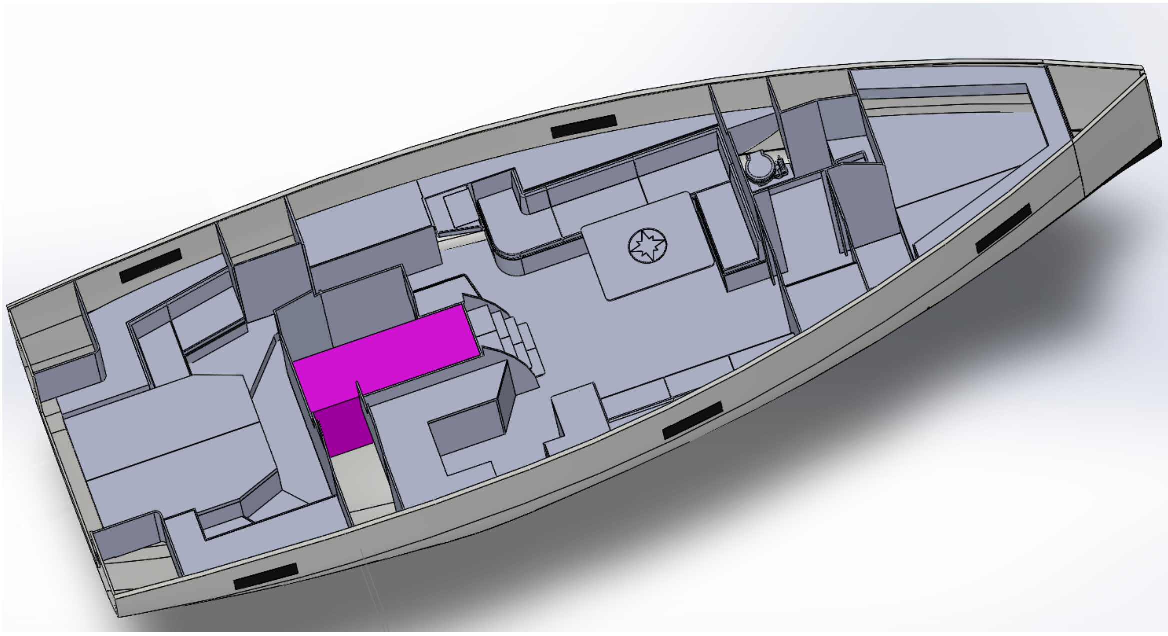

# Portable Battery for Marine Leisure

Collaboration between Chalmers University of Technology, The Pennsylvania State University and Volvo Penta

Bachelor thesis IMSX15-22-17


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Gothenburg, Sweden 2022

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Cover: CAD model of the placement of the final portable battery packet from GrabCad designed by Tom H. Modified on SolidWorks (2022) by Arlyn Buondonno.

Gothenburg, Sweden 2022

**Abstract**

Electrification is one of the biggest disruptive trends within the marine leisure sector. It follows a similar path as the automotive industry. One of the major challenges is the availability of charging. Many marinas do not have sufficient shore power for the charging of large batteries and if electrification is to succeed, more options for customers interested in electric boating is needed. One alternative this report concluded is the possibility to develop a portable battery swapping system where a sailboat owner could swap the discharged battery for a fully charged one via a swapping mechanism. This would allow a third party to own a limited number of standardized batteries for electromobility customers and charge the batteries slowly to avoid an excessive load on the power grid.

The methodology was firmly based on a project design and development process. An extensive study was conducted on the customers and the behavior of sailboat users in order to develop target specifications, needs and requirements for developing a portable battery swapping system. Meanwhile, the team partook in literature studies, contacting boat manufacturers and visiting different boatyards. The customer research was based on a quantitative and qualitative study through both a survey and deeper interviews that was answered in total by 187 sailboat users. With this solid foundation, concepts where generated and eliminated until a single concept was further developed and investigated.

The concept that was further developed resulted in a battery swapping system by function sharing with already existing equipment on the boat. The batteries where placed behind the staircase of the sailboat, where the conventional combustion engine many times is placed, and a hatch just above this position was implemented. The boom in co-operation with a pulley system is used to lift the batteries and swing it out over the docks. The same procedure in reverse is applied for reloading fully charged batteries onto the sailboat. Lithium-Ion was the chosen material for the battery because of the lightness of their building components, high loading capacity and longer cycle life.

The business case for this is based on a subscription model where the sailboat owners subscribe on a wanted amount of batteries. The swapping stations are planned to be as self-sustaining as possible, just like an unmanned fuel station. A third part stakeholder operates the swapping stations by making sure there is enough batteries to meet the demands, doing maintenance and providing the location where the batteries can be placed.

The project resulted in a model for a battery swapping system, complete with example modules and mechanical assistance to handle them. The concept allows sailboat users to maintain their current use of functions and equipment except for ways of heating the water and the cabin, which needs to be further researched if the project is to be continued.

**Sammanfattning**

Elektrifiering är en av de största disruptiva trenderna inom den marina fritidsbåtssektorn. Den följer en liknande utveckling som elektrifiering av bilindustrin. En av de stora utmaningarna är tillgången till laddning. Många småbåtshamnar har inte tillräckligt med landström för laddning av stora batterier och om en elektrifiering ska lyckas behövs fler alternativ för elbåtsintresserade kunder. Ett alternativ som denna rapport kom fram till är möjligheten att utveckla ett portabel batteribytessystem där en segelbåtsägare kan byta ut det urladdade batteriet mot ett fulladdat via en bytesmekanism. Detta skulle möjliggöra för en tredje part att äga ett begränsat antal standardiserade batterier för elektromobilitetskunder och ladda batterierna långsamt för att undvika en för hög belastning på elnätet.

Metodiken var fast baserad på en projektdesign- och utvecklingsprocess. En omfattande studie genomfördes av kundgruppens beteende för att utveckla en kravspecifikation av deras behov. Kundundersökningen baserades på en kvantitativ och kvalitativ studie genom både en enkät och djupare intervjuer som totalt besvarades av 187 segelbåtsanvändare. Med denna grund genererades olika koncept som evealuerades tills dess att ett koncept vidareutvecklades och undersöktes.

Konceptet som vidareutvecklades resulterade i ett partabelt batteribytessystem genom att använda redan befintlig utrustning på båten. Batterierna placerades bakom segelbåtens trappa, där den konventionella förbränningsmotorn är placerad, och en lucka precis ovanför denna position implementerades. Bommen tillsammans med en trissa, likt en travers, används för att lyfta batterierna och svänga ut dem över hamnen. Samma procedur tillämpas omvänt för att placera de fulladdade batterier på segelbåten.

Affärsmodellen för konceptet är baserat på en abonnemangsmodell där segelbåtsanvändarna abonnerar på ett önskat antal batterier. Bytesstationerna är planerade att vara så självförsörjande som möjligt, precis som en obemannad bensinstation. En tredje part driver bytesstationerna genom att se till att det finns tillräckligt med batterier för att möta kraven, utföra underhåll och tillhandahålla platsen där batterierna kan placeras.

Projektet resulterade i en CAD-modell för ett portabelt batteribytessystem, med exempel på batterimoduler och mekaniska verktyg för att hantera modulerna. Konceptet påverkar inte nuvarande funktioner och hjälpmedel som finns ombord en segelbåt, förutom möjligheten att värma ruffen eller producera varmvatten. Dessa funktioner behöver undersökas djupare ifall projektet skall utvecklas vidare.

## Acknowledgments

We could not have written this report by ourselves, and here we would like to thank those who have helped us along the way. First, we would like to thank Chalmers Technical University for funding the trip to Penn State University. It was a great learning experience and we are very thankful. We would also like to give thanks to Håkan Palm at Öckerö Bil & Båtlack Nya AB, whom invited us to roam their boat yard to get inspiration for our designs. Thanks as well to everyone who took time to answer our survey, and especially to those who participated in a more in depth interview. Your answers gave great insight.

A special thanks to our supervisors Mikael Enelund, Jimmy Ehnberg and Nicholas Vlajic for attending our meetings and providing feedback at all stages of the project. Another special thanks goes to examiner Lars Almefelt who shared his knowledge of writing, making sure the final report turned out as good as can be.

Finally, we would like to thank Björn Wessman from Volvo Penta for his engagement in this project, and for setting up meetings with experts within the Volvo Group when we were struggling. Thank you.



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Göteborg, May 2022
State Collage, May 2022

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# 1 Introduction

Electrification is taking shape in several areas of society and especially in the automotive industry which is growing at a rapid pace, mainly due to the higher reliability, efficiency and robustness of electrical systems [1]. The sailing sector is entering a new era of implementing solutions to reduce environmental impact. Due to the demands for a more sustainable society, which in this context means that the development and use of products must meet the population's needs without affecting the future in a negative way regarding environmental changes and emissions. Utilizing battery systems allows for systems to be charged using electricity that is generated through renewable means such as solar, wind, and geothermal energy. The electrification of boats follows a comparably similar path as the automotive industry. Although the charging infrastructure for the automotive industry is expanding throughout the world and one of the major challenges is the availability of charging.

Henceforth, electrification is emerging as a fast-growing societal trend. Even in the marine sector, electrification is one of the biggest disruptive trends. Several new and upcoming companies are taking advantage of the electrification of marine leisure. These companies offer a range of products from electric motors and components to complete boats. The number of companies is growing exponentially as the trend continues to gain momentum. The development of sustainable solutions challenges traditional solutions. Currently, the use of diesel engines on sailboats is extensive. The combustion engine serves multiple purposes such as propelling the boat, utilizing the heat energy from the engine by transferring it to the heater and charging the batteries.

## 1.1 Background

If electrification is to succeed, more alternatives for electric boat-interested customers are needed. An alternative, proposed by Volvo Penta, is to develop a portable battery swapping system. This could allow small business owners to maintain a limited number of standardized battery sizes for electromobility customers. This will also provide an extended battery life when there is an alternative to fast charging.

Despite that many marinas have access to shore power, most have insufficient power to charge multiple large batteries in a reasonable amount of time. A standard outlet in Sweden with 240 V AC has an output of 7.4 kW to 11 kW [2]. According to the previous reference, this can amount to 22 kW in special cases. Fast charging, also referred to DC fast charging (DCFC), has a maximum output of 350 kW DC and is most often limited by the acceptance rate of the battery used in the electric vehicle (EV) [3]. DCFCs are designed to fill an EV battery to 80% in 20-40 minutes, and 100% in 60-90 minutes. This type of fast charging is on the rise and it is expected that several years will pass until this is applicable on this segment due to its high cost and high power draw.

The idea that Volvo Penta requested is a concept that enables a smooth replacement of discharged batteries to fully charged batteries and allow for a slower charging time on land while the sailboat is in use. A slower charging time of the batteries would decrease the load on the power grid and increase the quality of battery life while at the same time give the boat owner a similar waiting time as refueling a sailboat with a conventional combustion engine. This includes boat design modifications and challenges to place the required components of an electric system, designing a system and any technical equipment that facilitates the handling the batteries. It also includes an investigation of other means of using the battery during off-season, as well as other possible extended functions and building a business case that handles the scenario.

## 1.2 Purpose & Objective

This project is a collaboration between the Chalmers University of Technology and The Pennsylvania State University that aims to explore the possibilities of a portable battery swapping system for sailboats powered by an electric driveline.

The project refers to battery characteristics, safety, and ergonomics by originating from goals given by Volvo Penta. Due to scarce availability of high capacity shore power at smaller marinas and the high cost for establishing fast charging options, this report researches other alternatives for sailboat users interested in electric boating. This entails a development of a portable battery swapping system where a discharged battery is replaced by a fully charged one.

Because of the short boating season in Northern Europe, a large quantity of batteries may be unused during longer periods. To prevent damage and avoid wasting the capacity of these batteries, potential uses during the off-season are discussed. Multiple aspects of the battery's design was researched and a model for a swapping system of modular battery units was created.

The points listed below are the main objectives to be achieved by the end of the report.

- Present alternative solutions to the combustion engine system for an environmentally friendly sailing experience.
- Contribute in lowering the load on the poorly developed power grids in marinas by utilizing slower charge cycles of the batteries.
- Reduce the time a sailboat user have to stop to recharge their batteries by implementing a portable battery swapping system.
- Make the swapping system user friendly by establishing customer needs and designing the system according to these criteria.
- Simplify the work for Volvo Penta regarding the development of a potential business case for the portable battery swapping system.

A few limitations and guidelines were given orally through meetings with supervisors and Volvo Penta. Other activities were given directly by Volvo Penta through the project proposal. The aim of these activities was to help define a proper point of origin and an endpoint for the project.

The activities listed below, among others, were used as a guideline to help realize the main objectives of the project.

- Study the challenges in how to swap batteries – literature, simulation, IP etc.
- Use a 20–60kWh battery size for 30–45-foot sailboats including boat design modifications
- Investigate the ergonomics/design challenges vs. battery size to decide kWh scope
- Design a system and possibly technical equipment that makes it easy to handle the battery
- Identify what battery characteristics are desirable and if current solutions satisfy the requirements.
- Study the safety aspects of the system with the focus on the challenges of cooling vs. no cooling of the batteries
- Come up with multiple possible solutions, maybe compare a few alternatives.
- Find other means of using the battery during off season, as well as other possible extended functions.
- Formulate a business case that handles the complete scenario.

