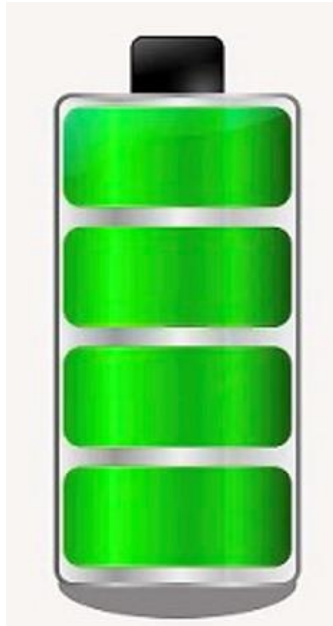




**CHALMERS**



# **Swappable batteries used as power source to reduce emissions in the shipping industry**

Interviews with Swedish shipping companies

Bachelor thesis for Marine Engineering Program

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CHALMERS UNIVERSITY OF TECHNOLOGY  
Göteborg, Sweden, 2023



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Department of Mechanics and Maritime Sciences

Chalmers University of Technology

Göteborg, Sweden 2023

## **PREFACE**

The authors of this report are two students who have studied the marine engineering programme at Chalmers University of Technology in Gothenburg for four years. During the study period, our interest in innovative technical solutions has increased, both in terms of the environmental aspect and technological development. We came across a new perspective within ship electrification in form of swappable battery solutions and decided to dedicate our bachelor thesis to investigate the Swedish shipping companies' opinions in this matter. The writing process has lasted from the beginning of January to the end of May 2023. During the writing process, we learned a lot about the topic but also about ourselves.

We would like to extend our sincere thanks to the representatives of the shipping companies that agreed to our request for interviews. You had an extremely accommodating attitude to our study which we really appreciated. Your competence and experience built the foundation of our research. We would also like to give a special thanks to our supervisor, lecturer Magnus Hellman, who has been very supportive and helpful throughout the whole process.

Gothenburg, May 2023

Jonas Andersson & Petter Elmdahl

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## **SAMMANDRAG**

Med tanke på dagens fokus på miljön och på klimatförändringarna, står det klart att sjöfarten behöver byta riktning från fossila bränslen mot mer hållbara alternativ. Här är eldrift ett lovande alternativ, men ett av många frågetecken är hur laddningen av batterierna ska gå till på ett praktiskt och klimatvänligt sätt. Utbytbara litium-jonbatterier i containerform som laddas iland har utvecklats och används bland annat inom flodtrafiken i Holland. Denna rapport undersöker om tekniken skulle vara möjlig att implementera inom svensk sjöfart. Rapporten presenterar intervjuer som genomförts med Svenska Ro-Pax rederier för att undersöka om de tror att utbytbara batterier skulle vara ett alternativ för dem och vilka för- och nackdelar rederierna belyser gällande underhåll, infrastruktur, säkerhet, logistik och teknisk kompetens. Resultatet visar att svenska rederier är positivt inställda till denna teknik, dock visade det sig att det krävs bättre logistiklösningar och batterier med större lagringskapacitet för att detta skall kunna bli ett attraktivt alternativ.

**Nyckelord:** Utbytbara batterier, grön energi, fartygsbranschen, alternativa energialternativ, sjöfarten, Ro-Pax.

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## **ABSTRACT**

With today's focus on the environment and the climate change, it is obvious that the shipping industry needs to move away from fossil fuels to more sustainable alternatives. Electric propulsion is a promising option, but one of many questions is how to charge the batteries in a practical and climate friendly way. Swappable lithium-ion batteries in container form have been developed and are used for river traffic in the Netherlands. This report examines whether this technology can be implemented in the Swedish shipping industry. The report present interviews with Swedish Ro-Pax shipping companies, to find out whether they are considering swappable battery container solutions to be an alternative for their operation, and the pros and cons in terms of maintenance, infrastructure, safety, logistics and technical competence. The results show that the Swedish shipping companies is positive towards this technology, but better logistics solutions and batteries with higher energy storage capacity are needed for this technology to become an attractive alternative.

**Keywords:** Swappable batteries, green energy, shipping industry, alternative energy, shipping, Ro-Pax.

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## ACRONYMS AND TERMINOLOGY

CII	Carbon Intensity Indicator
CO <sub>2</sub>	Carbon Dioxide
Current Direct	Innovation project by EU
DNV GL	Det Norske Veritas Germanischer Lloyd, classification society
ECA	Emission Controlled Areas
EU	European Union
GHG	Greenhouse Gases, primarily Carbon Dioxide, Methane and Nitrous Oxide
HFO	Heavy Fuel Oil
ICE	Internal Combustion Engines
IMO	International Maritime Organization
kWh	One kilowatt of power for one hour
LFP	Lithium Iron Phosphate
Li	Lithium
LiB	Lithium-ion Batteries
Li-ion	Lithium ion
LNG	Liquified Natural Gas
Long Range	71-350 nautical miles
MARPOL	The international convention for the prevention of pollution from ships
MDO	Marine Diesel Oil
Medium Range	5-70 nautical miles
MW	Megawatt, Unit of power
MWh	One Megawatt for one hour
NM	Nautical Miles (1852m)
NMC	Lithium Nickel Manganese Cobalt Oxide
NOVEC	Gas based fire extinguishing system
NO <sub>x</sub>	Nitrogen Oxides
PM	Particulate Matter
Ro-Pax	Roll on-Roll-off / Passenger ship
SEEMP	Ship Energy Efficiency Management Plan
Short Range	>5 nautical miles
SO <sub>x</sub>	Sulphur Oxides
UN	United Nations
ZES	Zero Emission Service

# 1. INTRODUCTION

Climate change due to carbon dioxide (CO<sub>2</sub>) emissions from burning fossil fuels is one of the most challenging problems facing modern society (Doyle & Johlas, 2017). CO<sub>2</sub> is the main contributor to the greenhouse effect which leads to global warming. As earth's temperature rises, a variety of impacts will change the aspects of the climate, including hotter summers, warmer oceans, melting polar ice, and increased storm activity (United Nations, 2015). Due to fossil fuel consumption and its environmental impact, the shipping industry is gradually moving towards the implementation of decarbonising measures as defined by policies and regulations. The awareness of the environmental and climate change together with technical developments, have led to better options that results in lower human impact on the planet. In the shipping industry, switching from traditional fossil fuels to renewable energy alternatives are more important than ever as environmental concerns grow (K. Andersson et al., 2016). Because of this matter, the International Maritime Organization (IMO) and local governments have implemented stricter regulations when it comes to emissions emitted from the shipping industry.

According to Jeong et al. (2020), electric propulsion using battery systems is seen as one of the most credible options to address the emission issue and to achieve decarbonization of the shipping industry. Charging the batteries from the onshore power grid can radically reduce emissions. Over the past few decades, there have been great strides in developing rechargeable lithium-based batteries. The range of battery powered ships is still limited, but the discovery of new electrode materials and new storage mechanisms has significantly improved battery performance (Sun et al., 2016). The main requirement to make electrification of the shipping industry into a serious alternative is a stable supply of renewable energy. To achieve close to zero lifecycle emissions, the electricity itself must be generated from renewable energy sources (Anders, 2019). The conventional way to charge the ship batteries is through a generator on board, or by connecting a cable to the land-based power grid. The main disadvantage with the ship generator is that it is commonly fuelled by fossil diesel. One downside with shore-based charging of large stationary ship batteries is the extra load which the power grid is exposed to. Another issue is the time it takes to charge the batteries. One alternative to solve some of the challenges is to use mobile, swappable batteries instead of stationary. Using swappable batteries has the advantage that an empty battery can be swapped for a previously fully charged battery in a short time, minimizing the drawback of long battery charging times (Amiri et al., 2018). The charging of the battery can now be performed during a longer period and at a more favourable point of time, which can improve battery life and reduce the stress on the electric grid. According to Kopsakangas-Savolainen et al. (2017), the potential to reduce GHG emissions is clear by shifting electricity consumption to off-peak demand hours or by using electricity produced primarily with low GHG emission technologies. Initiatives already exists for developing a network of battery swapping stations for inland shipping in Europe. In those projects, Wärtsilä has developed and delivered a swappable battery container solution that enables the ship to travel with low climate impact when charged with renewable energy (Piña Rodriguez, 2021). Ro-Pax ferries is predictable and travel relatively short and fixed routes every day DNV GL (2020a), but encounter challenges because of short port stays. This makes them a viable candidate for the implementation of the swappable battery technology.

## 1.1 Background

For decades, the shipping industry has been burning fossil fuels without regulations and with no second thoughts of the future generation or environmental impact. This has led to the release of CO<sub>2</sub>, particulate matters (PM), sulphur oxides (SO<sub>x</sub>), and nitrous oxides (NO<sub>x</sub>) into the atmosphere (K. Andersson et al., 2016). The result of this is global warming, acidification of oceans, soil and freshwater, eutrophication of ground and waters, and a negative impact on human health. On July 15<sup>th</sup>, 2011, IMO adopted for the first time internationally binding measures to improve the energy efficiency of ships. Over the past decade, the IMO has taken further steps, including regulatory action and the adoption of a GHG strategy. To assist in their implementation, IMO is conducting extensive capacity building and technical assistance programs, including several global projects. As a part of the UN organization, IMO is working towards the 2030 agenda for a sustainable transportation. The 2030 Agenda is an action plan implemented by the UN to move towards a sustainable society for people, planet, and prosperity (IMO, 2023). The goals that concern the shipping industry is mainly:

Goal 13: Climate change is one of the greatest challenges of our time. Much of the increase in greenhouse gas emissions into the atmosphere is due to the way fossil fuels are extracted, converted, and used. Increased emissions threaten global warming of more than 2 degrees Celsius on average, pose risks to ecosystems, ocean acidification, human security, food production, water supply, health, and weather, and increase the risk of natural disasters. It can have a serious impact on growth.

