbound shipments during winter, ICV-transports are reduced which saves costs. Also, the train freight should be maximized during winter, when sea freight is expensive, while the departures during summer can be fewer, since sea freight is cheaper then.

6.2.3 Change Rostock to Gdansk

Rostock is currently one of the planned outbound coils shipping destinations. H2GS wants to utilize return flows as this makes logistics operations more efficient and environmentally friendly. Also, return logistics can enable receiving new production scrap, E2 and E8, from their customers. The customers of H2GS's steel are not set yet and hence their locations are not 100% known. Depending on the final locations of the central European customers, Gdansk may be an equally good or even better port compared to Rostock. Rostock is not a good scrap harbor, and therefore the recommendation is to change the outbound shipping to Gdansk instead if it is possible, as this will facilitate return flows.

6.3 Risks and challenges

The main challenge with the recommended solution is regarding return cargo for return train transports. One-way trains were excluded in the results as they were too expensive but return trains can be cost competitive, especially considering the volatility of sea freight fares. Scrap is transported with bulk trains, in wagons designed for bulk cargo. However, there is an imbalance in the amount of bulk cargo going north compared to going south in Sweden, with much larger volumes going north. In order to fill the cargo of the return transport, cooperation with other players in the region is necessary. This could include LKAB, SSAB and/or Boliden. Another risk with train freight is regarding railway issues. Without regularity and large volumes the train will not get priority on the tracks which increases the risk of disruptions. Thus, many departures might be a requirement.

For sea freight, the volatility of sea freight fares and bunker costs impose a great risk due to the difficulty to predict costs and the liability towards increased costs. Another risk is the sourcing with 35k DWT vessels during the winter as there may not be any ice classed vessels of that size available. 35k DWT vessels carry another risk which is that there may not be sufficient scrap volumes available in the port to completely fill the vessel. As mentioned earlier, scrap availability fluctuates a lot and the overall availability is predicted to decrease. If this is the case, an alternative would be to change to smaller vessel sizes, such as the 16k DWT. However, a potential risk with the 16k DWT vessel is that the loading rates and times will be slower due to the fact that they are only utilizing one crane. This will cause the 16k DWT shipments to be more expensive as relative to the cargo size, more time is spent in the port.

Lastly, a challenge with the proposed solution is that it will be difficult to source scrap in Ruhr, as the scrap generated in this region likely already has a set destination either through the very established flows of scrap from Germany to the export harbors in Benelux, or to a steel producer nearby.

7. CONCLUSION

The European scrap market is a complex market. It is the largest scrap exporting market in the world, and the prices and volumes of scrap are very fluctuating and highly dependent on seasonality. The largest buyers on the market, such as Turkey, have a remarkable power and influence. The geographical areas which export the largest volumes of scrap are the UK, Germany, Benelux and France. Moreover, scrap is a low value, bulky product which makes scrap a logistics business. Sea freight with bulk vessels is the most common way of transporting scrap longer distances. Furthermore, the demand for scrap is dramatically increasing due to the decarbonization trend and the transition from BOF to EAF, which will change the characteristics of the market in the future.

7.1 Insights from project

The first phase of this project was researching the scrap market and scrap logistics. Based on industry reports, interviews with industry experts, and insights from various other sources a thorough summary of the market and its most important aspects was conducted. A conclusion from this phase was the high level of experience of all the interviewed industry sources. All of them had been working in the industry for at least twenty years. This also reflects the market in general, where most of the players are very established. Another conclusion from this phase is the lack of transparency and the noticeable subjectiveness it entails, especially in terms of scrap volumes and qualities. As mentioned at several points earlier in this report, different industry sources tend to give distinct views and numbers regarding the same matters.

Developing a model and evaluating sourcing origins and transport modes was the second phase of this project. The knowledge gathered in phase one was formulated into hypotheses for the most suitable sourcing routes, and these routes were then further analyzed in the model where total logistical costs were calculated. A central insight from this phase was how difficult it is to estimate logistical costs. To collect data for the model, several additional interviews had to be held, and new sources had to be found. In addition, it was common among the interviewees to not be able to give straight answers or exact numbers. Consequently, many numbers in the model had to be approximated. This is applicable to industrial logistics in general, where actors usually approximate costs in order to rank alternatives, anticipating the approximation is accurate enough.