- Provide design sketches/simplified CAD-models and simulation results of the final candidate.

## 1.3 Problem Description

Few harbors have fast charging solutions, and many lack the infrastructure to support it at all. Using traditional charging methods would require stops for hours or even entire days before batteries are fully recharged. According to Volvo Penta's request, along with the increased need for more environmentally friendly use, this problem requires a solution that gives boat owners a quick and efficient solution to use the system for an extended period.

The solution requested by Volvo Penta is an efficient replacement of a discharged battery with a fully charged one. It is the actual replacement process that has been investigated during this project. The problem is divided into the sub-problems listed below. These need to be dealt with to formulate a solution to the main task.

- Where will the system be installed/located on the vessel to not interfere with the customer's needs or the functionality of the boat?
- What kind of swapping mechanism can be utilized based on position?
- What type and size of battery is needed to meet the requirements of travel length and load capacity?
- What will the battery housing look like and will it be modular? If so, what will the individual module design look like?

Figure 1 explains how the problem statement is divided into several sub-problems and how they are connected to each other. The order of how the sub-problems are being solved, influences the prioritization of the solutions. The location of where the batteries are going to be placed influence how big the volume of the batteries can be, since the sailboat has a finite amount of space where the batteries can be placed. Another aspect of the location is the weight distribution of the sailboat. Where the batteries are going to be placed influence how the swapping mechanism can be designed and what type of batteries that can be implemented. The prioritization of the sub-problems influences each step on the way when designing solutions to this problem.

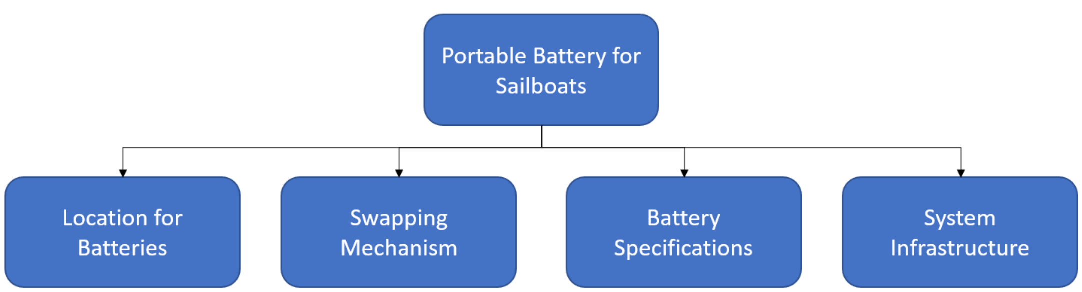


Figure 1: The problem statement divided into sub-problems

The prioritization of the sub-problems was determined by the grade of importance each function has based on the required specifications. The listed sub-problems are organized in chronological order of completion based on how much each previous task affects the latter. However, each sub-problem will have some level of effect on the others regardless of chronological positioning and must be considered for each proposed solution as well. The order of the sub-problems is visualized in figure 2

The battery specifications and the performance of the system was first determined. Then the location of the batteries were to be decided and if the location does not match battery specifications, which in this case means the volume of the batteries according to the specifications, another iteration was generated. If the concept matched the demands, it progressed to designing the swapping mechanism. In the final steps, iterations was conducted if sub-problems do not match the demands on the solutions as earlier described. However, the main goal for the solution was to perform at its best in each sub-problem. This implied that the team worked towards maximizing battery specifications, at the best possible location on the sailboat, with the easiest handled swapping mechanism at the same time designing the most optimal system infrastructure.

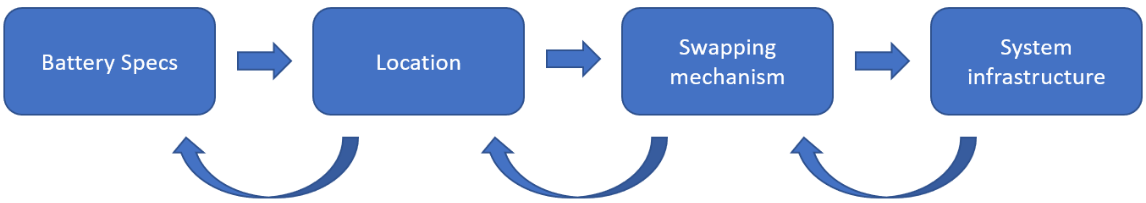


Figure 2: The selected prioritizing scheme of the sub-problems and the interconnections between the problems

### 1.3.1 Problem Statement

Overall, the main goal of this project is to construct an electric energy storage system that can be easily replaced via a swapping mechanism. Hence the team have researched how a battery swapping system on a sailboat with an electric driveline can be constructed to easily replace a discharged battery with a fully charged one.

## 1.4 Demarcation

It was assumed that the infrastructure of any swapping station required on land already existed and is functioning properly regardless of which solution that was the most suitable. The project team also assumed that the charged batteries on land are ready for swapping.

Nowadays there are no electric drivelines that can match the performance of a combustion engine system. Hence, the team did not compare the range between the two systems. Instead, a system was designed to meet Volvo Penta and the user's requirements.

The project was explicitly adapted to sailboats in sizes between 30-45 feet and did not cover any other marine vessels. Design modifications on the sailboat were allowed as long as it did not affect the functionality of the sailboat. It was preferable to have the least amount of intrusions on the design.

Due to the complexity, safety concerns, and high cost of manufacturing a battery system, the final product was created using modeling software to replicate a tangible prototype.

## 1.5 Risk Analysis

Over the course of the project a list of considerable risks were generated with the goal of assessing and developing a strategy to avoid them. Some risks were updated and altered during the process. Table 1 below consisting of the risks found most substantial during the course of the project. Each risk has been assigned a level of high, medium or low. The levels shows the probability of the event and how big of consequence it can lead to.

Table 1: Risk Analysis

| Risk | Level | Act to Minimize | Fallback Strategy |
|---|---|---|---|
| Corona complications | Low | Set up meetings and interviews through zoom or telephone rather than in person | Try to find another source with similar information as the expert the team intended to meet with |
| Time limitations | High | Proper demarcation and making sure research is relevant for the project. Well structured meetings leaving more time for individual work | Revising goals and adding additional demarcations. Putting in extra effort closer to deadline |
| Limited creative thinking and concept generation | High | Have the entire team dedicate time to creative thinking and discussions about what the system should entail. Try to have multiple iterations if a concept have major flaws | Use a previously generated concept and have deeper discussions regarding the pros and cons of that concept |
| Inability to use existing CAD models | Moderate | Reach out to manufacturers and offer to sign NDAs | Create a CAD-model of system from scratch or find and alter an existing boat model using Hallberg-Rassy 412 as a reference |
| Loss of work due to technical issues | Moderate | Make backups on hard drives and cloud storage | Ask supervisor if previously submitted documents can get redistributed |
| Customer needs not met | High | Establish main customer and their needs. Consult with experts, and make steps to meet needs | Often revise functions of system, and how they connect the customer needs. Discuss alternative ways of realizing project |

## 1.6 Outline of the Report

The report covers the development process and results of a portable battery swapping system. The process is written in chronological order starting with an introduction and theoretical information regarding the technical aspects of the project. The idea is to establish the topic and its significance and explain the research objectives. This is to give the reader a basic understanding of the content.

The following chapter after the introduction and theory is a description of the chosen methodology that was followed throughout the project. The methodology chapter answers the questions of how the working process entails and why it was executed in that manner. It presents an overview of the structure of the process and gives the reader an understanding of the specific approach.

The report also covers the process of determining the customer needs, including results from a quantitative and qualitative study which later was used as a foundation for the concept generation phase of the project. This phase is also covered in an independent chapter and presents the process of evaluating and eliminating different concepts before determining the final concept.

The ending chapters cover both the results of the final concept accomplished by the team and discussions of other potential possibilities with the project. They also cover recommendations for further work and development.

The appendix contains the information that did not contribute enough to the readers understanding to take place in the main structure. This includes the survey and interview questions used to determine the customer needs.

# 2 Theory on Systems on Board Sailboats

The development of a portable battery swapping system require knowledge from several different areas. In following sections initial research of batteries suitable for electric vehicles in a marine environment and certain safety aspects regarding these have been gathered from different literature sources.

## 2.1 Batteries for Electric Vessels

This section aims to research the battery most suitable for a swapping system implemented in sailboats with an electric driveline. There are several parameters to consider when choosing the most suitable battery for EVs and especially for those implemented in a marine environment. The three most important parameters chosen for this project is energy density, life cycle and safety performance. Since the purpose of the system is to be portable, it is important to look for a battery type that has a higher battery density, meaning higher energy per volume and mass. Higher energy per volume and mass is important for the battery to not be to heavy to handle as well as to not increase the weight carried by the boat. It is also important to look at the cycle life of the battery used for EV-application. Depending on the amount of charging cycles of the battery, the life time of the battery can be determined. The third parameter to look in to is the safety performance of the battery. Making the battery system resistant to phenomenon like overcharging and thermal runaway is key for a higher safety performance. Protecting the batteries from physical traumas will also be essential for the batteries to have a long lifespan.

According to [4] Lead-acid batteries have been the most commonly used battery type for EV-application in the last century. However, the most commonly used battery for electric vehicles today is Lithium-Ion batteries. It also said that there are some promising alternatives for the next generation of EV-batteries such as Li-$O_2$ batteries, Li-S battery, all-solid-state batteries (ASSBs).

Lead-acid batteries are the oldest kind of rechargeable batteries and is most common in conventional vehicles with an internal combustion engine but also for EV applications. It has very low specific energy and energy density ratios [5]. According to the same source Lithium-Ion batteries have the advantage of the lightness of their building components, their high loading capacity, internal resistance, and their high loading and unloading cycles. This makes Lithium-Ion batteries a more suitable choice for the implementation of the swapping system aimed to be created in this project, mostly since the weight of the batteries is of high importance for a system such as this. [5] also says that Lithium-Ion batteries has to operate within a safe and reliable window of operation based on the temperature and voltage levels. Exceeding these levels could lead to lowered battery performance and causing a security hazard. Despite this, Lithium-Ion batteries are the most commonly used in today's market for EVs and are safe to use if these restrictions are kept within the desired levels for these batteries.

### 2.1.1 Cooling Methods

Safety is key when using batteries for electric vehicles, especially when using them in a marine environment. As mentioned previously, Lithium-Ion batteries are today the most commonly used battery for EVs, mainly for their significant benefits including lighter weight, higher energy density, longer cycle life, etc. Despite these benefits, there are some safety aspects to consider when using Lithium-Ion batteries, especially regarding the temperature of the batteries. According to [6], the temperature of Lithium-Ion batteries quickly increase during high power or acceleration which can lead to a decrease in cell efficiency, safety, life span and could perhaps even create thermal runaway issues. Lithium-Ion batteries are very sensitive to temperature changes and have an acceptable operating range between -20°C to 60 °C but that the optimal operating range should be kept between 20°C to 40°C. Hence, maintaining the right temperature of the batteries and making sure no overheating occurs is of high importance.

Applying a cooling method to the batteries to stay in the most optimal temperature range is a way to solve this problem. There are different types of cooling methods which can be used for the battery packets. The most suitable ones can differ depending on the environment in where the battery packet will operate. It is safe to say that cooling could be a good option to avoid overheating in batteries installed in sailboats which mostly are in use during the summer when the temperature is higher.

Deng, et al, [7], divides the cooling system into active and passive cooling according to the control strategies of the system. A traditional passive cooling system utilizes the high sensitive and/or latent heat of liquids and transfer heat from the battery to the coolant which is then exchanged with external air. The air is then exhausted by an exhaust fan. To avoid overcooling or overheating of the battery packet it is important that the temperature of the incoming air is between 10-35°C for passive cooling. The active cooling system uses liquid/liquid heat exchanger to exchange the heat absorbed by the coolant. For active cooling the active components including an evaporator, pump, heating core, coolant and sometimes an electric heater and fuel heater is needed. Hence, the structure of the passive cooling system is less complicated and the cost of manufacturing is lower.

According to [8] liquid cooling performs better than other various cooling technologies or battery thermal management in EVs. The article categorizes existing technologies into four types, air cooling, liquid cooling, phase change material cooling, and a combination of all three. The method chosen for application depends on many factors such as compactness, lightweight, energy consumption, cooling efficiency and cost. The most commonly used technology for EVs today is liquid cooling.

## 2.2 Amenities on Board Sailboats

A large part of boating require the opportunity for stay-overs on the boat for a period of time. This means that a number of amenities on board are required to make this possible. For example, heating the cabin and water but also cooking facilities and power generation. At present, other systems on board are used to fulfill amenities that are appreciated on board. This can be, for example, utilizing the heat generated by the diesel engine. When changing from a diesel engine system to an electric driveline, these conditions will change and require new solutions. The following paragraphs will describe how some of the amenities works today, thereafter, section 2.3 describes potential solutions or adaptations to sailboats without a diesel engine system.