Goal 14: It is important to continue to develop countermeasures and management tools to combat known impacts such as pollution, depletion, and the depletion of natural resources. Protecting and restoring coastal and marine areas is an important action not only to conserve biodiversity and fisheries resources, but also to build resilience to climate change (United Nations, 2015).



Figure 1 - Sustainable development goals (United Nations, 2015).

## **1.2 Aim of the study**

The aim of this report is to investigate Swedish shipping companies' opinions to battery swapping technology as a part in a possible electrification of their fleet. What difficulties and what possibilities with battery swapping can be seen with regards to the safety, infrastructure, logistics, maintenance of machinery and technical competence.

When comparing the shipping companies' answers, do they have similar opinions about implementing a swappable battery solution or do their opinion differ depending on ship types, power output and/or route distance.

## **1.3 Research questions**

Based on the initiatives in Europe for developing a standard for swappable batteries, what are Swedish shipping companies' opinions of the idea of using swappable battery technology as a solution for electrification of their fleet?

With regards to the technical maintenance, infrastructure, safety, logistics and technical competence aspects:

- What would it take to implement this technology?
- What challenges can be seen by the shipping companies?

## **1.4 Delimitations**

Only Swedish shipping companies operating Ro-Pax-vessels that is visiting Swedish ports will be targeted. This is because of the limited capacity in today's battery technology. Due to the complexity of the economical perspective regarding present and future prices of fuel, electricity, materials and components for batteries, taxes etc, the economical perspective will not be discussed in the report. Neither will the environmental impact from the production of batteries be discussed.

## 2. THEORY

This chapter explains the regulations regarding emissions, where the emissions from the shipping industry come from, possible options for reducing emissions and different battery solutions to give the reader an understanding of the subject. It also explains the concept of swappable battery technology in the shipping industry and the importance of using renewable energy.

### 2.1 International climate goals and regulations

The United Nations is a global international organization founded in 1945 and has currently 193 countries as members. It's an organization that works for world peace, human rights and for a sustainable future (United Nations, 2023). The Paris Agreement is a legally binding international agreement on climate change, adopted by 196 countries at the United Nations Climate Change Conference in Paris 2015. The Paris Agreement states that global temperature rise must be kept well below 2°C and efforts must be made to limit it to 1.5°C. This is done primarily by reducing greenhouse gas (GHG) emissions. Another part of the agreement concerns increasing our capacity to adapt to negative impacts and to cope with the damage and losses caused by climate change (Regeringskansliet, 2020). As a part of the UN, IMO's initial strategy to reduce GHG emissions from shipping sets some important goals. One of the goals is to reduce the annual GHG emissions from international shipping by at least half by 2050 compared to 2008, and to eliminate GHG emissions from shipping as early as possible during this century. Another part of the strategy is to reduce the carbon intensity of international shipping by at least 40% on average by 2030, and an 70% by 2050, compared to 2008. Carbon intensity is a measure of how clean our energy is. It indicates the number of grams of CO<sub>2</sub> emitted to produce one kilowatt hour (kWh) of energy. Energy generated from fossil fuels is more carbon intensive as the process emits large amounts of CO<sub>2</sub> (IMO, 2018). IMO states that GHG emissions from the shipping sector reached 1,076 million tons in 2018. Furthermore, IMO projects that in a business-as-usual scenario, the GHG emissions related to maritime transport will increase by 50-250% by 2050 compared to 2008, as maritime trade is expected to increase by 40-110% (IMO, 2020).

In November 1973, IMO adopted MARPOL (the international convention for the prevention of pollution from ships). The intention is to prevent and regulate pollution of the environment from ships, both from operational and accidental causes. Annex VI (regulations for the prevention of air pollution from ships) covers air pollution. It states requirements for control of emission from ships and regulations regarding carbon intensity of international shipping. Since 1<sup>st</sup> of January, 2020, the sulphur content in the fuel is limited to 0,5 % from the former 3,5% in all seas to reduce the SO<sub>x</sub> emissions. An exception is in the Emission Controlled Areas (ECA). In ECA areas there is even lower limits, with a maximum allowed sulphur content of 0.1%. Current ECA areas are in the Northern Sea, Baltic Sea, Caribbean Sea, North America and the English Channel, and new areas is under consideration, *see figure 2*. ECA areas does not only apply to sulphur content but also to NO<sub>x</sub> and PM (Gray et al., 2021; Transportstyrelsen, 2020b).

The NO<sub>x</sub> emissions are regulated in different levels called tiers (1,2,3), each level limits NO<sub>x</sub> emissions to a certain value. Different levels depend on the keel-laying date of the ships. Annex VI also states that all ships should be rated according to the carbon intensity indicator (CII) on a scale from A-E, where A is the highest grade and E is the lowest. The performance level shall be recorded in the ships energy efficiency management plan (SEEMP). If the ship has a D or E performance, an action plan is required to obtain a higher rating. The IMO will increase the demands for the performance ratings by 2% every year from 2023 to 2030.

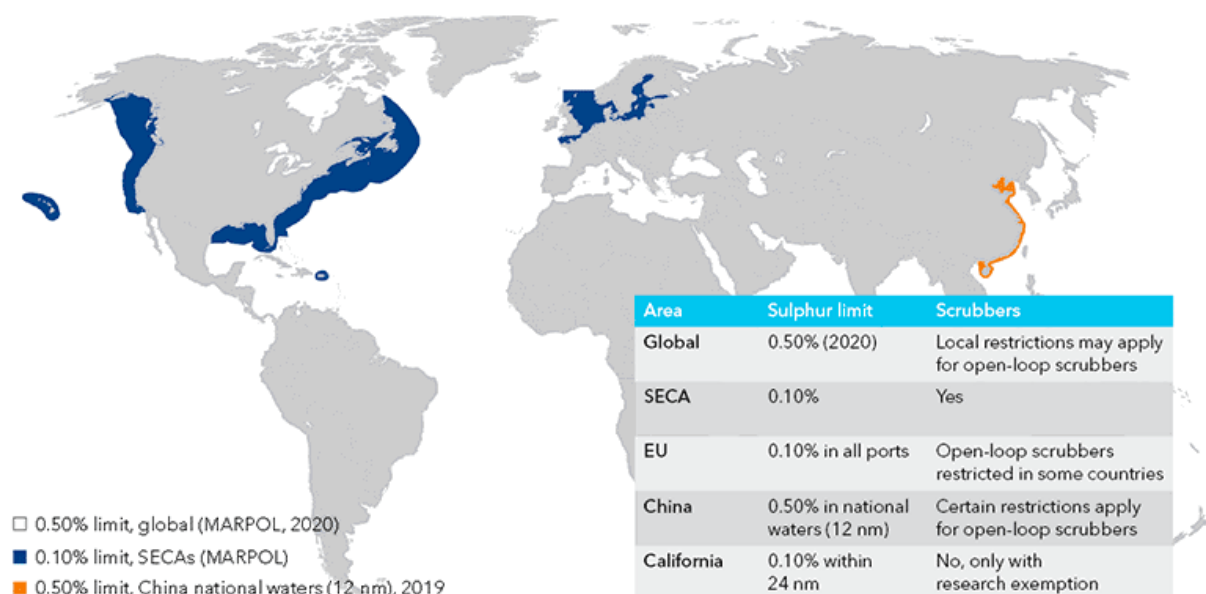


Figure 2 - Emission control areas (DNV GL, 2020b).

## 2.2 European and Swedish climate goals

The transport sector accounts for almost a quarter of Europe's GHG emissions and is the only sector with higher emissions than in 1990, the shipping industry accounts for about 13% of the emissions (Scialla et al., 2022). This undermines the goals of the EU, the Paris Agreement, and the IMO aimed at significantly reducing the volume. As a response to this, EU adopted a new energy action plan in December 2019. The plan is called *The European Green Deal*, and the aim is to promote the efficient use of resources through transitioning, to a clean circular economy that is restoring biodiversity and reducing environmental pollution. EU's goal is to become climate neutral by 2050 (Eurostat, 2023). In 2017, the Swedish parliament pledged that Sweden will be fossil fuel free by 2045 and reduce GHG from domestic transport by at least 70% between 2010 and 2030. Reducing Sweden's dependence on fossil fuels for transport will help achieve other environmental and social goals in addition to the climate goal (Transportstyrelsen, 2020a).

## 2.3 Conventional propulsion for ships

In most cases, a conventional ship is powered by internal combustion engines (ICE) in the form of four-stroke trunk diesel engines or two-stroke crosshead engines that today can deliver an efficiency of up to 50% (Kuiken, 2008). Inside the main engine, energy contained in the fuel is converted into kinetic energy which, through the propeller shaft and the propeller, moves the ship forward. In addition to the engines for propulsion, there are auxiliary engines that produce the ship's electric power needs through generators. There is also the so-called diesel electric propulsion, where the main engines are connected to generators, and the electricity are used to power the electric motors connected to the ship's propulsion system (SSPA et al., 2018).