The final phase was to develop and recommend a sourcing strategy. In short, all qualitative information and quantitative results were compiled and evaluated, and four sourcing routes were recommended along with some other qualitative arguments. The conclusion from this phase is how important it is to include the whole picture, to use evaluation criteria and to consider limitations. Within logistics and especially in this industry, cost is not the only factor to examine, on the contrary, other factors are equally or nearly equally as important. Logistical limitations such as capacity restraints of a storage warehouse, a harbor or a railway will determine the feasible solution. For example, a cheap route is worthless if it can not provide enough scrap nor the right scrap qualities, and train is environmentally friendly but can impossibly provide sufficient volumes.

7.2 Future research

Conducting future research on the scrap market is very interesting, partly due to the change an increasing demand will result in, and partly due to the lack of research there is currently on this subject.

It will be in H2GS's interest to monitor how the market develops and adapt to upcoming changes. The market structure is key, in particular how the relationship between collectors, suppliers and steel producers will develop, as well as if the power balance on the market will change. This is important for predicting where to tie strategic relationships and securing supply. For example, as mentioned earlier in the report, ArcelorMittal is vertically integrating and acquiring suppliers. It is important to actively observe the market and see if other competitors will do the same.

The scrap generation areas and the geographical spread of supply is also critical to keep track of. What countries will be new importers or exporters, and which will remain what they are today? When demand is increasing and supply is not, it is likely a requirement for many steel producers to increase their sourcing radious beyond Europe and find new areas with enough scrap supply. Thus, following and researching the scrap generation and flows of scrap is essential.

Another area where future research should be conducted is regarding the optimization of H2GS's logistics. This study has been exploratory due to the uncertain project phase that H2GS currently exists in. There are no established flows of scrap nor any established suppliers. When the site is operating and has inbound scrap flows, there will be much more specific data to investigate. This could include stock levels per scrap grade, shipments per month, shipping volumes, safety stock levels and warehouse utilization and localization. All these logistical considerations can be optimized when there is more certainty regarding the volumes, suppliers and storage and transportation costs. I.e., future research can be directed towards optimizing each scrap grade inbound flow and their stock levels. Also, when the exact outbound and inbound shipping data exists, the potential return flows can be examined in detail to find the optimal strategy.

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APPENDIX 1

This appendix includes screenshots from the Excel model. In the sheet below, the routes are ranked by cost (lowest to highest) and the scrap availability and comments are added.