### 2.2.1 Water Heating

According to [9], a raw water cooling system is a type of cooling system that uses the water in which the boat floats, both saltwater and freshwater are used to cool the engine. This works by a seacock fitting drawing water into the engine and pumping it through the engine's water jacket using a mechanical water pump. This water only passes through the engine and ends up directly in the exhaust. The cold water absorbs heat to keep the engine cool. Newer marine engines use a closed cooling system which means a tank that contains a mixture of fresh water and coolant. This liquid is circulated through the engine passing a heat exchanger where the fresh water absorbs heat from the engine. According to [10], an alternative cooling solution used for diesel engines also provides the boat with useful hot water, for example for showers and cooking. This is done instead by the coolant, which in this case consists of only fresh water circulates through the engine block and through a heat exchanger, which recovers part of the energy that is not converted into electricity by the engine. Therefore, the circulating water recovers heat from the block and from the exhaust gases, which maintains the exhaust temperature at the exit of the system. This flow of hot water is then sent for consumption, while a fan coil ejects excess thermal energy before the cooling water is sent back to the engine.

### 2.2.2 Other Current Amenities on Board Sailboats

An important part for living on board a boat for several nights is the convenience of home-cooked food. Liquefied petroleum gas (LPG) is the most common fuel for the stove on a boat [11]. This method needs a spark or a flame to ignite. This can be in the form of a lit match or with the help of an electric spark. The disadvantage of LPG is that it is highly flammable and rather explosive. LPG is available for fixed stoves as well as portable ones. As this form of fuel is flammable, it is a good idea to update this in connection with the implementation of the system discussed in this report.

A diesel generator converts the chemical energy in diesel to electrical energy by connecting a diesel engine with an AC alternator [12]. The diesel engine spins the alternator creating an AC electrical current and is often used to power electrical equipment or charging small batteries.

## 2.3 Amenities Adapted for Electric Sailboats

Technology used on today's sailboats is often dependent on the diesel engine and its alternator. This project assumes that the diesel engine will be completely replaced, which means that the amenities need to be adapted accordingly.

### 2.3.1 Electric Heating

The search for a potential system that could be used to heat an electric sailboat and its amenities yielded the following. Heater-in-Converter technology (HiC) is known as "pseudo-cogeneration" as power electronic converters already present on the vehicle are used to generate heat by selectively and temporarily reducing its efficiency [13]. According to the previous reference, using the power loss of an electronic converter to heat the battery as a sort of reversal of cogeneration. This method is an alternative to resistance heating since it eliminates the need for a separate heater. Resistive heating and HiC are equivalent technologies as they both provide that electrical energy is converted into thermal energy. This energy can therefore be used to satisfy the boat's needs. In both cases the system is completely enclosed in the boat, which limits the sensitivity of the system to parameters typical in the open air, as the operating temperature range being the main driver. HiC can be applied under most conditions where temperature can cause problems for an electric propulsion system.

### 2.3.2 Generator and Cooking Equipment

Generating electricity is a good idea if amenities that are electrically powered should be used when sailing. An example of this solution is a hydrogen generator that produces renewable electricity while moving [14]. When the hydrogenerator is in use, it charges the batteries, which are often batteries that supply the sailboat's equipment with electricity, for example a stove, navigation system etc. This generator can generate up to 300 W at 10 knots and has a low noise level which enables the generation of electricity during movement.

There are fixed and portable cooktops available for electric boats equipped with a generator [15]. These stoves most commonly use 120 Volts. This may be a viable option if the generator is running as the stove is in use. An alternative that can be used on board an electric sailboat is a stove that uses electromagnetic induction rather than electric heat or an open flame. This option drastically reduces the risk of fire compared to LPG.

# 3 Methodology

The project aim is to find a solution for a portable battery swapping system for a sailboat driven by an electric motor upon request of Volvo Penta. A concept development methodology was implemented in order to find a viable solution.

## 3.1 Project Setup and Structure

The execution of this project followed a project design and development process with a focus on concept development. The process tree in figure 3 explains the methodology and each step towards finalizing the report. Documentation has taken place continuously and in parallel with the development of the assignment. Ideas that did not reach the end have been documented and reflected on to give a clear explanation as to why they were sifted away.

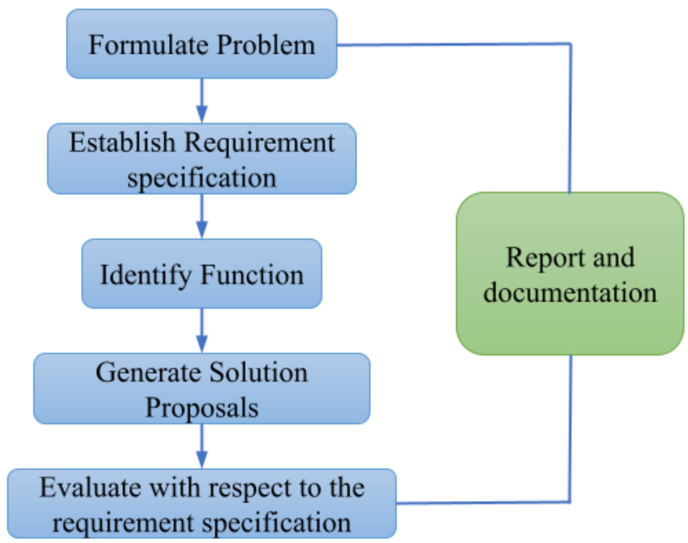


Figure 3: Process Tree

## 3.2 Analysis

To fully understand the different aspects of the project, an analysis of each area has been conducted to fulfill the requirement specification made with respect to the customer needs and target specification established in section 4.3.

Research and analysis of existing systems for sailboats have been conducted via literature research, customer research and conversations with various experts within the area to find an equivalent system for an electric driveline with comparable power capacity as the diesel engine system.

The analysis also includes an overview of what battery is most suitable for electric drivelines implemented in a marine environment, this include decisions regarding battery size and safety aspects, such as ergonomics and alternative cooling methods. Potential swapping systems are investigated to determine the most suitable solution concerning the requirement specification. This includes an analysis of what type of solution is the most beneficial concerning the weight and the number of batteries and if the swapping system will be manual or system supported.

## 3.3 Scoping and Information Gathering

Information gathering was carried out in a variety of different ways. Information pertaining to existing techniques has been conducted similarly to a literature study. With regard to requirements specifications, the information was mostly collected from current boat owners through the use of a survey.

### 3.3.1 Definition of Customer Group

The project's main customer is Volvo Penta and hence the system needs to meet their requirements. However, the system also needed to apply to the needs of Volvo Penta's customers. The sailboat manufacturers are customers as they are the ones meant to implement this system when manufacturing sailboats. The end-user of the system is the sailboat user which means that the requirement specification also were made with regard to a sailboat user's needs and preferences. Keeping in mind that a new system should aim to follow the same standard as current technology so as not to impair and complicate the boating experience for a sailboat user. The marinas were assumed to be adapted to our project and thus not the customer group the project focused on.

To facilitate the implementation of this type of information search, the questions in the survey were designed as open-ended questions so as to not influence the customer responses. In addition, questions were asked to be able to categorize customers in different areas such as the duration of their boat interest, how often they use the sailboat, what distances they travel, etc. to get an understanding of the users' behavior. Once this information was gathered, a requirement specification was completed to weigh the requirements against each other. This was helpful when planning and scheduling the various tasks.

### 3.3.2 Quantitative & Qualitative Study

Information gathering in this form follows the steps of data collection, data analysis and implementation of conclusions. This process was carried out with the help of quantitative and qualitative research. In order to begin, a sailboat user survey was conducted in two steps. First, a survey was distributed to sailboat users. Subsequently, the respondents who were interested in a more in-depth interview were contacted.

Quantitative research is a method used for data collection that aims to describe the area studied. It is most often used because of its simplicity and low requirements. A larger number of respondents were meant to answer a questionnaire and then process and evaluate its statistical information. This method examines questions marginally and was not time consuming for the respondents. The method uses deduction from the result. This means that a conclusion is formulated after a large amount of data is collected. The disadvantages of the method are that the results can be large and relatively superficial. This can lead to the conclusions being formulated missing important characteristics of the test group because the answers are concertized and lack the larger perspective. Advantages of the method are that the number of answers is often large. The big data collection provides an effective way for decision-making and formulation of a target specification. Another great advantage of this method is that the large amount of information is collected over a short period, which means that a conclusion can be drawn quickly.

In the case of qualitative data collection, the selected sample group is a small number of respondents and is carried out primarily with the use of individual interviews, which provides an opportunity to investigate questions in depth. The disadvantage of this method is that it is more time consuming than the previously mentioned method. The method uses induction from results, meaning that a general conclusion is drawn from a small amount of data collected by a small number of respondents.

The two methods, qualitative and quantitative research, are used as a complement to each other to create a realistic overall picture and to use the information to continue in the project in the form of a target specification and beginning to an idea generation.

## 3.4 Concept generation and Evaluation Process

Based on the customer needs and respective target specification formulated after the qualitative and quantitative studies different concepts were put together through an idea generation phase. Methods such as brainstorming took place jointly as well as individually. Every member of the group formulated some concepts that were thoroughly discussed and evaluated both within the team and with supervisors, who provided guidance.

An Analytic Hierarchy Process (AHP) and a Weighted Decision Matrix were used in order to determine which of these concepts best meets the customers' requirements. Through this process, the pros and cons of each solution concept were thoroughly discussed. Each concept was scored after how well it meets each customer need and respective target specification. Once all of the concepts were evaluated, the scores for each category were multiplied by the weight that was found from the AHP matrix. The total scores were then added up and the concept with highest score became the final concept the team chose to move forward with and continued to develop.

## 3.5 Potential Business Case Research

The development of a business case for this concept was conducted by researching similar business models in other segments and with similar concepts. Since this was not the main focus for the project, the amount of time and resources the team spent on this was not that extensive in comparison with the development of the concept. The research looked into other portable battery systems such as electric scooters, cars and mopeds. After that, the team discussed and brainstormed a business model for the concept and came to the conclusions presented.

# 4 Customer Needs

To develop a user friendly system, customer surveys were distributed to gain knowledge of the typical sailboat user. The sought information from the survey was to estimate the sailboat market in Sweden and the behavior and needs of those who engage in frequent sailing. These were to be fulfilled when implementing a portable swapping system. According to [16], there are approximately 52 300 sailing yachts in Sweden designed for multiple overnight stays and 29 400 sailboats with possibilities for temporary stay overs. It is of great importance to Swedes to experience a sense of freedom and get close to nature. The source approximated 90% of the boat enthusiasts in Sweden find that experiencing nature is one of the most important aspects of their boat life. The same goes for the sense of freedom, approximately 83% find that as important.

## 4.1 Results From Quantitative & Qualitative Study

When designing a system like this, it is important to have an understanding for how the customers behave, meaning how sailboat users use their boat and what preferences need to be prioritized, since this can act as a foundation for the future design of the swapping system. In order to get a deeper understanding of the customers, a survey was conducted. The survey contained a lot of questions, with the clear purpose of seeing, understanding and analyzing how sailboat users use their boat and its amenities today. To see how the customers utilizes the equipment today gives a clear view of the behavior, preferences and interaction with the equipment. Based on this, many conclusions and insights can be summarized. This method was used since it is sometimes hard for a participant to imagine what kind of problems and opinions that is important for a non-existing system and at same time being unbiased. However, all opinions and experiences might not be applicable to the final system. Due to this, conclusions were formed in a cautious manner.

The conducted survey in Appendix A provided insights to determine customer needs and problems. The quantitative survey contained questions in order to observe the customer's behavior in different situations and handling of the sailboat. The survey was primarily meant for Swedish sailboat users and was posted in a Facebook group, a forum for sailboat owners who shares ideas for maintenance, re-makings and restorations of sailboats. There were 187 respondents to the survey, and out of these 69 were willing to participate in a deeper and more qualitative interview. However, due to the short time frame for the customer research part, there were not enough time to contact more than 11 interviewees.

### 4.1.1 Summary on Consumer Findings

To summarize the customer research, the main takeaways from the quantitative survey are the following:

- The range of the system does not need to match the general range of a conventional fuel tank. A majority of sailboat users only refuel at maximum three times per summer season and most of the respondents would accept a range of 60 nautical miles.
- A majority of sailboat users can spend more than five nights without visiting a harbor for getting the essential necessities. Most of the respondents also want to be able to produce their own electricity on board the sailboat.
- Almost all of the sailboat users use their engines to go in and out of the harbors. However, there are also several other situations most of the respondents use their engines. For example when there is no wind, in canals, when there is to much wind, when going against the wind, and to charge the batteries.
- The time for charging the batteries is not as important since many of the sailboat users are staying for the night when they are visiting harbors. Charging the batteries during the night is

then a viable alternative. Sometimes there are situations when a fast swap is necessary.

- The silence of an electric driveline is appreciated.
- The feeling of using renewable energy instead of fossil fuels is an important factor when choosing this system. If the respondents were to buy a new boat, many would choose an electric driveline instead of a conventional combustion engine system.

The key takeaways and comments from the qualitative interviews that were conducted are the following:

- The health of the batteries are an important consideration, since when a sailboat user is swapping the batteries for fully charged ones, they need to have equally as good health as the ones you are swapping.
- The economical part of the system is of outer most importance. Relatively, the system need to be reasonably priced compared to the conventional alternatives in order for many sailboat users to choose this.
- The availability of batteries needs to be equally as good as refueling your sailboat today.
- The swapping system should be easily handled by one person.
- An advantage with an electric driveline is that it doesn't need as much maintenance compared to a conventional combustion engine and it can also many times be more reliant.
- The status of how much energy that is left in the batteries is important to know for sailboat users, just like a combustion engine often has a fuel gauge.