### 2.3.1 Emissions

The shipping sector today is mostly powered by heavy duty diesel engines which has a major environmental impact in terms of air pollution, as most ships burn heavy fuel oil (Kuiken, 2008). HFO is a fossil-based fuel and consists mainly of residuals from the distillation refining process of crude oil. Apart from hydrocarbons, it also contains a relatively large part of sulphur,

ash, carbon residuals and different kind of metals. Exhaust emissions from ICE vary depending on the combustion process, which fuel used and the engine design (K. Andersson et al., 2016). When burning HFO, the major harmful emissions emitted are CO<sub>2</sub>, SO<sub>x</sub>, NO<sub>x</sub>, and PM. These emissions adversely affect the environment, climate, and biological health (Güven & Özgür Kayalica, 2023). It is the reaction between the oxygen and the carbon that forms CO<sub>2</sub>, which is the main contributor to global warming. The SO<sub>x</sub> are formed during the reaction between oxygen and the sulphur contained in the fuel. SO<sub>x</sub> contribute to the formation of acid rain and adversely affect the environment and human health. NO<sub>x</sub> is generated when oxygen reacts with nitrogen during high temperatures in the combustion process. NO<sub>x</sub> emissions are harmful to human health and contribute to climate change, acidification and eutrophication of soil and water (Naturvårdsverket, 2023). PM emissions from the internal combustion engine is mainly formed due to incomplete combustion of hydrocarbons from the fuel and lubricating oil. PM emitted into the atmosphere is harmful to biological health and contributes to climate change (K. Andersson et al., 2016).

### **2.3.2 Fuel alternatives**

One way to reduce emissions from ICE is to change the fuel. There are several different fuel alternatives to HFO and the most common is different varieties of diesel oil and liquefied natural gas (LNG). The advantage with Marine Diesel Oil (MDO) is that it contains less sulphur and impurities depending on the quality, compared to HFO. This results in less SO<sub>x</sub> and PM into the atmosphere (K. Andersson et al., 2016). The downside is that it is still a fossil-based fuel and releases high amounts of CO<sub>2</sub> and NO<sub>x</sub> during combustion. Another fossil option is LNG, a liquefied gas most consisting of methane and the hydrocarbon fuel with the lowest carbon content (Anders, 2019). Combustion of LNG emits very low amounts of SO<sub>x</sub> and PM, and a significant lower level of NO<sub>x</sub> compared to HFO. The CO<sub>2</sub> emissions from LNG are also a bit lower compared to HFO. The main regression is the possible slip of methane into the atmosphere, since methane is 25 to 30 times more potent GHG compared to CO<sub>2</sub> (Fun-sang Cepeda et al., 2019). LNG has a relatively low unit cost and requires cryogenic storage, which effectively reduces capacity requirements by a factor of 600 (McKinlay et al., 2021).

There are also fossil free alternatives of diesels like HVO and Biodiesel, but today these fuels only cover a small part of the market (Anders, 2019). A range of new fuels, including hydrogen, ammonia and methanol are also being researched. These fuels could be a better alternative to HFO and diesel oil in the future if it is produced in a renewable way (Shi et al., 2023). Hydrogen and ammonia are promising solutions since they are carbon free, this means that no CO<sub>2</sub> are emitted during combustion (Pasini et al., 2023). However, there are still issues concerning safety, storage, and production. With renewable fuels, emissions from ships can in theory become CO<sub>2</sub> neutral (McKinlay et al., 2021).

### **2.3.3 Machinery modifications and aftertreatment**

When it comes to the machinery itself, there are several possible measures to reduce emissions without changing the fuel, including how the machinery and vessels are operated, but also modifications to the engines and various types of aftertreatment.

Different ways to increase the total efficiency can be achieved by operate the engines at the most efficient load and reduction of speed and hull resistance (K. Andersson et al., 2016). This leads to lower fuel consumption and emissions. The use of auxiliary energy on board can also be made more efficient. Energy efficiency is the only practical way to reduce the CO<sub>2</sub> emission without changing fuel or use battery power.

To reduce the  $\text{SO}_x$  emissions and PM without changing the fuel, it is possible to install a so-called scrubber, which cleans the exhaust gas from sulphur with water. There is different type of scrubber systems, and they remove the sulphur from the exhaust gas efficiently (K. Andersson et al., 2016). Although, open loop systems are environmentally problematic because they release the dirty exhaust water into the sea.

There are several possible ways of reducing  $\text{NO}_x$  emissions, both with combustion related modification of the engine and with aftertreatment systems. Temperature regulation of scavenging air, delayed injection timing, exhaust gas recirculation and compression ratio are combustion related ways to reduce  $\text{NO}_x$  through temperature reduction. Water can also be injected into the fuel or combustion chamber (K. Andersson et al., 2016).  $\text{NO}_x$  is created during high combustion temperature and can be lowered if the temperature is reduced. Although, when reducing combustion temperature, the release of PM will increase. This is called the diesel dilemma. Another way to reduce  $\text{NO}_x$  emissions is to install an SCR (Selective Catalyst Reduction). It is an exhaust gas after treatment system that effectively reduces the  $\text{NO}_x$  emissions by injecting a reducing agent into the exhaust gases.

## 2.4 Battery solutions for ships

Electrification can be used to power ships at berth and to charge ship batteries (Anwar et al., 2020). Electrification of ships can eliminate emissions of  $\text{CO}_2$ ,  $\text{SO}_x$ ,  $\text{NO}_x$ , PM, and noise. However, this is dependent on the electricity from land being produced from renewable energy (DNV GL, 2020a). When it comes to use of electric batteries as energy source onboard ships, there are both all-electric and different kind of hybrid solutions. Hybrid diesel-electric or all-electric propulsion systems can significantly save fuel and reduce emissions (P. Andersson et al., 2018). The electrification of ships requires onboard electrical energy storage as well as an energy infrastructure in the port area (Anwar et al., 2020). Ro-Pax ships represent a part of the industry that already has made progress in different battery solutions. Most ships are technically hybrids with diesel generators onboard, although many can operate on battery power only, during normal operation. According to DNV GL (2020a), ships equipped with batteries in 2019 are divided into 50% hybrids, 23% plug-in hybrids and 18% all-electric. Ro-Pax generally have short, fixed routes every day, which makes them suitable for all-electric operations. The challenges are short port stops for charging and long lifetime of the vessels, which means that the vessels outdate the batteries (DNV GL, 2020a).

Between traditional ICE and full-electric operation, there are several degrees of hybrid solutions. In the simplest applications a battery is connected to the ship's main switchboard and can represent an auxiliary engine, the batteries also act as a redundancy system in case of a black out (DNV GL, 2020a). With this solution the auxiliary engines can run on optimal load as the batteries manage the variations in power demand which results in a higher efficiency and cleaner combustion, this also increases the lifetime of the generators and reduces the fuel consumption (SSPA et al., 2018). During power peaks, the battery can take the load instead of having to start an additional auxiliary engine, known as peak shaving. These batteries are normally not charged from shore but from the ship's generators, this results in emissions depending on the choice of fuel. In a plug-in hybrid ship, it is possible to charge the batteries with shore power like a plug-in hybrid vehicle and the battery can often be used for propulsion, but the ships also have a conventional main engine on board. Due to the limitation of battery capacity, hybrid operations works well when it comes to longer routes compared to all-electric ships (DNV GL, 2020a). Some ships operate only on batteries in certain sections of the route, for example while manoeuvring or waiting in port. Other ships can be operated 100% electric,

with the ICE only used as a backup or under special operating conditions (Anders, 2019). The emission decrease in proportion to the degree of hybridisation (DNV GL, 2020a).

In a fully electric ship, both propulsion and auxiliary systems is entirely powered by batteries charged with electricity that has been produced on land. Due to low energy density and high energy requirement, this is only used in vessels with short range and for limited time operations (Anwar et al., 2020). However, there is an emergency generator on board to charge the batteries in case of an emergency. Battery capacity reduces ship autonomy and requires more frequent charging compared to conventional fuel. The batteries are limited by its size and weight, which is a challenge due to stability impact and limited space. According to Piña Rodriguez (2021), electric propulsion system is more energy efficient than conventional ICE systems.

### **2.4.1 Charging infrastructure**

The conventional electrification of modern ships faces concerns regarding charging infrastructure, more shore-based facilities for battery charging is needed. Fully electric ships require access to charging infrastructure in harbours which requires access to the electricity grid, this limits the places where it is possible to charge batteries (Piña Rodriguez, 2021). The demand for charging facilities depends on several factors, for example the ship's energy needs, the time spent in port and the distance between ports (Anwar et al., 2020). Short harbour stops mean high power transfer in a short period of time, which affects the lifetime of the battery and means higher load on the electricity grid. In the absence of a functioning charging infrastructure, ships are forced to charge their batteries with on-board generators. This causes emissions, depending on the choice of fuel (SSPA et al., 2018).

### **2.5 Swappable batteries**

An innovating solution for battery charging could be the use of mobile swappable batteries. Using swappable batteries in a swapping station or docking station has the advantage that an empty battery can be swapped for a previously fully charged battery in a relatively short time, minimizing the drawback of long charging times (Amiri et al., 2018). The used batteries will be recharged ashore, and the vessel can continue its journey. The charging process can now be performed during a longer period, these benefits both the lifetime of the battery and the stress on the power grid compared with fast charging. This also make it possible to charge the batteries when the energy prices are lower, for example during nights, and times with high production of wind or solar energy (Piña Rodriguez, 2021). When the batteries are maintained and charged in the docking station, they can also act as stabilisation for the electricity grid. With a swappable concept, it is also possible to share batteries between ships, this reduces the number of batteries needed per ship. This could be a big advantage, as battery costs are a huge investment when it comes to electrification of ships. Another possibility with swappable batteries is the concept “energy as a service”, which means rentable batteries. This can reduce investment costs for shipping companies as they do not own the batteries, but only pay to use them. With standardisation of batteries and swapping stations, this system can easily be scaled up. According to Piña Rodriguez (2021) the system can be used on both new and retrofitted vessels. However, the disadvantages are that ships require a lot of energy, which making the batteries large and heavy.