Route	Description	Total cost (EUR)	Cost including Luleå-Boden (EUR)	Scrap exports (Mt/year)	*Comments*
Gdansk-Luleå	35k dwt	29,83	40,20	0,6	*Gdansk cheap due to short distance and low handling costs*
Gdansk-Luleå	16k dwt	30,30	40,66	0,6	*May be a suitable vessel size considering smaller scrap supply in the area*
Gdansk-Luleå	25k dwt	30,98	41,34	0,6	
Rostock-Luleå	35k dwt	32,90	43,26	<0,1	*Rostock cheap due to short distance - NOTE extra fees for scrap supply might be added (15-20EUR/tonnes)*
Rostock-Luleå	16k dwt	33,03	43,39	<0,1	*Rostock is not chosen as an inbound port (although return flow possibility) due to low scrap availability*
Rostock-Luleå	25k dwt	34,05	44,42	<0,1	
Immingham-Luleå	35k dwt	35,55	45,91	0,3	*Cheaper, but small scrap supply, may not be able to fill a 35k dwt vessel*
Tilbury-Luleå	35k dwt	36,05	46,42	1	*Tilbury better than Immingham since similar cost but larger scrap supply*
Amsterdam-Luleå	35k dwt	36,40	46,76	2,5	*Large scrap supply, relatively low cost, return flow possibility, a few large suppliers*
Rotterdam-Luleå	35k dwt	36,68	47,04	3	*Large scrap supply, relatively low cost, return flow possibility, efficient scrap handling, many suppliers*
Immingham-Luleå	16k dwt	37,05	47,41	0,3	
Immingham-Luleå	25k dwt	37,45	47,81	0,3	
Tilbury-Luleå	16k dwt	37,70	48,06	1	
Tilbury-Luleå	25k dwt	38,06	48,42	1	
Amsterdam-Luleå	16k dwt	38,07	48,43	2,5	
Amsterdam-Luleå	25k dwt	38,32	48,68	2,5	
Rotterdam-Luleå	16k dwt	38,65	49,01	3	
Rotterdam-Luleå	25k dwt	38,74	49,11	3	
Göteborg-Boden	Return	52,98	52,98		*Good alternative for scrap transport within Sweden*
Helsingborg-Boden	Return	59,91	59,91		
Malmö-Boden	Return	61,72	61,72		
Rheinkamp-Boden	Return	66,79	66,79		*More expensive, but great E2/E8 supply, environmentally friendly, and avoids Luleå port (pot. Bottleneck)*
Rotterdam-Göteborg-Boden	Intermodal (35k dwt)	84,74	84,74	3	*Expensive, but best intermodal option*
Göteborg-Boden	One way	88,65	88,65		*One way train can be excluded from further analysis*
Rostock-Helsingborg-Boden	Intermodal (35k dwt)	89,02	89,02	<0,1	
Rostock-Malmö-Boden	Intermodal (35k dwt)	90,67	90,67	<0,1	
Helsingborg-Boden	One way	100,80	100,80		
Malmö-Boden	One way	104,03	104,03		
Rheinkamp-Boden	One way	112,32	112,32		

In the following sheets, the details of each route are included.

		SHIP 35k DWT					
	Unit	Rotterdam-Luleå	Amsterdam-Luleå	Rostock-Luleå	Gdansk-Luleå	Tilbury-Luleå	Immingham-Luleå
TOTAL LOGISTICAL COST/TON	*EUR/tonnes*	36,67674599	36,39670566	32,89872727	29,83278235	36,05094347	35,54540347
TOTAL LOGISTICAL COST/TON	*USD/tonnes*	**39,87**	**39,56**	**35,76**	**32,43**	**39,19**	**38,64**
Shipping cost	*USD/tonnes*	23,36	23,06	20,22	19,77	24,52	23,97
o/w Fuel	*USD/tonnes*	*4,79*	*4,65*	*3,54*	*3,31*	*4,96*	*4,77*
o/w Charter	*USD/tonnes*	*14,29*	*14,04*	*11,94*	*11,52*	*14,62*	*14,26*
o/w Port disbursement fees	*USD/tonnes*	*3,37*	*3,37*	*3,94*	*3,94*	*3,94*	*3,94*
o/w Other	*USD/tonnes*	*0,92*	*1,00*	*0,80*	*1,00*	*1,00*	*1,00*
Handling cost in ports	*USD/tonnes*	16,51	16,51	15,54	12,65	14,66	14,66
o/w Loading origin	*USD/tonnes*	*8,72*	*8,72*	*7,79*	*4,91*	*6,95*	*6,95*
o/w Unloading destination	*USD/tonnes*	*7,41*	*7,41*	*7,41*	*7,41*	*7,41*	*7,41*
o/w Switching docks origin	*USD/tonnes*	*0,38*	*0,38*	*0,34*	*0,34*	*0,30*	*0,30*
Train cost	*USD/tonnes*						
o/w Wagon	*USD/tonnes*						
o/w Transport	*USD/tonnes*						
o/w Additional cost for return	*USD/tonnes*						
o/w Other	*USD/tonnes*						
Train handling costs	*USD/tonnes*						
o/w Loading origin	*USD/tonnes*						
o/w Unloading destination	*USD/tonnes*						