## 4.2 Summary of Customer Needs

Based on the customer research conducted, a final set of customer needs were established. These were specified to be able to determine the most important factors when designing and implementing the swapping system. The estimated values in the table are only rough estimates based on the information pertained in the survey.

Table 2: Final set of customer needs showing the major considerations and the metrics for each need

| **Value** | 60 km | 50 kWh | $< 50$ °C | $< 30$ min | 1 Person | $>$ 2000 charging cycles | $< 20$ kg | $< 75$ kg | 1 m$^3$ | <60 km |
|---|---|---|---|---|---|---|---|---|---|---|
| **Metrics**<br>**Needs** | Range | Battery Delivery Power | Temperature of Battery Surface | Swapping Time | Number of Users | Charging Cycles | Weight (manual) | Weight (assisted) | Volume | Distance Between Swapping Stations |
| Performance | X | X | | X | | | | | | |
| Safety | | | X | | | | X | X | | |
| Perceived Security | X | | | | | | | | | |
| Sustainability | | | | | | X | | | | |
| Usability | X | | | X | X | | | | | |
| Size | | | | | | | X | X | X | |
| Availability | | | | | | | | | | X |

## 4.3 Target Specification

Ten target specifications were established using the customer research along with Volvo Penta's instructions to produce product concepts. The specifications are shown in Table 3. They were designed according to the battery's performance and its physical design, but also according to the swapping and its implementation. The threshold value is the minimum or maximum acceptable value for each specification and the objective value is considered to be the most optimal value for each area. The scoring criteria for each specification is scored on a scale from 1 to 5, where the the score of 5 is considered to be of most importance.

Table 3: Target Specification for the Portable Battery Swapping System

| Specification No. | Specification | Importance | Threshold | Objective Value | Units |
|---|---|---|---|---|---|
| 1 | Range (Maximum Use) | 4 | >15 | 20 | km |
| 2 | Range (Average Use) | 4 | >75 | 110 | km |
| 3 | Battery Delivery Power | 4 | >40 | 50 | kWh |
| 4 | Temperature of the Battery Surface | 4 | <60 | <50 | Celsius (°C ) |
| 5 | Swapping Time | 3 | <60 | <30 | Minutes |
| 7 | Number of Users | 5 | 2 | 1 | Persons |
| 8 | Charging Cycles | 3 | >1500 | >2000 | Charging Cycle |
| 9 | Weight (manual) | 4 | <50 | <20 | kg/module |
| 10 | Weight (assisted) | 4 | <100 | <75 | kg/module |
| 11 | Volume | 4 | 2 | 1 | $m^3$ |

The range requirements are based on how far the consumers would be willing to accept at maximum use, meaning full throttle, and at average use, meaning low to medium throttle. This is an average estimated value based on the sailboat owners current use that they prefer to keep due to safety and comfort. Swapping time, number of users and weight of the batteries during manual or assisted swaps are also based on the customer research along with an estimate based on how ergonomic the design can be to be accepted by the users. The main concerns sailboat owners had was about how many people that were required to replace the battery and subsequently the charging time. They were less concerned about the weight of the batteries, neither in manual or assisted swapping other than that it should be feasible. As Volvo Penta requested to keep ergonomics in mind, a weight limit was estimated.

The battery delivery power is also a requirement that Volvo Penta requested, 50 kWh was preferred. The temperature of the battery surface is based on the maximum temperature of a Lithium-Ion battery according to the theory in 2.1.1. The volume in target specifications refers to the volume that the batteries occupy in the boat. This is an estimate after visits on multiple sailboats in the size of 30-54 feet.

As mentioned in section 4.1.1 the cost is an important factor to consider. However, the team was not able to estimate a reasonable price for this system to be implemented and be successful on the market. As the sailboat owners did not provide what they consider a reasonable price for such a portable battery swapping system, other than as low-cost as possible, the cost was left out of the target specification.

The number of charging cycles was assumed to maintain the same amount as other batteries in the automotive industry. The estimate was made according to [17].

## 4.4 AHP-Matrix

The most important needs to consider were usability, safety and performance after discussions with support from the AHP-matrix. The concepts should be assessed mostly on how well they perform in each selection criteria. However, one main objective with this system is to make sailing more sustainable and that should not be neglected even if it got the lowest score, when eliminating the concepts. The scoring was rated 1-5 in how important each selection criteria is, just like in the target specification.

Table 4: AHP-matrix where each selection criteria are weighed against each other in order to determine the importance of each criteria. The criteria with the highest percentage is considered to be of most importance.

| | Performance | Safety | Sustainability | Usability | Lifetime | Size | Total | Weight (%) |
|---|---|---|---|---|---|---|---|---|
| Performance | 1 | 1 | 3 | 1/2 | 2 | 1/2 | 8 | 17.0% |
| Safety | 1 | 1 | 4 | 1 | 2 | 3 | 12 | 25.5% |
| Sustainability | 1/3 | 1/4 | 1 | 1/3 | 1/2 | 1 | 3.42 | 7.3% |
| Usability | 2 | 1 | 3 | 1 | 3 | 2 | 12 | 25.5% |
| Lifetime | 1/2 | 1/2 | 2 | 1/3 | 1 | 1/2 | 4.83 | 10.3% |
| Size | 2 | 1/3 | 1 | 1/2 | 2 | 1 | 6.83 | 14.5% |
| Total | | | | | | | 47.08 | 100% |

# 5 Concept Generation

In this phase of the project, alternative solutions concepts was generated and thoroughly discussed and analyzed to determine which concept to select for further development. Each team member got some time to generate a simplified concept of the working system. Not many of the concepts made it far in the elimination process, but by combining and reworking these early iterations a few more refined ideas could be presented. By dividing the systems into their basic functions and attributes the concepts could be compared against the customer needs specified earlier and other limitations due to risk or space efficiency. After evaluation the concepts were compared to one another using a Weighted Decision Matrix to reach a final model that was developed further.

## 5.1 Function Analysis

For the design to function properly and for it to be easy to implement, there are a couple of main aspects the system need to handle well. Many of these aspects tie into each other but were all important to take into consideration during the design process. By defining the attributes of each system, it was also easier to compare two system abilities to satisfy a set of criteria. Both mechanical and electrical functions of the system were evaluated.

### 5.1.1 Electrical Functions

For users to be interested to swap to a completely electric system there need to be solutions for all the ordinary functions of the combustion engine. This includes necessary functions such as propulsion and driving pumps but also more quality of life functions such as having hot water for showers or charging non-crucial electrical devices.

Listed below are the functions that were deemed to require extra discussion.

- Propulsion
- Appliances
  - Lanterns
  - GPS and communication devices
- Heating and warm water
- Other amenities
  - Kitchen stove
  - Charging of other electrical devices

Table 5 below presents a list of some of the most common amenities and their general power consumption in a sailboat. These are critical factors to consider when converting to an electric driveline as it is not only the propulsion that a conventional combustion engine contributes.

Table 5: Power Consumption of Common Amenities

| Type of equipment | Power (W) |
|---|---|
| Lights inside the sailboat (LED) | 20 W (in total) |
| Fridge/cool box | 10 W (on average when already cool) |
| Bilge pump | 42 W |
| Septic tank pump | 66 W |
| Freshwater pump | 48 W |
| Navigation & communication devices | 40 W |
| Inverter from DC to AC | 800 W* |

* Top capacity of 800W, depends on what equipment that are plugged in.

Some functions translates well to an electrical system, for example propulsion, which is an implied matter of swapping the combustion based system for an electrical driveline. Hot water is a good example of a function that needs a less prominent solution, since neither an electric motor nor the batteries usually reach the temperatures needed to simply swap out the engine for an all electric solution. At the same time, heating by using purely electric means would require a lot of power. This would lead to limited range for those who want to use the stove or heated water.

### 5.1.2 Mechanical Functions

Since batteries are modular by nature, it is assumed that a specific battery can be constructed for each concept. While this makes the design process easier, it is still important to think about aspects such as weight, volume and shape of the battery modules to make sure the design is feasible. Even if the design of the modules may be different, the criteria remain virtually the same.

Physical characteristics of the batteries need to consider the following factors:

- Weight
- Volume
- Shape
- Number of Modules

Splitting the battery into separate modules is beneficial as it allows for a system with lower weight limit than required otherwise. Smaller modules could also allow for manual swapping of the batteries when mechanical solutions are unavailable.

When working in a confined space such as a sailboat it is important to consider what areas are available. The batteries themselves will already be of a considerable size and likely take up much of the space gained by removing the motor and gas tank(s). By making sure the system itself is compact and space efficient little to no room is taken from other functional areas of the vessel. Access points could be limited, and the design should have an easy way to get to the batteries when it is time to swap them. If the swapping system has moving mechanical parts, such as hatches, pulleys or rails, maintenance of these parts would likely fall on the consumer. When poorly implemented, maintenance and safeguarding of these parts can get difficult and might scare away potential users. Easy installation could also affect a consumers decision to move to a purely electrical system and should be considered as well.

Considering these factors, the aspects listed below were decided as the ones to be considered when evaluating the swapping system itself.

- Space efficiency
- Getting batteries into place
  - Positioning on the boat
  - Means of moving battery modules
- Maintenance
- Installation

## 5.2 Idea Generation

As soon as the needed functions were decided, generation of concepts for the battery swapping were initiated. In order to make reasonable assumptions for system placement a model had to be found. Since Volvo could not provide their models the Hallberg-Rassy 412 sailboat was used for design considerations in the beginning of the project. A model sketch of the vessel layout is shown in Figures 4 and 5.

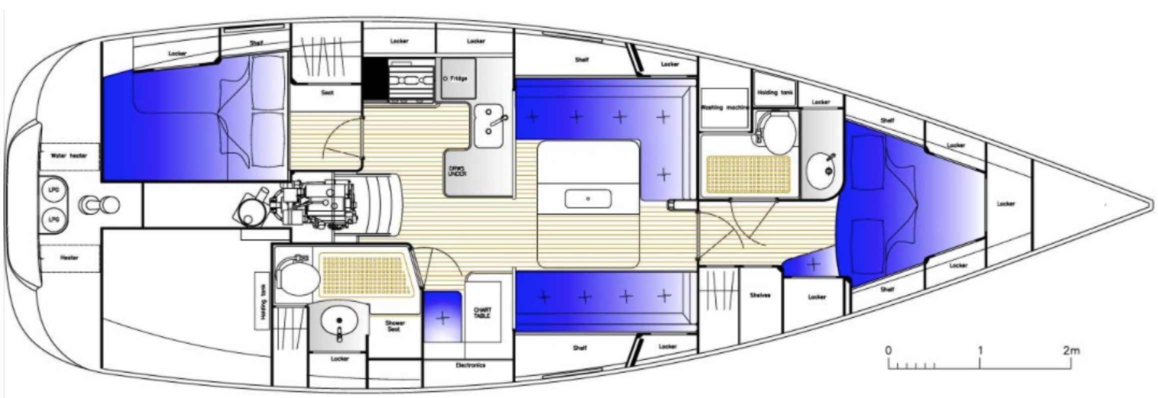


Figure 4: Hallberg-Rassy 412 interior drawings (Top View). From [18]

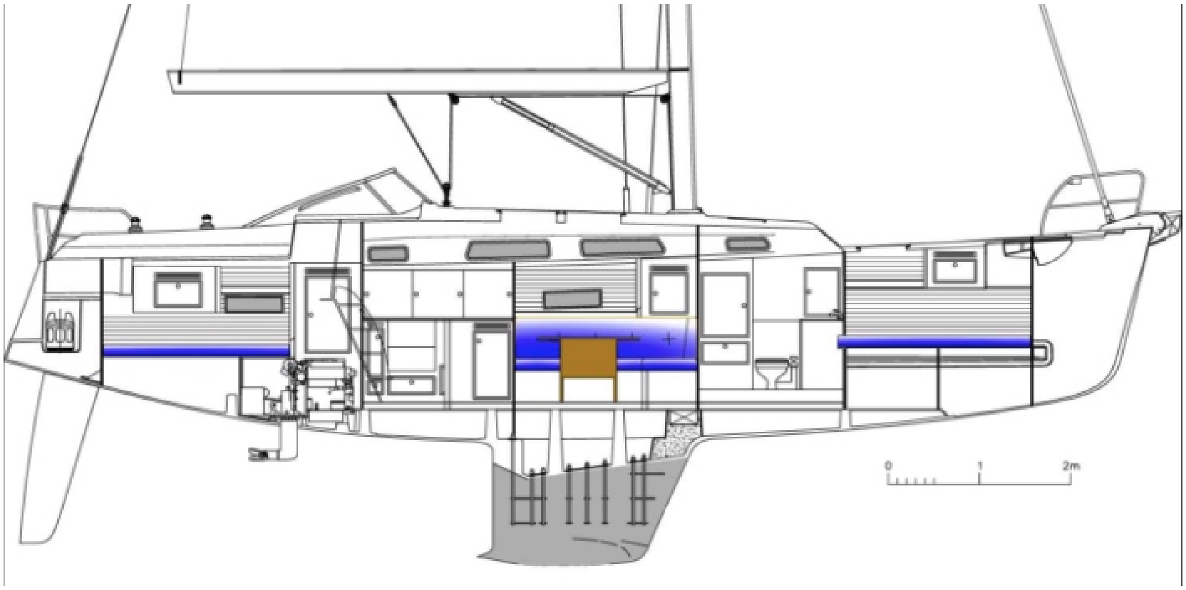

Figure 5: Hallberg-Rassy 412 interior drawings (Side View). From [18]

Different concepts were during this phase generated and each one is described in section 5.2.1, 5.2.2 and 5.2.3. These concept were later discussed during an evaluation and elimination process.