Two interesting projects involving swappable batteries is the company ZES and their ambition to electrify the inland and short sea shipping in the Netherlands and the Current Direct project founded by the EU. Both of those projects use a similar technology with a network of swapping stations and a complete container solution, including lithium-ion batteries, cooling, safety systems, ventilation, and fire protection, packed in a 20ft container (Piña Rodriguez, 2021;

Scialla et al., 2022). The container form makes it possible for accessible updates of the system (Zero Emission Services, 2023).

According to the Zero Emission Services (2022) the project now operates an inland container barge that has been modified to carry two battery units on board, allowing the barge to run on electric power alone, with no CO<sub>2</sub> emissions. The barge is 90 metres long and 10.5 metres wide. It has a deadweight of 1900 tonnes and can carry 52 cargo containers. With two batteries of 2 MWh each on board, it has a range of 50-100 kilometres. The weight of the batteries is limited to 25 tonnes, allowing them to be loaded, unloaded, and transported with current terminal equipment (Piña Rodriguez, 2021). On 14 April 2022, Zero Emission Services (2022) announced that they will invest in the development of 75 battery containers for maritime use, 14 docking stations where the battery containers can be exchanged and recharged, and 45 electrified inland vessels. The infrastructure will consist of charging and swapping stations where the batteries can be quickly replaced. The batteries can be recharged by renewable energy on land at a favourable rate to increase battery life and reduce the load on the electric grid (Piña Rodriguez, 2021). The plan is to use a "pay-per-use" system where shipping companies only pay a fee for the use of the battery container and the cost of the renewable energy consumed and the batteries do not belong to specific ships, but to the system itself. The batteries left at the terminal can be used for other ships or other businesses like constructions sites and festivals.

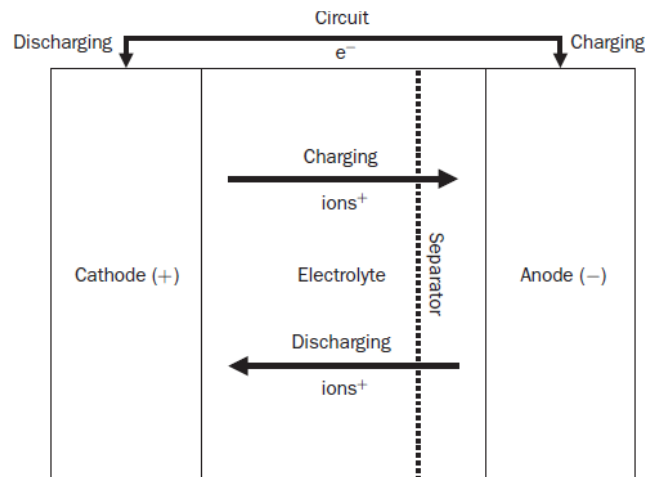
Current Direct is a research and innovation project funded by the European Commission's Horizon 2020 programme, that also uses swappable containerised batteries, powered by an energy service platform. The project targets inland waterways and short sea shipping as these ships fit the battery type solution profile. Current Direct aims to develop a 20ft containerised battery system with a capacity of 3 MWh, that enables easy exchange operations to provide a low-emission energy source for ship propulsion and auxiliary power (Scialla et al., 2022). The batteries will be charged at dedicated charging stations on land, deployed at several strategic locations along inland waterways and coastal shipping transport lanes. The swapping of battery containers will be handled by cranes operating between the ship and shore side. The project aims to increase the number of ships using battery power as their primary energy source and according to Scialla et al. (2022) the project will facilitate the electrification of shipping with the help of swappable batteries.

## **2.6 Battery technology**

Battery propulsion is according to P.Andersson et al. (2018) a key element to reach the marine sector's environmental goals. There are a variety of different batteries, and the type of battery used in almost all ship applications is the lithium-ion battery. It has many advantages when it comes to power and energy density compared to other types of batteries on the market today, but unfortunately some drawbacks when it comes to safety (P. Andersson et al., 2018). Over the past few decades, there have been significant commercial and academic progress in developing rechargeable lithium-based batteries. The discovery of new electrode materials and new storage mechanisms has improved battery performance. Nanomaterial design has emerged as a promising solution to address many of the underlying problems of conventional battery materials (Sun et al., 2016).

The batteries consist of several cells that together form a so-called battery pack. Each cell consists of a positive electrode (cathode) and a negative electrode (anode), in between them is an electrolyte that allows ions to travel back and forth between the electrodes, depending on charging or discharging (Per et al., 2021). There is also a separator that prevents the cathode and anode from coming into contact and causing a short circuit. When the battery is discharging,

the electrons from the anode travel through the load to the cathode, at the same time the ions travel from the anode through the electrolyte and separator to the cathode, *see figure 3*. When the battery is charging, an external power source is used to transport electrons from the cathode to the anode, while an equivalent number of positive ions move from the cathode, through the electrolyte and separator to the anode, *see figure 3*.



*Figure 3 - Lithium ion battery, charging/discharging (Per et al., 2021).*

In a lithium-ion battery, the cathode is made of a lithium compound and is the natural place for the positive ions when the battery is completely discharged. The anode is made of another lithium compound which can store the ions temporarily when the battery is charged (Per et al., 2021). The electrolyte is made up of a substance that allows the positive ions to pass through but blocks the electrons from doing so. In a lithium-ion battery, the electrolyte usually consists of a type of lithium salt. The separator consists of a porous non-conductive material that holds the electrodes apart while allowing the electrolyte to pass through. Each cell in the battery has its own nominal voltage and, in a lithium-ion battery, the voltage is usually 3.6 volts. To reach the working voltage, several cells are packaged together and integrated with sensors, control systems and physical protection, in so-called modules (SSPA et al., 2018). The modules are connected in series to achieve the desired system voltage into a battery string. The battery strings are built up in parallel to increase the available current and power output of the battery packs.

Batteries are compared to each other based on their characteristics. Important aspects for marine batteries are energy density, power density, lifetime, thermal stability, and safety (DNV GL, 2020a). Using different materials for the anode, cathode and electrolyte gives the battery different properties. The capacity of the battery can be presented both in power and in energy, where the power can be compared to the power output of a traditional ICE and the energy can be compared to the amount of fuel on board.

The main type of battery used in the shipping industry today is the Lithium Iron Phosphate (LFP) and the Lithium Nickel Manganese Cobalt Oxide (NMC) batteries (Li et al., 2018). The LFP battery use phosphate as the cathode material and a graphite carbon electrode as the anode. LFP batteries have a long lifetime with good thermal stability and electrochemical performance. The NMC battery combines the advantages of the main elements used in the cathode (nickel, manganese, cobalt). Nickel alone has a high specific energy but is not stable. Manganese is very stable but has a low specific energy. Their combination gives a stable chemistry with high specific energy.

There are several reasons that contribute to the ageing of lithium-ion batteries such as the number of cycles, how fast the batteries are being charged and the temperature of the battery (Piña Rodriguez, 2021). Generally, lithium-ion batteries are more sensitive to fast charging than fast discharging. According to DNV GL (2020a), fast charging is only recommended when it's necessary, to avoid reduction of the battery life. The batteries should neither be completely charged or completely discharged. A lithium-ion battery should be operated between 20 and 25 degrees Celsius. This means that for Scandinavian conditions, both heating and cooling of the batteries may be required. When it is too cold, the battery has reduced capacity and power output. When it is too hot, the battery life is reduced (SSPA et al., 2018). Piña Rodriguez (2021) states that a typical lithium-ion battery capacity is reduced by 20% in 10 years. After the battery has aged to the point where it is no longer suitable for use on board, there is a chance for a second life where it potentially could be used to stabilise the electricity grid. When the battery has reached the end of its useful life, it can be recycled (DNV GL, 2020a).

### **2.6.1 Fire and safety hazards regarding batteries onboard**

Lithium-ion batteries, like any other energy source pose significant hazards in terms of fire and safety (Anders, 2019). Systems and tools are available that can fully manage these risks, but a better understanding regarding both these risks and the tools available are needed so that they can be implemented appropriately. Safety concerns with regards to lithium-ion batteries originates from the presence of flammable electrolyte, and combustible metal electrodes which often releases oxygen during fire (Helgesen, 2019). These components represent a risk where battery abuse can lead to thermal runaway and the release of toxic and explosive gases. Thermal runaway is an exothermic reaction that can occur when a lithium-ion battery is burning. The reaction often starts in a single cell when the electrolyte ignites by some kind of abuse, this fire poses a serious risk of igniting the metal electrodes, which can start a chain reaction. Fire in a single cell is typically no threat to the safety or survival of the ship according to Helgesen (2019), but battery systems used in ship applications are composed of multi-cell packs and modules. A thermal runaway in a single cell can cause thermal runaway in adjacent cells, a stage of very rapid self-heating that results in the release of toxic and combustible gases and can result in fire and explosion. The main conditions that can lead to a thermal runaway is electrical abuse, mechanical abuse, internal short circuit, and external fire. An electrical abuse can be caused by overcharging to a higher voltage than the battery is rated for, or over-discharging, a scenario in which the battery voltage has fallen below the manufacturer's recommended limits (Ghiji et al., 2020). Electrical abuse can also be caused by overcurrent. All those situations can lead to excessive heat, ignition of the electrolyte and short circuit. Thermal abuse, which is when the internal temperature gets beyond acceptable limits. At temperatures above 200°C, hydrocarbon electrolytes can decompose and release heat. Overheating may be caused by insufficient cooling or external fire. Mechanical abuse caused by external violence in form of penetration, pinch or bends. During a collision or accident, the electrode may come in contact and cause an internal short circuit. An internal short circuit can also be caused by a rapid charge or discharge of the battery or by an internal defect. Most of the electric failures can be prevented or detected by a well-functioning battery management system or passive electrical protection as fuses and breakers (Helgesen, 2019).