	Unit	SHIP 25k DWT Rotterdam-Luleå	Amsterdam-Luleå	Rostock-Luleå	Gdansk-Luleå	Tilbury-Luleå	Immingham-Luleå
TOTAL LOGISTICAL COST/TON	*EUR/tonnes*	38,74271844	38,31920155	34,05082015	30,9776183	38,05728009	37,4507752
TOTAL LOGISTICAL COST/TON	*USD/tonnes*	**42,11**	**41,65**	**37,01**	**33,67**	**41,37**	**40,71**
Shipping cost	*USD/tonnes*	25,48	25,02	21,36	20,90	26,60	25,94
o/w Fuel	*USD/tonnes*	*5,17*	*5,02*	*3,74*	*3,49*	*5,37*	*5,15*
o/w Charter	*USD/tonnes*	*15,30*	*14,99*	*12,41*	*11,89*	*15,71*	*15,27*
o/w Port disbursement fees	*USD/tonnes*	*3,71*	*3,71*	*4,22*	*4,22*	*4,22*	*4,22*
o/w Other	*USD/tonnes*	*1,30*	*1,30*	*0,98*	*1,30*	*1,30*	*1,30*
Handling cost in ports	*USD/tonnes*	16,63	16,63	15,65	12,77	14,76	14,76
o/w Loading origin	*USD/tonnes*	*8,72*	*8,72*	*7,79*	*4,91*	*6,95*	*6,95*
o/w Unloading destination	*USD/tonnes*	*7,41*	*7,41*	*7,41*	*7,41*	*7,41*	*7,41*
o/w Switching docks origin	*USD/tonnes*	*0,50*	*0,50*	*0,45*	*0,45*	*0,40*	*0,40*
Train cost	*USD/tonnes*						
o/w Wagon	*USD/tonnes*						
o/w Transport	*USD/tonnes*						
o/w Additional cost for return	*USD/tonnes*						
o/w Other	*USD/tonnes*						
Train handling costs	*USD/tonnes*						
o/w Loading origin	*USD/tonnes*						
o/w Unloading destination	*USD/tonnes*						

	Unit	SHIP 16k DWT Rotterdam-Luleå	Amsterdam-Luleå	Rostock-Luleå	Gdansk-Luleå	Tilbury-Luleå	Immingham-Luleå
TOTAL LOGISTICAL COST/TON	*EUR/tonnes*	38,64817486	38,06961172	33,02757683	30,29737595	37,69638503	37,05009032
TOTAL LOGISTICAL COST/TON	*USD/tonnes*	**42,01**	**41,38**	**35,90**	**32,93**	**40,97**	**40,27**
Shipping cost	*USD/tonnes*	25,10	24,47	20,00	19,92	25,99	25,29
o/w Fuel	*USD/tonnes*	*5,17*	*5,02*	*3,70*	*3,43*	*5,38*	*5,16*
o/w Charter	*USD/tonnes*	*13,93*	*13,59*	*10,80*	*10,24*	*14,36*	*13,89*
o/w Port disbursement fees	*USD/tonnes*	*4,47*	*4,47*	*4,85*	*4,85*	*4,85*	*4,85*
o/w Other	*USD/tonnes*	*1,54*	*1,40*	*0,65*	*1,40*	*1,40*	*1,40*
Handling cost in ports	*USD/tonnes*	16,91	16,91	15,90	13,01	14,99	14,99
o/w Loading origin	*USD/tonnes*	*8,72*	*8,72*	*7,79*	*4,91*	*6,95*	*6,95*
o/w Unloading destination	*USD/tonnes*	*7,41*	*7,41*	*7,41*	*7,41*	*7,41*	*7,41*
o/w Switching docks origin	*USD/tonnes*	*0,78*	*0,78*	*0,70*	*0,70*	*0,62*	*0,62*
Train cost	*USD/tonnes*						
o/w Wagon	*USD/tonnes*						
o/w Transport	*USD/tonnes*						
o/w Additional cost for return	*USD/tonnes*						
o/w Other	*USD/tonnes*						
Train handling costs	*USD/tonnes*						
o/w Loading origin	*USD/tonnes*						
o/w Unloading destination	*USD/tonnes*						