### 5.2.1 Concept Based on a Rail System

The first concept focus on having fewer battery modules, and making them easy to move when on board the boat. By making the batteries modular and interchangeable, the time to fully charge the battery is reduced and the duration of the swapping is dependent of the users swapping procedure. Additionally, a modular system provides the ability to carry extra batteries for longer trips.

The sketch in figure 6 a rail installed into the floor of the cabin to allow the user to easily slide each module to an access point below the skylight. This rail system lets one individual transport modules weighing between 80-150 kg, across the entire vessel. Each module has built in handles for easy contact from the user, and a grove at the top that will allow a crane or pulley system to be attached to lift the module from the boat. An example of such pulley is demonstrated in figure 7. The fully charged module will be lowered onto the rail and easily transported along the boat to the battery housing. The placement of the batteries will be in the same location where the engine currently resides to correct the weight displacement from removing the engine.

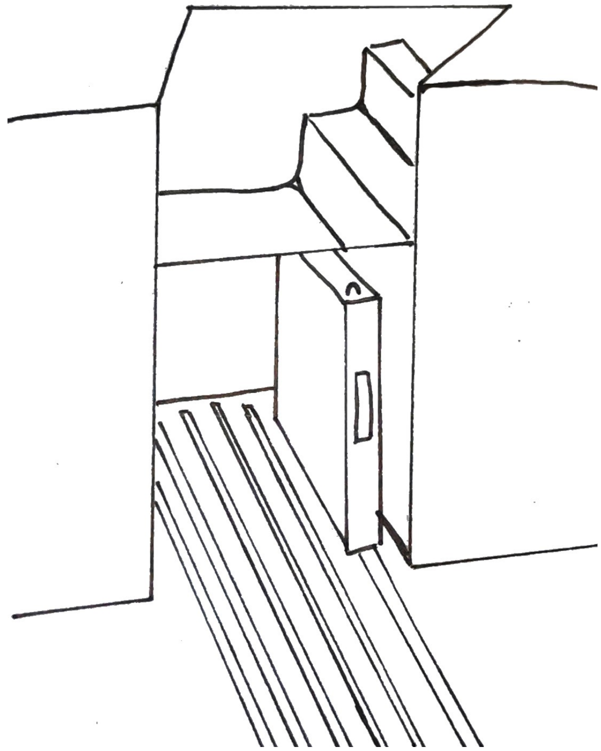

Figure 6: Prototype Sketch 1

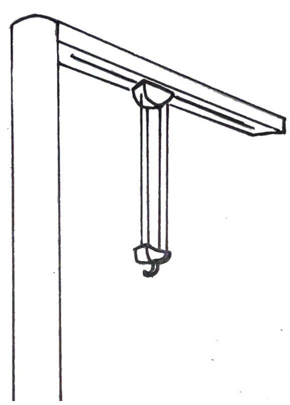

Figure 7: Sketch of Crane Pulley System

### 5.2.2 Concept based on Multiple Lighter Modules

Second concept puts more emphasis on making swapping more modular. With multiple lighter modules they could even be lifted and swapped manually. Smaller modules also allows to place batteries in more places on the vessel, leaving more space for other functions or living space. The sketch in figure 8 shows an example of a suitcase-like module, as well as possible placements on the boat marked with X's. The same crane modeled in figure 7 could be used to move multiple modules safely onto the boat at once.

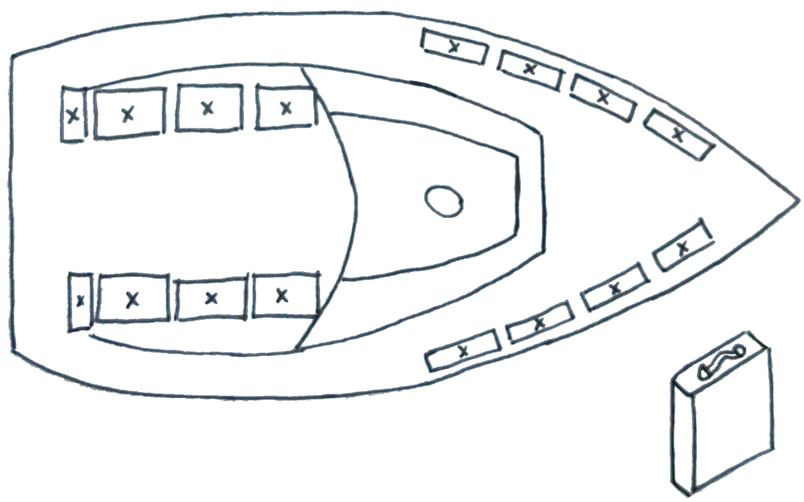

Figure 8: Prototype Sketch 2

### 5.2.3 Concept Based on Using the Boom for Swapping the Batteries

Lastly, a developed concept used the already existing infrastructure of the boat. Like the first concept, batteries are placed in the same location of where the engine currently resides to keep weight distribution in balance. Instead of moving the batteries to an access point, a pulley system attached to the boom can reach the modules directly. The boom could then swing out onto the docks with one or more modules hooked to the pulley. This way swapping can be done at any harbor with available modules without relying on any infrastructure installed at the docks. The idea was first introduced with figure 9, and when developed further clarified with figure 10.

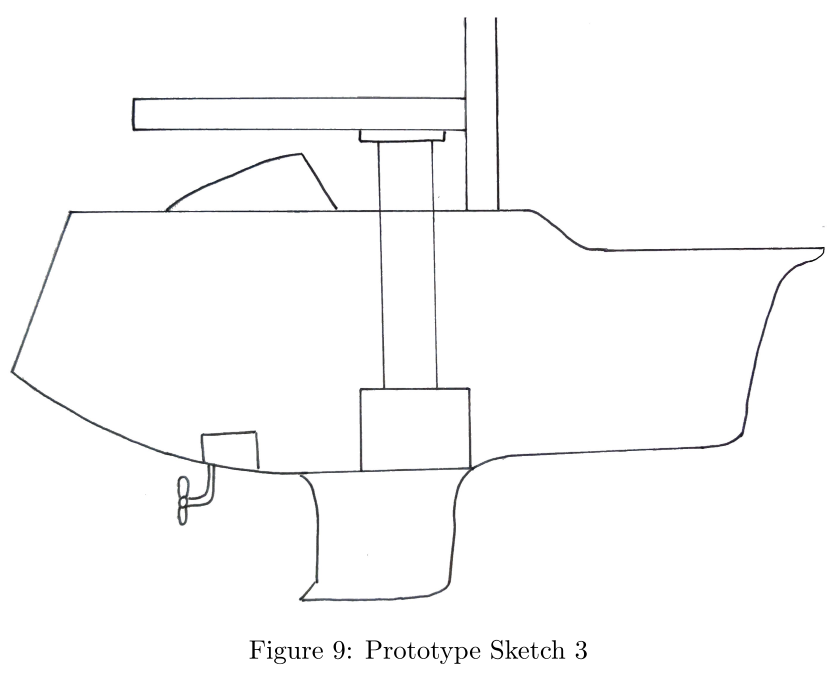

Figure 9: Prototype Sketch 3

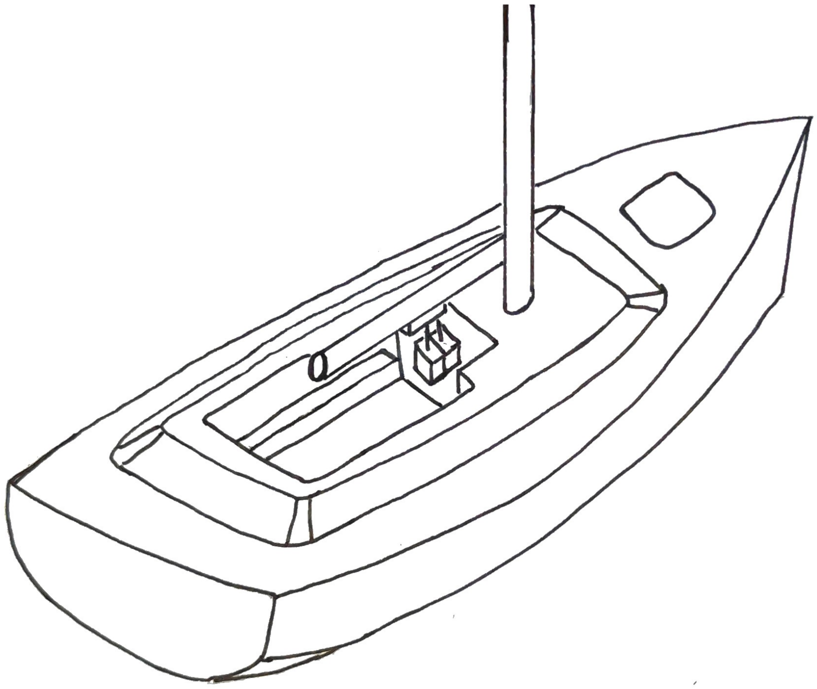

Figure 10: More Advanced Sketch of the Third Concept

## 5.3 Evaluation and Elimination

After the idea generation phase the concepts presented in section 5.2.1, 5.2.2 and 5.2.3 were generated. A firm evaluation criteria (Weighted Decision Matrix) was used to motivate which design was more optimal to implement than the others. A concept was not chosen, instead all three concepts were evaluated to be able to find the best suited one based on elimination rather than deciding. The Weighted Decision Matrix was used as support in making the decisions for eliminating concepts. However, even if a concept gets the highest score this does not imply that it is the best solution.

### 5.3.1 Elimination Using the Weighted Decision Matrix

A Weighted Decision Matrix was used in order to determine which of these concepts best meets the customers' requirements. Through this process, the pros and cons of each solution concept was thoroughly discussed and the most suitable concept became the final solution that was further developed. Each concept was scored as to how well it meets each customer need and respective target specification. The concepts that where discussed in the Weighted Decision Matrix did all fulfill the essential demands that the system requires. Then the discussions where based on how well they meet the demands on the system.

The following list explains the three concept evaluated.

1. The concept based on a rail system
2. The concept based on multiple lighter modules
3. The concept based on using the boom for swapping the batteries

Table 6 describes how well each concept scores in each selection criteria. When discussing the performance, the conclusion was that all three concepts scored the same, since the same capacity for the batteries and type where used in all concepts. There can be some minor differences in performance, such as swapping time but the team estimated that it would not be that big, which is why they scored the same. The safety can be viewed from different perspectives. By using the boom in concept 3, it can both increase the safety when applying extra help and standing further away from the lifting, at the same time be more dangerous since the weight is of the batteries are heavier. When carrying the batteries by hand, the risk of dropping a module is bigger which is more dangerous.

The sustainability of the system is assessed to be approximately the same since the concepts are based on the same type of batteries. When looking at usability, it is both easier, quicker and more flexible to use the boom for lifting the batteries. The rail system in concept 1 is not so usable since there are multiple objects in the way for the railway inside the boat. This means that a lot of time is spent on moving things around, resulting in a less user-friendly system. The modules that the user is carrying manually in concept 2 is not equally as user-friendly as concept 3, since there are a several more modules to carry and that they are located on different spots on board the sailboat. The lifespan of the concepts are assessed to be the same since the concepts are using the same batteries, which are estimated to the most age-crucial component in the solutions. The size of the system is not distinctive, since the same battery capacity is being used in all concepts. But the smaller module batteries can be located on the sailboat in a more size-effective manner compared to the other two concepts. The railway system in concept 1 is covering more space than the other two, which is why it gets a lower score.

The comparison between the concepts is used to easier get an understanding of the elimination process of the concepts. However, the Weighted Decision Matrix is relative to the target specifications and the discussions about this have focused on how well each concepts perform in each selection criteria. This method has been a way to both compare them against each other, at the same time discussing how well they perform against the selection criteria.

Table 6: Weighted Decision Matrix

| | | **Concepts** | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | |
| **Selection Criteria** | **Weight** | **Rating** | **Weighted Score** | **Rating** | **Weighted Score** | **Rating** | **Weighted Score** |
| Performance | 0.170 | 3 | 0.510 | 3 | 0.510 | 3 | 0.510 |
| Safety | 0.255 | 2 | 0.510 | 2 | 0.510 | 4 | 1.020 |
| Sustainability | 0.073 | 3 | 0.219 | 3 | 0.219 | 3 | 0.219 |
| Usability | 0.255 | 2 | 0.510 | 3 | 0.765 | 4 | 1.020 |
| Lifetime | 0.103 | 3 | 0.309 | 3 | 0.309 | 3 | 0.309 |
| Size | 0.145 | 2 | 0.290 | 4 | 0.580 | 3 | 0.435 |
| | **Total Score** | | 2.348 | | 2.893 | | 3.513 |
| | **Rank** | | 3 | | 2 | | 1 |
| | **Continue** | No | | Yes- Alternative Design | | Yes - Primary Design | |

Table 7: Relative Performance Rating Chart is the scoring system that was used in the weighted decision matrix. The scoring is relative in how each concept perform at each target specification in table 3

| **Relative Performance** | **Rating** |
|---|---|
| Much Worse than Target Spec. | 1 |
| Worse than Target Spec. | 2 |
| Same as Target Spec. | 3 |
| Better than Target Spec. | 4 |
| Much Better than Target Spec. | 5 |

# 6 Results and Illustrations of the Final Concept

This section provides the final specifications regarding the portable battery swapping systems. This includes a description of the final concept divided in to three subsystems, battery, on board swapping system and maintenance accompanied with CAD models and decisions regarding specific materials suitable for the system.