It is of great importance to have an efficient fire oppression system, able to absorb heat and reduce the fire propagation between cells and batteries. Early detection and release of extinguishing medium is crucial. In the DNV GL report by Helgesen (2019), four different kind of extinguishing systems was tested. The different systems were water mist, direct water injection and a foam-based system injected directly into the modules. The fourth was NOVEC,

which is a gas system that consumes oxygen. Their conclusion was that all these systems had their pros and cons, but none was the obvious choice. They recommend that for each battery installation, the most suitable extinguishing agent for the specific project should be evaluated. The foam was the media that showed the best heat mitigating properties, water also performed well but is not recommended in high voltage applications. NOVEC effectively extinguish flames but showed less heat mitigating properties. Since the electrolyte inside the batteries consists of a flammable organic solvent, it may result in toxic or explosive gases during a failure scenario (DNV GL, 2020a). With this in consideration, the batteries must be kept from ignition sources and be provided with sufficient ventilation. A designated battery room with fire rated boundaries provides significant protection from external ignition sources.

### 2.7 Energy infrastructure

A successful electrification of society requires developed infrastructure, renewable energy production and a stable electricity grid. This also applies to the electrification of the shipping industry (Anwar et al., 2020). The electric energy production in Sweden has a relatively large share that is considered renewable (Statistiska Centralbyrån, 2022). During 2021, the production of electricity in Sweden consisted of hydropower, nuclear, wind, thermal power (mostly fired with waste and biomass) and solar power, *see table 1*.

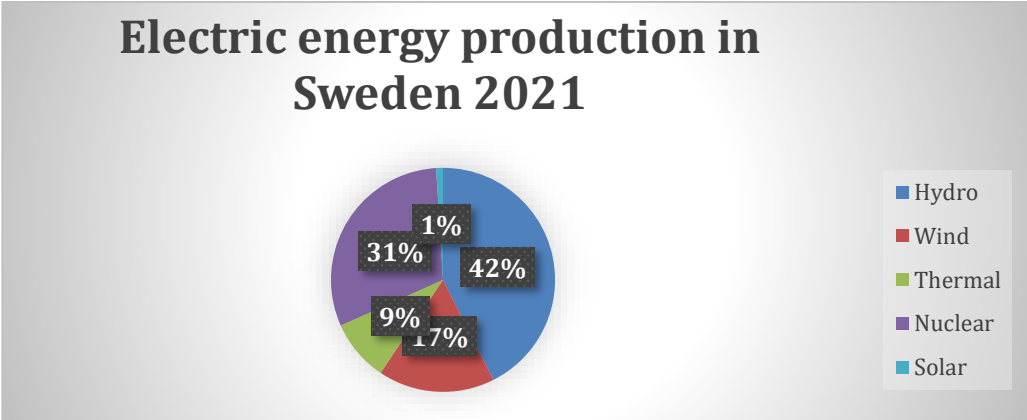


Table 1 - Electric energy production in Sweden (Statistiska Centralbyrån, 2022).

This can be compared with the electric energy production in EU during the same year (Eurostat, 2023). The production of electricity consisted of nuclear, wind, hydro and solar, *see table 2*. The main concern is the remaining part, which comes from combustible fuels, mainly fossil fuels like coal, oil, and natural gas.

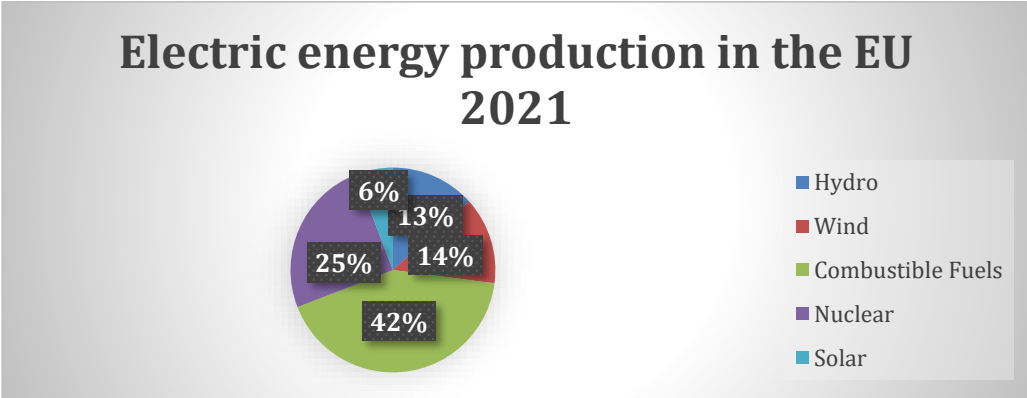


Table 2 - Electric energy production in the EU (Eurostat, 2023).

### **2.7.1 Renewable energy**

To get the environmental benefits from battery powered shipping, it is crucial to charge the batteries with renewable energy (Piña Rodriguez, 2021). United Nations definition of renewable energy is: *energy produced from natural sources that are replenished at a higher rate than they are consumed* (United Nations, 2023). Solar, wind, thermal and hydropower are all examples of renewable energy. Bio energy is also included as a renewable resource even though GHG is emitted during production. This is because the way biomass capture carbon from the atmosphere as it grows. Wind and solar energy are currently the most promising sources of future large-scale renewable energy. However, a high penetration of wind and sun into the power grid is problematic due to its irregularity and unpredictability (Doyle & Johlas, 2017). The sun only shines during daytime and wind power produces a lot of energy during windy days. One possible way to solve this problem is through energy storage for example in batteries, the energy is stored during high production hours and can be used during days with low production or high demand. The renewable energy can also be transformed into e-fuels like methanol, synthetic diesel, hydrogen, or ammonia, these can be used to power vehicles and ships (Shi et al., 2023). Unfortunately, turning electricity into e-fuels are an energy consuming processes with an efficiency of only 44-55% (Pasini et al., 2023).

### **2.7.2 The electric grid**

The power grid is a dynamic system, this means that the power production must always be equal to the consumption, a power balance (Svenska Kraftnät, 2021). In the event of sudden power peaks or drops in the production, the balance can be disturbed, and the frequency of the electrical system will drop, which can result in damage to electrical equipment. To avoid this, some form of back-up power is needed that can be immediately connected, otherwise parts of the grid will have to be disconnected. Currently, this back-up power is often generators powered by gas turbines or diesel engines as these can be started up quickly. In the future, batteries could be used for this purpose. The electricity grid is also limited in terms of infrastructure, i.e. power lines and transformers (Svenska Kraftnät, 2022). When the demand for electricity increases, there can be a so-called capacity shortage in some places, which means that the capacity of the lines is insufficient. This is a major challenge when it comes to future electrification. Problems usually arise locally, but also at national level. In Sweden, the challenge is that a large part of the electricity is produced in the north, while most consumption takes place in the south, which means that large amounts of energy need to be transferred (Ingeberg, 2019). Lack of electric capacity locally means that new projects with large power requirements can be stopped until the infrastructure to the site has been extended, a process that takes time and requires large investments (Svenska Kraftnät, 2022). Another way to reduce the risk of capacity shortages is through efficiency improvements and by spreading out power consumption during the hours of the day (Zahedi, 2014). New smart battery solutions combined with renewable energy have the potential to help stabilise the grid and contribute to the green electrification of both society and shipping.

### 3. METHODS

The methods chapter describes our approach to find the answers to the research questions. The report is a study to find out what opinions Swedish shipping companies in the Ro-Pax sector have towards the implementation of swappable batteries in their fleet. The method used, was qualitative research through semi-structured interviews with technical representatives from three different Swedish shipping companies. The interviews were analysed through compiling and evaluation to reach the result. Based on the results of the interviews, the research questions were answered. Due to the small sample group, the qualitative method is a good way to get a detailed insight within the topic compared to quantitative research (Höst Martin et al., 2006).

A brief description on how we conducted our study from top to bottom.

- Performed research within the area to get a wide range of knowledge before conducting the interviews
- Decided which shipping companies we wanted to establish contact with
- Wrote a brief introduction about our study and the interview questions that would give us answers to our research questions
- Contacted the shipping companies
- The introduction and the interview questions were sent to the interviewees
- Conducted the interviews over video calls
- Transcribed the recorded interviews
- After the transcription was completed, an editing process was made to code and analyse the material
- The coded material and editing method laid the foundation for our result, discussion and conclusion

#### 3.1 Data gathering and analysis

During this study we used different methods for gathering data for the thesis. The methods used was qualitative semi-structured interviews with different shipping companies in the Ro-Pax industry as well as scientific studies of relevant books, articles, and reports. To amplify the accuracy of the study we used more than one method (Denscombe, 2014).

The interviews were used to investigate shipping companies' opinions on the subject. The investigation of scientific articles and reports was to get a stable and extensive background understanding. We interviewed technical representatives from three Ro-Pax shipping companies in Sweden. Their experience and understanding within the topic played an important role in answering our research questions from a technical perspective (Denscombe, 2014).