	Unit	TRAIN ONE WAY Luleå-Boden	Helsingborg-Boden	Malmö-Boden	Göteborg-Boden	Rheinkamp-Boden
TOTAL LOGISTICAL COST/TON	*EUR/tonnes*	9,535064	100,7952	104,0333486	88,64967058	112,3237857
TOTAL LOGISTICAL COST/TON	*USD/tonnes*	**10,36**	**109,56**	**113,08**	**96,36**	**122,09**
Shipping cost	*USD/tonnes*					
o/w Fuel	*USD/tonnes*					
o/w Charter	*USD/tonnes*					
o/w Port disbursement fees	*USD/tonnes*					
o/w Other	*USD/tonnes*					
Handling cost in ports	*USD/tonnes*					
o/w Loading origin	*USD/tonnes*					
o/w Unloading destination	*USD/tonnes*					
o/w Switching docks origin	*USD/tonnes*					
Train cost	*USD/tonnes*	3,76	102,96	106,48	89,76	114,59
o/w Wagon	*USD/tonnes*	1,69	*N/A*	*N/A*	*N/A*	3,11
o/w Transport	*USD/tonnes*	1,62	*N/A*	*N/A*	*N/A*	111,48
o/w Additional cost for return	*USD/tonnes*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
o/w Other	*USD/tonnes*	0,45	*N/A*	*N/A*	*N/A*	*N/A*
Train handling costs	*USD/tonnes*	6,60	6,60	6,60	6,60	7,50
o/w Loading origin	*USD/tonnes*	3,30	3,30	3,30	3,30	4,20
o/w Unloading destination	*USD/tonnes*	3,30	3,30	3,30	3,30	3,30

		TRAIN RETURN				SHIP (35k dwt) AND TRAIN		
	Unit	Helsingborg-Boden	Malmö-Boden	Göteborg-Boden	Rheinkamp-Boden	Rotterdam-Göteborg-Boden	Rostock-Helsingborg-Boden	Rostock-Malmö-Boden
TOTAL LOGISTICAL COST/TON	*EUR/tonnes*	59,91319304	61,72450315	52,98493187	66,79057334	84,73548419	89,01809332	90,67292676
TOTAL LOGISTICAL COST/TON	*USD/tonnes*	**65,12**	**67,09**	**57,59**	**72,60**	**92,10**	**96,76**	**98,56**
Shipping cost	*USD/tonnes*					18,01	16,10	15,93
o/w Fuel	*USD/tonnes*					*2,90*	*2,04*	*1,98*
o/w Charter	*USD/tonnes*					*10,74*	*9,11*	*9,00*
o/w Port disbursement fees	*USD/tonnes*					*3,37*	*3,94*	*3,94*
o/w Other	*USD/tonnes*					*1,00*	*1,00*	*1,00*
Handling cost in ports	*USD/tonnes*					16,51	15,54	15,54
o/w Loading origin	*USD/tonnes*					*8,72*	*7,79*	*7,79*
o/w Unloading destination	*USD/tonnes*					*7,41*	*7,41*	*7,41*
o/w Switching docks origin	*USD/tonnes*					*0,38*	*0,34*	*0,34*
Train cost	*USD/tonnes*	58,52	60,49	50,99	65,10	50,99	58,52	60,49
o/w Wagon	*USD/tonnes*	*N/A*	*N/A*	*N/A*	1,56	*N/A*	*N/A*	*N/A*
o/w Transport	*USD/tonnes*	*N/A*	*N/A*	*N/A*	55,74	*N/A*	*N/A*	*N/A*
o/w Additional cost for return	*USD/tonnes*	*N/A*	*N/A*	*N/A*	7,80	*N/A*	*N/A*	*N/A*
o/w Other	*USD/tonnes*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
Train handling costs	*USD/tonnes*	6,60	6,60	6,60	7,50	6,60	6,60	6,60
o/w Loading origin	*USD/tonnes*	3,30	3,30	3,30	4,20	3,30	3,30	3,30
o/w Unloading destination	*USD/tonnes*	3,30	3,30	3,30	3,30	3,30	3,30	3,30