## 6.1 Subsystems

After the evaluation and elimination process a final concept was generated. The system was divided into the three subsystems listed below. Each subsystem is important in order to build a functional system.

- On-board swapping system
- Battery
- Maintenance

### 6.1.1 On board Swapping System

The technical specifications and preferences for this project highlighted the importance of the system being operable by one person. A mechanically assisted swapping method was developed to load the battery modules in and out of the vessel. The swapping mechanism was designed so that one person could load the battery modules onto a pulley mechanism and lift the battery modules by themselves. Pulley systems allow a single person to lift more weight by redistributing the downward force of the object. The pulley mechanism has a sliding effect so that the battery can be moved up and down the boat length wise by using the boom. This eliminates the need to manually lift the battery modules. Utilizing the boom of the sailboat is an efficient and effective method of shifting the battery along the boat and positioning it to be lowered into the hull. Some redesigns on the boom might be necessary in order to utilize it for the swapping system.

Weight distribution is another important factor to consider. The battery was designed to be situated near the center of the hull to maintain the balance of the vessel and for the easiest insertion of the battery through the opening in the deck. When removing battery modules from the boat and back onto land, a dolly or cart can be used to transport the batteries so that they do not have to be lifted by hand.

### 6.1.2 Battery Characteristics

Since no specific battery with the desired requirements exists, research was conducted on existing solutions and adapted for the project's purpose. Target aspects include optimizing battery capacity for a specific weight, ergonomic shape for easy handling, and a low emission life cycle. Literary studies and interviews with experts knowledgeable in relevant technologies gave a foundation for the calculations and decision-making during the design process.

When selecting an appropriate battery packet for sailboats with an electric driveline it is clear to say that Lithium-Ion is the preferable choice because of the benefits mentioned in section 2.1. It was also important for the battery packet to be easy manageable, that is, easy to to remove from its place in the boat as well as easy to install. The battery packet should also preferably be close to the boat's center of mass as to not disturb the weight balance in the boat. This made it difficult to find a specific battery type that would meet the desired requirements of the project. Since it is was specified to be outside the limits of the project and the level of competence for the group to construct a completely new battery module that exactly meets the desired requirements, the battery type is instead based on existing battery packets offered by companies on the market today.

The company whose battery packets used as a model for battery design, Cleantron, have several different battery packets which uses either no cooling, passive cooling or active cooling [19]. Based on the research made in section 2.1.1 it was determined that cooling is necessary for the system. Hence, decisions regarding the final battery choice were only based on the battery packets using passive or active cooling. The Cleantron P4X packet is an advanced 48V modular battery packet where passive cooling is realized by a smart thermal path design. It works through an optimal thermal path using advanced heat conductive technologies like thermo conductive plastics and gap filling technology. The same battery packet also exist with active cooling where the system module is equipped with a unique light and compact cooling system which is executed by side cover plates with integrated cooling channels, allowing optimal active cooling.

The battery considered the most suitable chosen for this system was designed to be broken down into 10 modules totaling 50 kWh of output, which is within the required battery capacity requested by Volvo Penta. Each module will weigh 60.2 kg. The internal components of each battery module were modeled after the The Cleantron P4X 48V modular battery pack. Each modular utilizes passive cooling via an optimized thermal path using advanced heat conductive technology [19].

At this weight each battery module would be to heavy for one person to swap manually, but with the pulley system previously discussed, each of these modules should be easily handled by one person. The total weight of the entire battery case will be 602 kg. The run time of the battery can vary based on impacting conditions such as weather, boat drag, battery output, water currents and a number of other factors. This makes it difficult to develop an exact numeric value for the range of the battery. The battery characteristics should optimize the ergonomics of the design for easy handling. Handles were added to the top of each module to make them easier to transport and attach to the pulley mechanism. This also makes the modules easier to move in and out of the casing.

#### 6.1.3 Operation and Maintenance of the Battery Swapping Station

The main focus of this project is not the battery swapping stations on land, but some work in this field has been conducted. The battery swapping stations will be as self-sustaining as possible in order to reduce the cost and resources of the operations. This means that it is unmanned during the swapping process just like an unmanned fuel station. The operations include maintaining the swapping station and the batteries. A diagnosis system will check the health of the batteries when inserted into the battery swapping station. The availability of batteries is also an important part of succeeding with this concept and making sure that there are enough batteries to meet the demands of the sailboat users at the specific battery swapping station is a major part of the operations. To know the demand from the sailboat users, a reservation system will allow the sailboat users to reserve batteries in advance and also contribute to estimating the demand for batteries at each station.

### 6.2 Business Case of the Concept

The business model for the concept is based on a subscription model and the customers do not own the batteries. The subscription will be paid during the season and the customer will also pay a fee when swapping batteries. The customer will subscribe on an chosen amount of batteries depending on the energy demand of the sailboat. The business case includes partners for operating the battery swapping stations and where they can be located. The stations need to be placed at strategically chosen locations in order to meet the demands of the availability of the batteries. A partnership with the land owners where the battery swapping stations can be placed needs to be established. The operation part of the business case is narrowed down to maintenance of the swapping stations, the batteries and making sure that there is enough batteries to meet the demand from the sailboat users.

## 6.3 Material Selection

Based on the research conducted in section 2.1 the selected material for the battery packet in the system was chosen to be Lithium-Ion. There are several companies that offer battery packets for electric vehicles today, Oceanvolt, GreenStar Marine and Cleantron are examples of companies offering battery packets for vehicles aimed for marine use. Oceanvolt offers hybrid or electric power and propulsion systems in partnership with many leading monohull boat builders [20]. GreenStar Marine is a Swedish company that offers electrical inboards that gives an efficient driveline with minimal maintenance that are cheap to operate. GreenStar Marine complete electric propulsion system offers a silent energy source dimensioned to deliver maximum power and operating time [21]. As mentioned in section 6.1.2, it was primarily focused on the battery packets offered by Cleantron. Cleantron is a specialist producer of Lithium-Ion battery modules and has a varied range of different modules to chose from based on the type of electric vehicle application [19]. Cleantron's battery packets were also the choice for one interviewee, interviewed during the customer research phase, that had converted its sailboat to an electric propulsion system.

In addition to selecting an appropriate battery for this project, a material was selected to use for the pulley system. The metal chosen needed to be lightweight, yet strong enough, to hoist 60.2 kg battery modules out of the hull of the boat. A stainless steel is preferable for this use as it will resist rusting in the wet sailing environment. SAE 316 stainless steel was chosen because it is commonly used in marine environments due to its greater resistance to corrosion.

## 6.4 CAD Models of the Final Concept

To successfully complete the assigned project, developing a CAD model was necessary. Computer aided design models make it significantly easier to view and edit renderings of parts and assemblies that will make up a final product. SolidWorks were utilized to make 3D models of the different parts that were needed for a solution to the project proposed by Volvo Penta. This allowed a visualization on how the different parts worked together and came together to make the design.

To start, a 41 foot long sailboat was found on GrabCAD designed by Tom H. This model can be viewed in figure 12 and 13. In addition, the modular battery system that was found during the research phase was also modeled in SolidWorks. The batteries modeled in the housing is shown in figure 11.

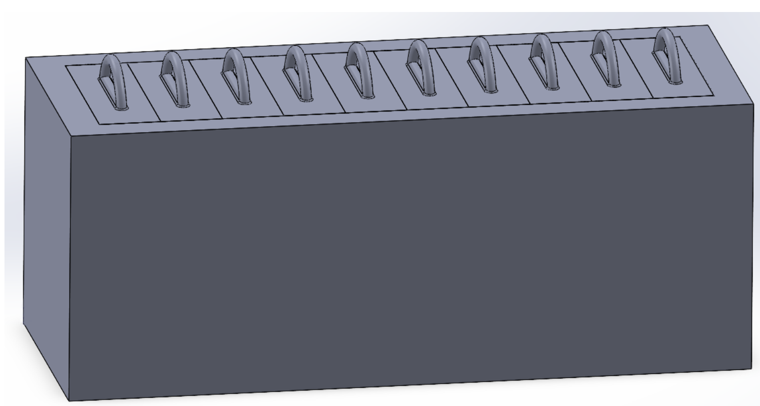

Figure 11: CAD model of the battery packets and housing that will be implemented in the system.

Based on the research that was conducted and the previous prototypes of the solution, the best location to place the batteries was determined to be behind the stairwell that leads down into the saloon of the boat. In diesel powered sailboats this space houses the engine which will be stripped out, making space for the batteries. This will also be possible since an electric motor does not take up same space as a diesel engine. The batteries are designated by the purple block shown in figure 12. The size of the space behind the stairs in the model is larger than the battery modules from figure 11, making enough space, so the batteries fitting is not a concern.

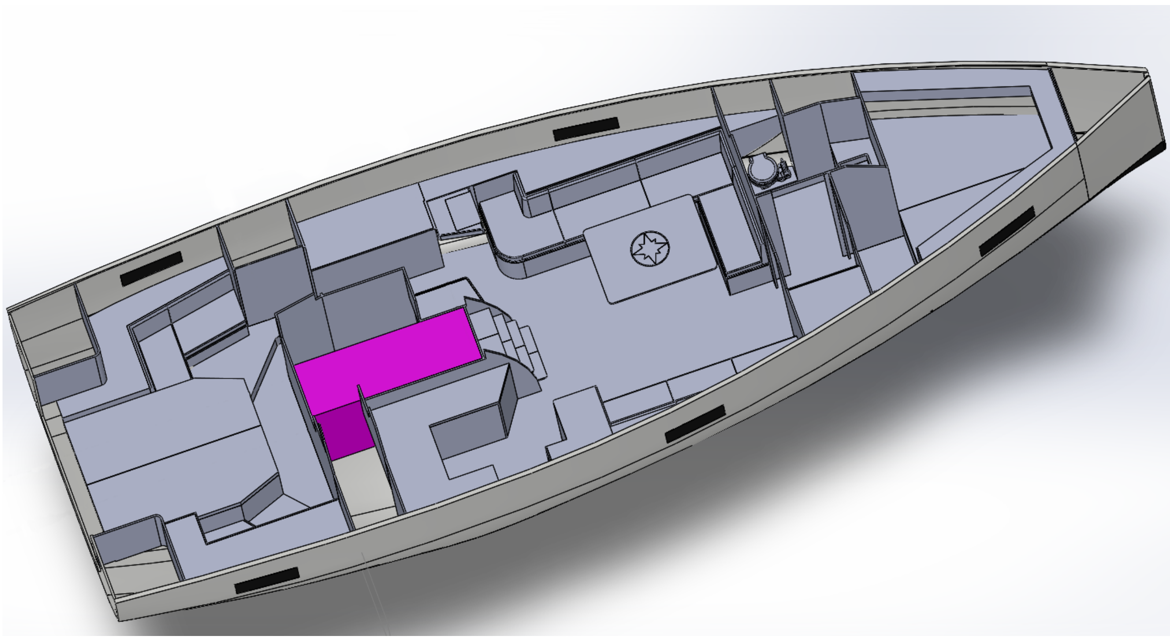

Figure 12: CAD model of the boat with the deck hidden to show where the batteries will be stored indicated in purple. Modified from [22]

In order to access the batteries, when swapping discharged modules for charged ones, the floor panel that is highlighted blue in figure 13 will be removable. The boat owner will be able to hinge the panel out of the way when they are swapping and place it back after the swap is completed.