Contact was established over the phone and email, when we got in touch with the right persons for the interviews, a meeting was booked. The three interviews were conducted over video link by the request of the interviewees. The interviews were recorded with the interviewer's permission, and notes were taken during the interviews. The interviews were transcribed and coded with an editing method to find the relevant information to answer our research questions, and to remove irrelevant information. An edited method is used to create categories of subjects through keywords within the data provided. The analyst's interpretation of the content forms the basis of the categories (Denscombe, 2014; Höst Martin et al., 2006). The coded data from the interviews was summarised into a single presentation of the results, broken down into the

following categories: General approach to electrification and swappable batteries, technical maintenance, infrastructure, safety, logistics, technical competence, and alternative solutions.

### **3.2 Theory Material**

To get a good theoretical knowledge about the subject and to be able to write relevant questions to our interviews, we have processed relevant literature according to (Denscombe, 2014). The material was mainly taken from books, scientific articles and reports found in databases like Web of Science. The material was evaluated according to the Chalmers library CRAAPP guide. Some of the information concerning specific projects was taken directly from the companies involved.

### **3.3 Interviews**

A semi-structured interview technique means that the interviewer has prepared a list of questions related to the topic. During the interview, the interviewer has the flexibility to ask prepared supplementary questions as well as spontaneous follow up questions depending on the interviewee's answers. The answers are open-ended which means that the interviews can be developed spontaneously (Denscombe, 2014). With this type of interview, we could get a better understanding of the shipping companies' opinions.

In this specific report an interview guide and a short introduction were prepared according to Bryman Alan (2018), the interview guide consisted of a few main questions which was asked during all three interviews. Several supplementary questions were also prepared based on possible answers to the main questions. Well in advance before the interview, a short introduction about the subject and the main questions was provided to the interview subjects. In this way the interview subject were well prepared and had a chance to discuss with colleagues before the interview. This improves the chance of getting the questions answered as accurate as possible (Denscombe, 2014).

We followed the instructions by Bryman Alan (2018) and Kvale (1996) for conducting correct interviews. They emphasise that the interviewer should be well prepared and structured, not ask leading questions, use understandable language, and ask well formulated questions. They also pointed out the importance of showing consideration, be flexible and conduct the interview in a quiet and safe place.

### **3.4 Selection of respondents**

The selection of respondents to the interviews was made with a strategic method according to (Trost, 2010). The goal was to cover different parts of the Ro-Pax sector when it comes to traveling distance and power output. This made it possible to compare and evaluate the potential for the battery swapping technology in different parts of the sector. The objective was to get in touch with people who is responsible for technical development and innovation in their company. The interviewees had many years of experience in the industry and high expertise in the field and are seen as very credible sources and representatives of the Ro-Pax sector, which is the basis for our strategic choice of interviewees. The interviewees were all middle-aged men and the active years in their profession ranged from 20 to 35 years. Two of the interviewees were trained shipbuilders and the third a marine engineer. The shipbuilders were responsible for their shipping companies' new building projects and the marine engineer worked as senior chief engineer on board a battery powered Ro-Pax ferry. They were all very qualified for answering our research questions.

### **3.5 Ethical aspects**

In our initial email with information about ourselves, the study, and the interview, we assured that everything reported in the results will be anonymous, so the interviewees involvement doesn't lead to any personal consequences (Denscombe, 2014). We distinguish between the shipping companies' work and the representatives' private opinions. When it comes to the shipping companies' work, it will be referred to as company 1, 2 and 3, and when it comes to the interviewees opinions themselves, they will be referred to as representatives of the respective company.

## 4. RESULTS

In the following chapter, the results of the interviews will be presented. The parallels between the different shipping companies' opinions of implementing swappable battery technology will be presented. We will address opportunities and challenges and summarise these. We have conducted interviews with three different Ro-pax shipping companies that all have different profiles in terms of sailing distance, maximum power output for propulsion and auxiliary loads. The sailing distance is categorised in short, medium, and long range, which represents <5 Nm, 5 – 70 Nm and >70 Nm. The three different shipping companies, and the interviewees we have been in contact with are presented below.

- **Shipping company 1:** A market-leading shipping company with Ro-Pax operations in Europe within the medium and long-range segment. The maximum power output on board their vessels is 15-30 MW. The interviewee is a trained shipbuilder and works as a project manager for newbuilding projects with a focus on electrification.

- **Shipping company 2:** A shipping company with national Ro-Pax operations that operate within the long-range segment. The maximum power output on board their vessels is 31-55 MW. The interviewee is a trained shipbuilder and works as a technical manager for newbuilding and future projects.

- **Shipping company 3:** A local shipping company with Ro-Pax operations within the short-range segment. The maximum power output on board their vessels is 4-10 MW. The interviewee is a trained marine engineer and works as senior chief engineer on one of the company's vessels.

### 4.1 General approach to electrification and swappable batteries

All three shipping companies are positive to electrification of the shipping industry, but in varying degrees. The degree of electrification depends mainly on the sailing distance and power requirements on board. The representative of company 1 states that battery operation is the most efficient green option. With battery operation, the efficiency is around 80 %. If you produce e-fuel, 50% of the energy is lost during production, and another 50% in the ICE. This results in a total efficiency of only 25%. However, the representative of company 2 pointed out that it is mainly in countries like Sweden, with a relatively green electric energy profile, that electrification solves the environmental and climate challenges. None of the three companies believe it would be possible, with today's technology, to use only batteries to power Ro-pax ships on long-distance routes due to insufficient energy storage. The batteries would be too big, expensive, heavy, and with the amount of power that is needed to charge the batteries, it is not practically possible today. On the other hand, all three companies are positive to use batteries for auxiliary loads, peak shaving, or hybrid solutions, also during long distance routes. Company 1 and 3, which operate within short and medium range, have already invested in battery solutions today. Company 1 operates a ship with a battery container pack on deck that is used to power the bow thrusters and act as a redundancy system. They are now building three hybrid Ro-Pax ferries and working on a project that aims to have a ship capable of covering medium range distances on battery power alone by 2030. This ship is planned to get a battery pack capacity of about 70 MWh. Company 3 has converted two of their ships to battery powered propulsion, but they still have traditional diesel engines on board as a redundancy system. Their solution is battery containers located on the weather deck. The batteries are charged with shore power at all berths.

Swappable battery solutions are not currently used by any of the three companies, but all can recognise benefits of this idea. Company 2 is now investigating the possibility to implement such technology to power the auxiliary loads on board. The plan is to have a battery that can handle 75% of the maximal auxiliary load, when the load is above that point, an auxiliary engine will start. If they would decide to use swappable batteries, they would need three sets of battery containers per ship, one battery on board, and one in each port. This means it would be possible to share batteries between ships, which would reduce the number of battery containers.

The representative of company 3 believe that regulations from the governments must be introduced to push the shipping industry towards the transition to electrification. Subsidies are needed to build infrastructure such as charging stations for swappable batteries and governmental support packages and tax breaks are needed to kick-start the process.

## **4.2 Technical maintenance**

Company 2 sees potential with swappable batteries when it comes to maintenance, the technology can be replaced or upgraded more easily, compared to stationary batteries. They also see another positive aspect in a possible business plan of renting swappable batteries and paying for the energy consumed. In that way, large initial capital investments and maintenance costs can be avoided. Company 1 and 3, on the other hand, points out that specific modules in their current stationary batteries could easily be replaced or upgraded if they get damaged or outdated.

## **4.3 Infrastructure**

When it comes to infrastructure, all three companies agree that there is a major advantage with swappable batteries compared to stationary. Numerous harbours around the world have problems with the electrical infrastructure, and in those places, this could be a possible solution. If the battery is swapped and charged slowly ashore it means less stress is on the electricity grid. Another advantage mentioned by the representant of company 2 is that charging over a longer period puts less strain on the battery and can increase battery life. Company 3 believes that this technology may be suitable for archipelago or river traffic where there are fixed harbours and routes with less developed electrical infrastructure. This is the reason why company 2 has considered swappable batteries as an alternative. Their ports do not yet have the infrastructure capacity required to charge an integrated battery in the required short time needed and it is up to the ports, and not the shipping companies, to enhance the infrastructure. When it comes to company 3, they can charge their stationary batteries because of the lower energy requirement and because the ports they serve have been involved and supported their transition to electrification. The electricity grid can handle the load that occurs when the ships are in port, charging their batteries. Company 1 has chosen a different way to overcome the problem with heavy loads on the grid during charging. Their plan is to have a stationary battery bank in each port that is slowly charged and then is used to charge the ship battery. This battery can also be used for frequency compensation of the electric grid on land, which they believe could be a future market opportunity.

## **4.4 Safety**

Company 1 and 3 both use an aerosol system as extinguishing agent in their stationary battery containers today. Company 2 believes that manufacturers of battery containers are aware of what equipment is required when it comes to fire extinguishing, fire detection and cooling of the battery container. But the representative believes that more knowledge is needed when it comes to thermal runaway. He also believes that it can be a disadvantage to have the battery

placed on cargo deck, because of the consequential effects that can occur during a thermal runaway. Company 3 states that if a thermal runaway is initiated in a single cell of their batteries, it doesn't necessarily mean disaster, if the cooling water is circulating. Each module is also gas tight with its own ventilation. But if the thermal runaway should propagate between a larger number of cells, there is more serious. If this happens, the container is filled with seawater, and the cool-down can take several days. Company 1 and 2 believe that if a thermal runaway should occur, they see an advantage if the batteries is stored in some kind of enclosed battery room where the fire can be handled in a more efficient way without spreading. According to company 1, there was earlier no safety guidelines on how a battery room should be constructed, this is why their current battery pack was placed on the weather deck. Today there are more appropriate class rules concerning battery containment.