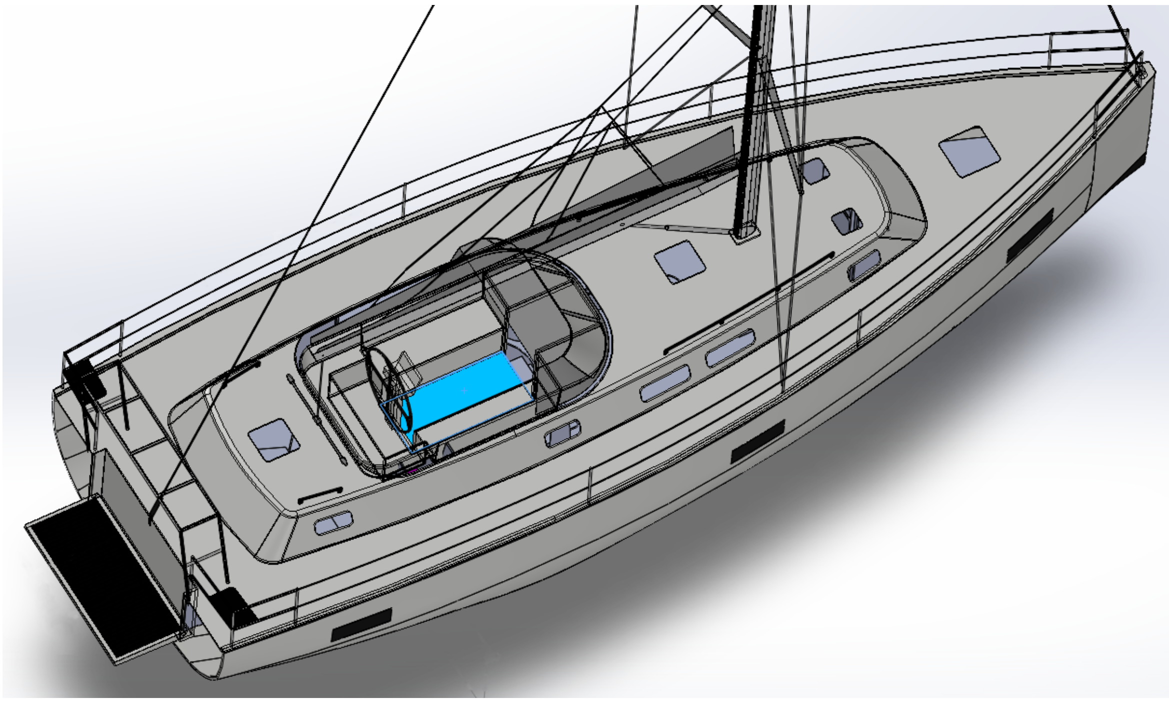

Figure 13: CAD model of the boat showing the floor panel, indicated in blue, that will be removed to allow access to the batteries during swapping. Modified from [22]

A front view of the pulley system is shown in figure 14 and a side view is shown in figure 15. The pulley was taken from GrabCAD. It was initially modeled by Saishankar Murali but the mounting system to the boom was designed by the team. The pulley is shown mounted on a track in the bottom of the boom in figure 16. The track allows the pulley to move along the boom to the vertical position that is needed when hoisting the batteries out of the hull and when placing them on the dock.

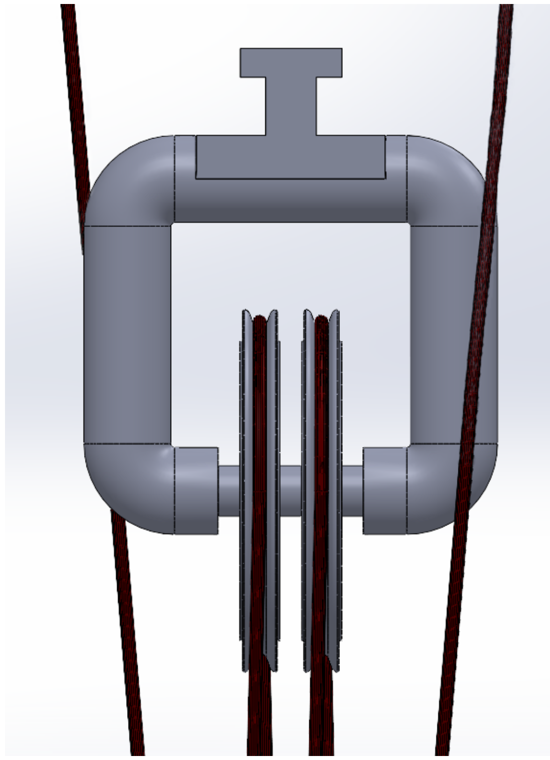

Figure 14: Front view of the CAD model of the pulley that will be used to pull batteries from the cabin of the boat when replacing them. Modified from [23]

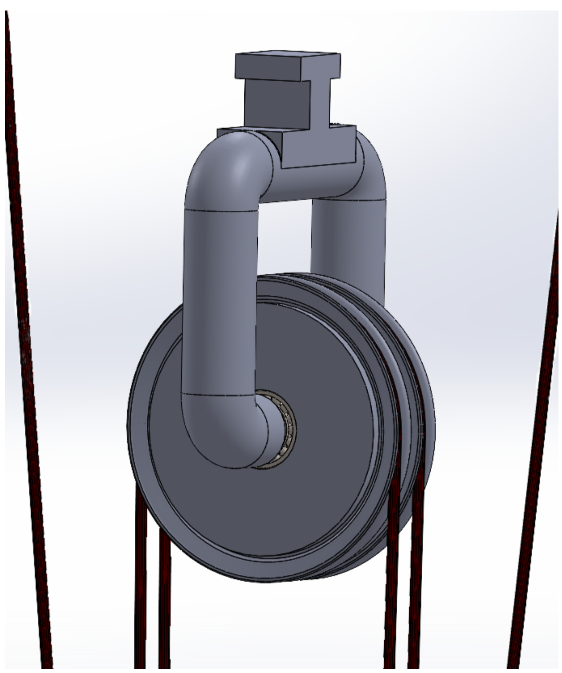

Figure 15: Side view of the CAD model of the pulley that will be used to pull batteries from the cabin of the boat when replacing them. Modified from [23]

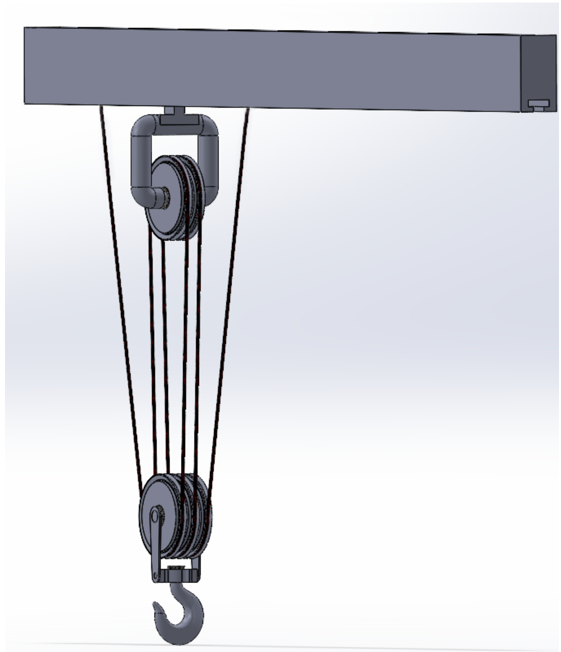

Figure 16: CAD model of the pulley on the boom. Modified from [23]

# 7 Discussion

This section aims to elaborate on the design beyond what could be presented as a result of our research. Discussions dive deeper into the methodology, design analysis, examples of business cases to handle charging and swapping infrastructure. It also covers ethical aspects and potential ways of using the batteries outside of marine applications and what happens when batteries become to worn out to be in circulation. Finally, the discussion includes recommendations on how the project could be taken further, including future works and the first few steps to finalizing an actual product.

## 7.1 Research Methodology

The execution of this project was meant to follow a project design and development process with a focus on concept development as described in section 3. This methodology proved to be well suited to the purpose of the project. In hindsight, the time distribution between the different phases of the project was not optimal. The Chalmers team and the Penn State team did also not follow the same deadlines, making it more difficult to follow the right order of the methodology. More time should have been spent on the idea generation phase in the project to develop more concepts to evaluate against each other and thus generating a more developed and well-thought-out system. Various concepts were instead pushed forward at an early stage of the process, and more focus should instead have been placed on completing the target requirements before moving on to the concept generation phase.

In section 1.3, decisions regarding which part of the system should be prioritized first were conducted in the process of researching a solution for the project. Battery specifications and the performance of the system were considered to be of most importance. Location, the swapping mechanism and system infrastructure were then modeled based on the capacity and size of the batteries. However, another important factor to consider is if the final system would look the same if another part would be prioritized first. Since the battery specifications was of highest priority during the designing of the system, the placement of the battery had to be on a location on the boat with enough space to accommodate a battery of that size. The location on the boat furthermore affected the design of the swapping mechanism. If the location would be prioritized first, the system might have looked different. If the batteries placement was put where it would be most convenience to access rather than where there is enough room this could have affected the size and capacity of the battery and hence also the overall performance of the system.

Customer research was completed to develop a system adapted to the requirements of sailboat users, manufacturers, and marinas. It was determined to be important to develop a system that today's sailboat users and manufacturers would like to implement. However, it is also important to consider how much of the design should be based on customer needs and if the information gathered has good quality and worked as a good foundation on which to base the research.

It is also essential to consider if the questions in the survey were asked in a way to avoid selective perception. Meaning, as to refrain from the process by which the questions were asked to perceive what the team want to and thereby missing or ignoring other viewpoints that could be good information to base important decisions. However, the questions were designed to avoid this problem.

The division of the various target groups were also discussed and whether the focus and development of the customer needs were based on the most suitable target group. Most of the focus went on basing the customer needs on the information gathered from sailboat users in addition to the information received by Volvo Penta. This was mainly caused by the boat manufacturers approached not wanting to contribute with valuable knowledge. This was caused by the lack of interest from some manufacturers. For the companies that found the project interesting, there was not enough time to share information within the time frame of the project.

It is also important to consider if the use of a Weighted Decision Matrix and similar methods is sufficiently justifiable and if the pros of the method outweighs the cons. When using such a method it might be hard to stay completely unbiased and the risk of manipulating the results of the matrix to those the team wish to be achieved may arise. By using an AHP matrix it might also be easy to miss that the concepts meet important requirements. Hence, these matrices need to be thoroughly overviewed to make sure that each concept is justifiably motivated.

## 7.2 Design Analysis

With the final design decided, an analysis was conducted to sort out its strengths and weaknesses. Problems are presented with possible solutions, or at least a direction of how to proceed with the issue. Even though many of the discussion topics tie into each other, they have been divided into broader categories.

### 7.2.1 User Safety

The system as of now, allows for flexibility and multi purpose use. The function sharing of the boom is great for both space efficiency and cost reduction. A pulley on the boom can also be used for any heavy lifting from the cockpit down inside the boat. However, with this free form pulley comes a few risks. One of the major direct risks of safety hazards is crushing damage to users. Even as the boat lays docked in a harbor it will move around with the waves and wind in the marina. The boom itself may also be moving relative to the boat. This causes a risk of battery modules making contact with the walls of the housing or the lifted hatch on the way in or out of the boat. If any limbs were caught between these objects they could certainly suffer a significant amount of crushing damage to any user. A possible solution is installing guiderails to lead the battery into a certain position during hoisting. Handling this risk is of highest priority if the system is to be developed further.

When swapping multiple modules, users may also try to cut down on swapping time by hoisting multiple modules at once with the pulley. This could overload the system, breaking either the pulley blocks or the attachment to the boom. By equipping the pulley with a specially designed attachment tool, it could be ensured that the pulley lifts no more modules than what it is rated for. Making sure the system is well within safe weight capacity also cuts down on the maintenance work needed.

### 7.2.2 Battery Design

Battery modules as they are shown now does not distinguish any orientation when connected to the battery housing. Making the modules or the housing asymmetrical is an easy safeguarding technique that prevents users from connecting the batteries the wrong way around, possibly short circuiting a simpler electronic circuit.

The final concept uses ten battery modules as it has a good balance of capacity per module and weight. While swapping a module at sea would be heavy, it could still be done by a lone sailboat user since the mechanical assistance is not dependent on any infrastructure in the harbor. To be able to swap a module without assistance would be optimal, but with lighter modules comes the risk of capacity per module being too low, making a single swapped module insignificant.

Moving the battery modules on and of the boat always poses a risk. Moving modules with the boom pulley may be safer than carrying them by hand, but the risk of a battery ending up on the sea floor of a harbor is hard to avoid. Designing the battery modules to be resistant to saltwater makes sure they do not break when this happens. Of course it is important that if a battery module were to fall in the ocean it does not harm any local sea life, or pollute the surrounding environment.

### 7.2.3 System Applicability and Implementation

Even if swapping to an all electrical sailboat might have great environmental benefits, the solution is not suited for everyone. Those who often go for longer trips, or want a few nights stay out in natural harbors could find the shorter range to be limiting. Sadly, there is little that can be done at this time to increase the range or energy regeneration of the batteries. Hopefully the future will provide more energy dense solutions, allowing to expand into a broader market of sailboat users.

The concept for the swapping system have centered around a specific CAD model. Other vessels may have different limitations, and making the battery housing as well as the mechanical assistance more universal is key if the product is to be rolled out on a larger scale. In the future, boats could be designed with en electric propulsion system in mind, but in order to reach current sailboat owners and encourage them to swap the system needs to accommodate more vessels as well as have a streamlined instillation process. One advantage of this solution is that it utilizes the concept of function sharing, by using already existing infrastructure on board the sailboat, such as the boom.

## 7.3 Business Case

The business case can be planned in several ways and this is not the main focus for this project. But in order for this to succeed, the concept must be operated by some stakeholder. The core business for Volvo Penta in the marine leisure segment is to produce engines and propulsion systems for sailboats, it is recommended that some external stakeholder will operate the swapping stations, which is fitting since the locations of the swapping stations are many times owned by some external part. One suggestion to easier get access to the crucial locations where the battery swapping stations can be placed is to establish a partnership with RSG (Riksföreningen Svenska Gästhamnar). RGS is the national organization in Sweden for guest harbors. This could enable an easier access to key locations since they are already co-operating with the harbors.

### 7.3.1 Cost of the System

One important aspect of this concept to consider is the cost for the users of the system. The cost of the system can be divided into two parts; the investment for buying the system and the cost of using it.