#### **4.5 Logistics**

A major problem, that all three companies states when it comes to swappable batteries, is caused by the logistics associated with battery replacement which interferes with cargo operations. One solution, according to company 1, would be a separate logistic solution. For example, a hatch on the side of the ship where the battery could be changed without interfering with cargo operations. Another problem highlighted by company 2 is that a battery container takes up cargo capacity. If it would be possible to solve this with some kind of ramp so the battery could be rolled down into a lower battery compartment under deck, it could be a solution. Both solutions mentioned would involve major rebuilding, which would be too expensive and complicated to implement on existing ships today. Company 1 points out that a swappable battery container involves large weights, which means that the placement of the battery must be taking into consideration, regarding the stability of the ship. Company 1 also recognises a problem with daily connection and disconnection because of wear and tear on the equipment. Company 3, which currently has a stationary battery for propulsion, states that their main challenge has been the shore connection for charging of the battery.

#### **4.6 Technical competence**

The representative of company 1 believes the competence within the shipping industry when it comes to battery solutions is somewhat behind in relation to the automotive industry, but competence is slowly increasing. The representative of company 2 is a little sceptical about whether competence exists today or not, because the technology is not so proven yet. Although, this should not be a major problem for future investments, technical knowledge in the area can be provided in form of training. However, the representative believes that more research is needed when it comes to safety. When it comes to swappable batteries, the representative for company 3 believes that there is already competence available. At a battery fair in the Netherlands, a company exhibited their swappable battery system and has now received its first contract with a shipping company that operates river traffic.

#### **4.7 Alternative solutions**

All three shipping companies believe that ICE will remain for longer sailing distances and as a redundancy system to battery powered ships. But to meet environmental targets, other fuels are needed instead of diesel and heavy fuel oil and the three companies have chosen different paths regarding new fuels. Company 1 is investing in bio or e-methanol, company 2 in hydrogen and company 3 has a project with Wärtsilä where they are investigating the possibilities of using ammonia as fuel.

## 4.8 Results summary

Below, a summary is presented to clearly answer the research questions.

- The shipping companies is positive to swappable battery technology, but it is not an attractive option today. The major problem with the swappable battery solution is the number of battery containers needed to provide enough electricity to power the ship propulsion. Although, the technology would be possible to implement to support auxiliary loads.
- The most beneficial part would be that the battery could be recharged during longer periods, which would increase battery life and reduce the stress on the power grid.
- Another benefit is that components and technology would be easy to update when technology moves forward. A business plan regarding rentable batteries would relieve the shipping companies from huge investments.
- The swappable battery solution would make it possible to reach areas where strong electric grid is not accessible. With today's situation, the infrastructure to high-speed charging is not always possible.
- Aerosol systems seems to be suitable as a fire extinguishing system for battery containers. Thermal runaway is still a concern, and more research is needed within this area. The placement of the battery container also matters, placing it on deck can result in disastrous chains of event. If the battery container can be placed in a concealed battery room below deck, the interviewees believed that a fire could be handled in a more efficient way without spreading.
- Logistics associated with battery replacement interferes with cargo operations and reduce cargo capacity. The placement of the battery container is also important when it comes to stability, due to its heavy weight. Daily connection and disconnection of swappable batteries could result in wear and tear on the equipment.
- Technical competence of battery solutions generally seems somewhat behind in the shipping industry, but it's slowly increasing. More research is needed when it comes to safety.
- ICE will probably still be used for longer distances until the energy storage capacity for batteries has been improved and as a redundancy system. There is research on different, more environmentally friendly fuels as hydrogen, ammonia and methanol that might replace diesel, but there are still challenges.

## **5. DISCUSSION**

In the discussion chapter, the research methods in chapter 3 and the results obtained in chapter 4 will be discussed. The results of the interviews will be linked to the theory found in chapter 2 to confirm the differences and similarities with the answers given by the respondents.

### **5.1 Method discussion**

Our study has an exploratory nature, making qualitative methods well suited to obtain the answers to our research questions (Denscombe, 2014; Höst Martin et al., 2006). Obtaining such detailed results in a quantitative method would have been difficult. We choose not to implement more than three interviews, this might seem few, but the interview group was very knowledgeable and had great expertise within the research field. This allowed us to go deeper into our research questions during the interviews, but within our delimitations. A larger sample group with more respondents might had led to a broader answering base, but not necessarily better results. We feel that our research questions have been well answered with great expertise from the interviewees. An editorial analysis method was used to analyse the collected material, we interpreted the content of the recorded interviews and categorised the material, according to Höst Martin et al. (2006). This was a good choice as the interviews was rather long and generated a lot of raw material to process. During the process, we coded the material as accurately as possible within our means. With more interviews and with different Ro-pax companies, the coded material could have ended up differently, this could have resulted in more similarities and differences.

#### **5.1.1 Data collection**

The theory material presented in the study is considered relevant to provide prior knowledge in the field of research. The information comes primarily from independent sources, which increases the relevance for usage. The theory we have presented is based mostly on scientific articles, books, reviewed reports, and a few company websites. When it comes to several reports commissioned by DNV GL, we know that they are not peer reviewed, but we see them as credible as they are one of the leading classification societies in the maritime industry. But it is possible that the angle of the studies can vary depending on who commissioned the report. We also use some websites of private companies as sources, which we consider necessary to describe their products and projects. The theory chapter gives the reader greater understanding and background of the study questions, its purpose, and result.

#### **5.1.2 Selection group**

The selection group happened to be middle-aged men only, with experience in the industry of between 20 and 35 years. It can according to Trost (2010) be seen as problematic with such a homogenous selection group since it is desirable to have as wide a variety of interviewees as possible to get a representative response, but this is how the industry mainly appears today. We believe that the choice to only contact three companies was correct in terms of the results. Our believe is that the answers we received during the interviews, represent what Swedish Ro-pax shipping companies' opinions are regarding swappable battery containers. We understand that if more shipping companies had been interviewed, the result and conclusion could have been somewhat different, according to Denscombe (2014). On the other hand, we believe that we have managed to pinpoint a relatively wide range when it comes to ship power output and route distance. All three of the companies we interviewed were within our delimitations but at opposite ends of the boundaries. According to Trost (2010), too many qualitative interviews

can result in a large and unmanageable material where it becomes difficult, both to get an overview and to see all the important details that unite or distinguish the participants.

### **5.1.3 Interviews**

We got in touch with the interviewees surprisingly fast after being directed through the companies' contact numbers. All companies showed great interest in our project and all respondents agreed to be interviewed. When contact was established with the interviewees, the interview questions and a brief background of our study was sent through email, which from our perspective made the interviewees appear well prepared. We believe that our choice of a semi-structured interview method was correct. The interviews developed spontaneously and led to a broad understanding of the subject (Denscombe, 2014). The interviewees were easy to interview and seemed very knowledgeable about the topic. When preparing our interview questions, we broadened the questions somewhat, which resulted in longer interviews than we had expected. However, this was something we greatly appreciated as researchers, but it resulted in a significant amount of material to transcribe and code. A lot of information had to be sorted out as it was not relevant to our research questions. But in addition to having our research questions answered, we gained lots of insight and knowledge.

### **5.1.4 Reliability, validity and generalization**

Reliability is, according to Kvale & Brinkmann (2014) if the research questions has been answered with accuracy. The principle is that other researchers would have achieved the same result which is an important aspect of the reliability of the study. The researcher's interview technique is of importance where any leading questions may result in varying answers from the interviewees.

According to Denscombe (2014), it is more difficult to judge the validity of a qualitative research than quantitative research. For example, it is more difficult to control and replicate an interview in the same way as a scientific experiment. The reason is that it is hard to recreate a social setting. To achieve a good validity in the report, only people who have valuable knowledge about ship battery management within our delimitations was interviewed. In the literature used, the publisher of the work has been reviewed to determine its validity.

Generalisation of this study cannot be considered as the report will be based on qualitative research which according to Denscombe (2014), is not generalisable.

## **5.2 Result discussion**

After the authors coded and thematically analysed the raw data of the interview material according to Höst Martin et al. (2006), parallels were drawn between the different interview materials to find the similarities and to investigate whether there were areas of disagreement. In the following chapter this result is discussed against the theoretical background.

### **5.2.1 General approach to swappable batteries**

The interviews showed the same thing as the theory chapter, that battery power for propulsion is still mainly relevant for shorter distances and for ships with lower power output such as the ones company 3 operates. This applies to battery power in general, but also to swappable batteries. On the other hand, it was very interesting to hear how efficient battery electric propulsion is compared to converting electricity into e-fuels, also mentioned by Pasini et al. (2023). However, it was encouraging to see that company 2 is considering using swappable batteries for their auxiliary loads, which proves that the technology could be a serious solution.

The type of ships that the interviewed shipping companies operates, simply have greater energy requirements than what today's battery swapping technology can cover. To cover that requirement, the batteries would get too big, expensive, and heavy. Company 1 is planning a new building project with a battery capacity of about 70 MWh. In practice, this would mean 35 swappable battery containers with the same storage capacity as in the ZES project described by Piña Rodriguez (2021). It is easy to understand that it would be extensive in terms of logistics and would take up a lot of cargo space, even if there were separate battery logistics and storage. It is also worth repeating what company 2 explained; *Battery solutions will only solve the emission problems in countries such as Sweden, with a relatively renewable energy mix*. This statement corresponds well with the data from Statistiska Centralbyrån (2022). If countries that have a weaker infrastructure and could benefit from swappable battery solutions, do not produce their energy in a renewable way, no emission problems will be solved.

All shipping companies were in favour of the idea of swappable solutions, but it is possible that these solutions are better suited to a different type of shipping, as shown by Piña Rodriguez (2021) and Scialla et al. (2022), where projects such as ZES and Current Direct have focused more on container traffic on inland waterways and short coastal trade. This is a type of inland traffic that has also been discussed in Sweden, and it would have been interesting to also investigate these solutions. Another interesting aspect would be to investigate the Swedish shipping companies' opinions, concerning road ferries and archipelago traffic.

### **5.2.2 Technical competence and maintenance**

To the competence for this type of battery solution in the industry, the representatives interviewed had quite different opinions. What they had in common was that development is going in the right direction. It was interesting to hear from company 3, who had visited branch fairs in Europe, that swappable battery solutions were on the agenda and being discussed.

One of the companies, just like the theory section from Zero Emission Services (2023), saw an advantage in that technology would be easy to replace or update. But on the other hand, the two other companies pointed out that parts and cells can be replaced relatively easily in their stationary batteries. However, it is conceivable that a swappable battery would still be more convenient as the entire container could be transported to a workshop for maintenance, without disrupting the operation of the ship. An exciting aspect brought up by company 2, as well as Piña Rodriguez (2021) and Scialla et al. (2022), was the possibilities for different business models that swappable batteries represent. This means renting the batteries and pay for the energy consumed. This could probably get more shipping companies to invest in this technology, especially if there was a standardised solution from major actors on the market. However, it is very possible that it is as company 3's representative says, maybe support from the authorities and tax reductions are required for serious investments in new technologies.

### **5.2.3 Logistics & Infrastructure**

After the interviews was analysed, it was clear that logistics was one of the main disadvantages that the three companies could recognise with swappable batteries. In comparison to the battery solutions mentioned in the theory chapter, the ship types are different, and they are loaded in a different way. For example, the ship that uses ZES technology is a container ship travelling between two ports in river traffic, explained by Piña Rodriguez (2021). Their cargo consists of the same type of containers as the batteries, which means that the batteries can be loaded and unloaded in the same way as the regular cargo, which can be considered a better logistical solution. However, as mentioned in the interview, this could also have been solved on a Ro-pax ferry by modification. However, as the interviewees stated, this would have been an

extensive and expensive project. An important aspect brought up in the interviews was the possible wear and tear on the connection equipment, where the representative of company 1 thought that this could be a disadvantage for swappable batteries. At the same time, company 3, which uses shore power to charge its batteries, pointed out that this technology also caused wear and tear and operational problems. In the thesis by Piña Rodriguez (2021), an advantage could be fluctuating electricity prices between day and night, that was not mentioned in any of the interviews.

All three companies believe that there are great advantages with swappable batteries from an infrastructure perspective. It was interesting to note that company 2 did not have the electrical infrastructure at its terminals to be able to charge a battery intended for auxiliary loads in a conventional way, even if these loads are only a small part of the ship's energy requirements compared to propulsion. But when it is, as for company 3, possible to charge with a shore connection, it still seems to be the most convenient solution. But as all the three companies and Piña Rodriguez (2021) mentioned, swappable batteries may be a solution for smaller vessels and/or for shorter routes where the infrastructure is limited. Company 1's solution to the problem was very interesting, and something that we didn't find during our literature study, a stationary dockside battery pack solution. This would combine the advantages of both stationary and swappable batteries. However, they do not avoid the disadvantage that the battery on board is charged with high power for a short time, which according to DNV GL (2020a), can shorten the lifetime of the battery.

#### **5.2.4 Safety issues**

Our first thought was that it would be an advantage to have the battery in container form, but both Helgesen (2019) in the theory chapter and two of the companies point out that it is probably better to store the batteries in an enclosed space below deck where they are isolated and protected from external influences and can be monitored and managed in a better way when it comes to safety. This corresponds well with the report by DNV GL (2020a). An additional disadvantage which could be considered with swappable batteries is the risk of mechanical abuse during the actual battery change, which in extreme cases can lead to a thermal runaway. Company 2 was a bit sceptical about the competence regarding safety and how a thermal runaway situation should be handled, this reflected the theory chapter quite well. We found some research in this area, but it was difficult to find out which extinguishing method is the most effective, it seemed to be no obvious answers to that question. Helgesen (2019) evaluated several extinguishing agents, but surprisingly not aerosol systems, the type that is used by company 1 and 3.

#### **5.2.5 Future investments**

All three companies and the background theory agreed that ICE will be used for longer distances and that battery-powered ships will need generators on board, which is very reasonable when you consider that there may be disruptions in the electricity supply and/or with the technology. It is also imaginable that this is needed for transportation to, for example, shipyard or a change to a longer route. The most interesting thing when it comes to alternative solutions is that the three companies are investing in three completely different fuels to power their future engines. This indicates that in the present situation, there really is no obvious solution for the future. Time will determine who made the right choice or whether it will be as interviewee two predicted, that there will be a multitude of different alternatives on the market, to which shipping companies, harbours and distributors will have to adapt to.

## 6. CONCLUSION

The shipping companies interviewed for this report are in favour of electrification for short-distance propulsion, but they do not see swappable batteries as an attractive solution for them today. However, the technology could work for batteries that supply auxiliary loads on board. The advantages seen, compared to stationary batteries, are that swappable batteries can be charged under more favourable conditions on the dockside, this reduces both the load on the electricity grid and increases the lifetime of the batteries. The companies believe that the technical competence for this type of solution exists to varying degrees, and the development is moving in the right direction.

- For swappable batteries to become a more attractive alternative, an effective logistic solution for the battery exchange is required. It would also be desirable to remove the battery containers from the cargo deck. This would preserve cargo space and would also be a positive aspect in terms of safety. In an enclosed battery room, a possible thermal runaway can be handled in a safer way. Another attractive solution could be a business model where you rent the batteries and pay only for the energy used, this would avoid high investment and maintenance costs.
- The major challenge with batteries is the large amounts of energy that are required to power the propulsion for longer distances, this makes the batteries too large, heavy, and expensive. The logistics of battery swapping poses difficulties during a busy time schedule and the battery containers take up valuable cargo space on deck. Overall, the shipping companies are positive about swappable batteries, but it is not something they are ready for today.

### 6.1 Recommendations for further research

It would have been interesting to interview Swedish shipping companies with shorter routes and/or ships with lower power output, as this type of shipping was repeatedly mentioned in the interviews and in several academic articles. Examples could be Trafikverket, Styröbolaget or companies that is trafficking inland water ways. Another interesting thought for further research would be to see if it would be possible to implement this technology on small container ships.

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## 7. APPENDIX

### A.1 Introduction sent to the shipping companies (In Swedish)

#### Introduktion

Vi heter Jonas Andersson och Petter Elmdahl och läser sista året på Sjöingenjörsprogrammet på Chalmers tekniska högskola i Göteborg. Vi skriver vårt examensarbete om en alternativ energikälla för fartyg i form av utbytbara batterier. Vår plan är att genomföra intervjuer för att få en inblick i vad svenska rederier inom Ro-Ro, Ro-Pax och färjesektorn tror om att implementera denna teknik. Ett projekt vi har tittat på är ZES (Zero Emission Services) i Holland där fartygstrafiken drivs av utbytbara batterier i containerform. Batterierna är på 2MWh styck och är ett komplett system med integrerat övervakning, kyl- och brandsläckningssystem. Infrastrukturen består av laddnings- och utbytesstationer där batterierna snabbt kan bytas ut. Sedan kan batterierna laddas upp av förnyelsebar energi på land i gynnsam takt för att spara på batteriets livstid och minska belastningen på elnätet, detta kan även göras nattetid då efterfrågan och priset på energi är lägre. Syftet med vårt forskningsarbete är att ta reda på vad svenska rederier har för inställning till att implementera utbytbara batterier i deras flotta. Vi vill ta reda på eventuella problem eller möjligheter ur ett tekniskt, säkerhets, infrastrukturellt, logistiskt och underhålls perspektiv. Därför skulle vi vara väldigt tacksamma om vi kunde få föra en intervju med någon teknisk representant från ert rederi. Vi hade gärna sett att vi ses personligen men vi har full förståelse för att denna tid kanske ej finns, då funkar även ett videosamtal över exempelvis Zoom eller Skype. Även en telefonintervju funkar bra. Vi satsar på att intervjun tar cirka 15 minuter, vi garanterar anonymitet och svaren kommer endast användas i forskningssyfte.

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## **A.2 Questions asked during the interviews (in Swedish)**

### **Inledningsfrågor**

Befattning/position:
Typ av fartyg:
Fartområde:
Storlek på fartyg (kW):
Hur många år har du varit i branschen:
Godkänner du att vi spelar in intervjun:

### **Intervjufrågor**

- 1. Vad tycker ni som rederi om elektrifieringen i branschen?**
- 2. Är elektrifiering något ni som rederi satsar på idag?**
- 3. Hur sker uppladdningen av era eventuella batterier ombord idag?**
- 4. Hur ser ni på livstiden på era eventuella batterier?**
- 5. Vi har hittat projekt där rederier har implementerat utbytbara batterilösningar för sin flotta, både för framdrift och för allmän energiförsörjning. Är detta något in har hört talas om?**
- 6. Vad skulle det krävas det för att ni skulle överväga att implementera denna teknik?**
- 7. Vilka problem eller hinder ser ni med denna teknik?**
- 8. Tror ni det finns tillräckligt med kompetens i branschen för denna typ av batterilösning?**

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