The subscription model will specifically be applied on the batteries, since the other parts of the design needs to be installed on the sailboat. The investment cost covers the cost of installing the electric driveline, the housing for the batteries and the rest of the belonging components. For those switching out their combustion engine, this could also include the cost to safely dispose of old components. The cost for this investment has not been covered in this project, and needs to be assessed since this is an important customer need. When assessing the cost for the system, in order to determine whether it is attractive for the customers, a comparison between the cost for alternative products should be made.

The operational part of the concept should be as self-sustaining as possible just like an unmanned fuel station, because otherwise the profitability will decrease and the cost for the users of this system will increase. The subscription fee should cover the cost for batteries, battery swapping stations, charging the batteries and maintenance. The subscription model can make this concept attractive since the cost for purchasing the system could be decreased in comparison with buying the batteries, even if it can result in a higher price for using it.

### 7.3.2 Availability of Batteries

Another factor to consider is how many batteries that are going to be placed at each swapping station, since the availability of batteries need to be matched with the demand of batteries. One aspect to consider is to offer alternatives, since some sailboat owners many times spend the night at the harbor and then they might not need to charge their batteries as fast in comparison to swapping. One insight that was discovered during the customer research process was the possibility of letting the sailboat user reserve and check the availability of batteries at a specific location in advance. This allows the sailboat users to feel more comfortable and confident of receiving enough batteries when needed.

#### 7.3.3 Quality of the Batteries

During the customer research process, insights about their behavior and preferences were developed. One key aspect is that the quality of the batteries is an uncertainty for the sailboat users, since they want to get batteries that are of equal performance. The diagnosis system will cover that aspect, but when considering a subscription model there are several factors to investigate when it comes to the user interaction. When a sailboat user does not own the batteries, one major concern is how they will treat the equipment and this is an area that the diagnosis system aim to cover. The diagnosis system will not only provide information to the stakeholder that operates the stations, it will also check that the batteries haven't been mistreated by the user. A clear and straight-forward policy needs to be developed in order to decide whether the sailboat user who most recently used the batteries should pay for the damaged batteries or if it is the stakeholder that operates the swapping stations. What is considered to be normal wear of the batteries and what is considered to be mistreatment of the batteries is a question that needs to be answered.

#### 7.3.4 Effective Use of the Batteries

At the same time, the batteries are not going to be used to the same extent during off-season. This is partly why it is recommended to use some sort of subscription model. This allows Volvo Penta or the third party company that are operating the swapping stations to use them as much as possible. This also allows the concept to improve the resource efficiency, both economically as environmentally friendly. The subscription model is also applied since it enables several more opportunities of using the batteries during off-season. Multiple opportunities to use the batteries during off-season increases the possibilities for effective and profitable utilization of the resources.

### 7.4 Alternative Use of Batteries During Off-season

This section aims to present different alternatives to use the batteries during off-season. Since batteries are an expensive investment, a greater utilization of them could increase the return on the investment and hence giving the batteries an added value.

Given that the sailing season in Sweden is primarily in the spring and summer months of the year, the battery modules will mostly be used during that time. During the off season (winter and fall), a few options for alternative uses of the modules were proposed. One of the proposed options is leasing the modules to TV and movie camera operators to use as a power source for the equipment at remote filming locations. Similarly, the modules could be leased to audio companies to power speakers and audio equipment at outdoor venues where wired power is not readily available. The other proposed option was to use the modules to power small scale electric vehicles such as small electric cars and golf carts. Currently there are not many small scale vehicles that use a modular battery swapping system, but as the electric vehicle market grows, so will the need for modular batteries.

The modular batteries could possibly also work as an energy storage system. This could be done in the same manner as a private person with a small photovoltaic system at home uses the excess energy to charge a battery to later use as a power source during the winter. Using a fully charged battery packet of 50 kWh as energy storage during the winter could make a residential home less affected by higher electricity prices as owning a battery would reduce the need to buy more electricity. Including solar power to charge the batteries when not in use on the sailboat would also increase the degree of self-sufficiency for an individual with this system. However, this implies that the battery should be owned by the sailboat owner and not part of a subscription model where a third party would be the owner of the batteries as suggested by the team in section 6.2.

## 7.5 Ethics

Implementing a project like this makes it crucial to discuss and research aspects that are non-technical. The development and production of technical solutions such as this, it is important to account for the impact this has on the outside world. This can be in the form of how the solution's emissions during the life cycle affect the ecology on a local and global scale. It is also important to reflect, discuss, and account for how the solution affects society and people who are in the vicinity of production, use, and waste.

### 7.5.1 Ethical Aspects

As previously stated, the safety regarding the swapping of the battery is of major importance in the project. The aim of the project is also to be able to rely on renewable energy in activities regarding work, education, and entertainment to reflect its awareness of the ever-changing climate.

The customer research provides perspectives such as aesthetics being important as to not interfere with the natural beauty. This means that the aesthetic of marinas that may be affected by the solution in the project must be valid and justified and preferably blending in with its surroundings. This is ethically relevant as the majority of the respondents reflected over and were concerned that a solution like this could disturb the peace that sailing can bring to people. The respondents prefer to keep the sport or leisure interest as natural as possible and create a minimal impact on its surroundings, including the ports.

An additional ethical consideration that needs to taken into account is the impact of mining the elements required to build electric drivelines. If Lithium-ion batteries are to be chosen, Lithium-Ion batteries require a significant amount of lithium, cobalt and nickel, all of which must be mined. This will impact the surrounding locations of the mine as well as the populations in these regions. These mines are usually located in underdeveloped countries and regions that does not always have access to the proper personal protective equipment needed for mining. Many miners end up inhaling metal and chemical laden dust which has proved fatal. Also, many of the mines in these underdeveloped nations use child labor in order to make the tunnels smaller to reduce costs. It should be considered the potential impact that an increase in demand for these products may have on the population and environment in these mining locations.

### 7.5.2 Environmental Aspects

The purpose of this project is to contribute to a sustainable future and reducing the impact on the environment from using a sailboat. When considering to implement this, a thorough analysis must be conducted in order to determine whether the system will reduce the impact on the environment and society or not. This analysis will be the foundation for the decision and it's of outer most importance to cover all aspects of the life-cycle of the products.

There are many benefits to using renewable energy sources. Examples of this can be described as follows. Minimal emissions released from product use. Reduced dependence on fossil fuels. Formation of more jobs in various fields. However, these benefits come with some drawbacks that need to be considered when designing a system that uses renewable energy. Some of the drawbacks for our system specifically, which would use lithium ion batteries, include the emissions required to mine materials, manufacture the batteries, recharge the batteries, and recycle or dispose of them once they reach the end of their lifespan. The most common battery used in electric vehicles nowadays is lithium-ion batteries. According to [24], the mining and refining process produces 59 kg of $CO_2$ per kilowatt hour of lithium-ion batteries. The rest of the manufacturing process depends on how many renewable energy sources the companies that are building and charging the batteries use. The Swedish Environmental Research Institute estimates from 0-60 kg of $CO_2$ per kilowatt hour for the manufacturing of the batteries. The same paper estimates that the recycling of lithium-ion batteries produces roughly 15 kg of $CO_2$ per kilowatt hour of batteries bringing the total to between 74 kg and 134 kg for an average of 100 kg of $CO_2$ per kilowatt hour of lithium-ion batteries.

In addition, [25] states that to the carbon emissions, lithium mines have been found to pollute local water sources. The mining process is different in different parts of the world but the use of chemicals including hydrochloric acid to extract lithium from mines is common. The chemicals used can leak into water supplies and into soil and make it dangerous for people to drink or grow food. Many times the populations of these regions are faced with the decision of whether to drink contaminated water or drink nothing at all.

Furthermore, disposal of lithium ion batteries also poses risks to the environment. If lithium ion batteries are not disposed and recycled of properly the metals and fluids that are in them can leak into the environment. The fluids are highly flammable and have caused significant fires in landfills. These potential environmental impacts with the production, use, and recycling of lithium ion batteries should be considered in our final solution [26].

## 7.6 Recommendations for Future Work

There are several areas where the project can be continued and further developed. The recommendations for future work cover areas which are of different importance. Some topics needs to be further researched and give the right results in order to make the project applicable on this market. The project has so far given insights about what needs to be further researched and what result that needs to be established in order to continue and launch this project on the market. The following topics needs to be evaluated and determined:

- Study where the stations can and need to be placed in order to meet the demand for the availability of batteries. The objective for this is to determine whether there are enough potential locations where the battery swapping stations can be placed in order to meet the availability demand. The availability demand in this case refers to cover enough locations geographically. To determine this, a comparison with the availability of fuel stations along the coasts of Sweden can be done.
- The demand from potential users of the system needs to be researched and tested with a pilot project. An analysis of if the customers and users want and are willing to use this solution. During this research, several more insights about the customer interaction with the system can be developed.
- Research and test the business case in order to determine if the sailboat users are willing to buy and use this system based on this concept and business model. Determine if this can be scaled and become a sustainable and profitable business. This include creating a budget and calculate how much the system will cost.
- Study the environmental and social impact to determine whether the system is more sustainable compared to the conventional use of combustion engines. Since one of the objectives is to contribute to a more sustainable use of sailboats, this research is crucial. By conducting a life-cycle analysis and covering several environmental and social aspects, such as the amount of $CO_2e$, affect on biodiversity, working conditions, child work, etc.
- Research the infrastructure for battery swapping stations on land and also develop a concept for them.
- Reevaluate if the the battery capacity have to be of 50 kWh. With a smaller battery packet it might be possible to focus on the placement of the batteries rather then being forced to place them

on a location where there is enough room. With a smaller battery pack on a more convenient location, the system could be easier to maneuver, and thus also making it easier to motivate a conversion from a combustion engine system to an electric driveline with a portable battery swapping system.

- More research regarding if it is necessary to use cooling for the Lithium-Ion batteries and which method that is the most optimal in a marine environment is necessary for further development of the system.
- In conventional sailboats today, the excess heat produced by the inboard combustion engine is used to heat freshwater. On the engine, a heat exchanger is connected to the heater in the sailboat. When removing the combustion engine, this function is lost. Research on how, in an energy effective matter, the freshwater can be heated since this is a function that sailboat users do not want to lose when changing to an electric driveline.
- Conduct another iteration of idea generation based on the research that has already been done in this project in order to innovate even more.
- It is also necessary to investigate if there is a need for a heating system for the Lithium-Ion batteries in order for the batteries to stay in the acceptable operating range of -20°C to 60°C. That is, making sure that the batteries does not get to cold and function properly.

# 8 Conclusion

In summary, this report has addressed how an electric energy storage system can be utilized using a system that can replace the battery via a swapping mechanism. The basis for this work is the need for more alternatives for customer interested in electric boating and this was implemented by introducing a battery swapping system. This concept enables replacement of discharged batteries and allow for longer charging time on land while the sailboat is in use. The report addresses boat design modifications, technical equipment that facilitates handling of the battery and a business case that handles the scenario.

The sailing sector is entering a new era of implementing solutions to reduce environmental impact and one of the major challenges is the availability of charging. Some of the desired effects are to promote alternative solutions to the combustion engine system for an environmentally friendly sailing experience and contribute in lowering the load on the poorly developed power grids in marinas. It is also used to reduce the time a sailboat user has to stop to recharge their batteries and make the swapping system user friendly as well as simplify the work for Volvo Penta regarding the development of a potential business case.

The final concept describes that Lithium-Ion was the appropriate choice for the battery packet divided into ten modules with a total of 50 kWh output and that passive cooling will be used. A swapping method was developed to load the battery modules in and out of the vessel. The pulley system allows a single person to lift the weight of the modules out of the boat. The system was designed with a sliding effect so that the battery can be moved along the boom and swapping the modules in the hull situated near the center of the boat.

The business model is based on a subscription model and the subscription on a chosen amount of batteries will be paid during the season as well as a fee when swapping batteries. The battery swapping stations are unmanned during the swapping process. However, the swapping stations and batteries require maintenance. A diagnosis system will check the health of the batteries as well as that the availability of batteries is sufficient. This is done using a reservation system allowing for reservations in advance.

The system allows for flexibility and multi purpose use. The function sharing of the boom allows for space efficiency and cost reduction. The major safety risk of the swapping system is crushing due to movement of the boat. Over loading the system is also a risk of incorrect use. Construction of a slightly over sized system can reduce these risks and its maintenance.

In order to get a deeper understanding of the customers, a survey and interviews were conducted. This method was used to gain a deeper understanding of important aspects to consider when formulating a non-existing system.

To summarize the customer research, the main takeaways from the survey are the following:

- Main use of the engine is to go in and out of harbors, but it is also used in unfavorable weather, tight canals and to charge existing on board batteries.
- The range of the system does not need to match the general range of a conventional combustion engine.
- Since many users stay in harbors overnight, charging time is not as important. However, sometimes a faster recharge time is desired. A single user should be able to handle the system.

In order to develop the concept further thorough studies need to be concluded on the battery swapping availability and the functionality of a swapping station, as well as a complete life cycle analysis of both stations and batteries focusing on environmental and ethical aspects. Economical factors such as market demand and installation costs should also be properly evaluated.

To fully replace the combustion based system, further innovation is required to solve problems of regulating battery temperatures. On cold days they may need heating and on hot days they may need cooling to stay within optimal temperature ranges. A solution has to be found for heated water, as it would require too much power to heat by purely electrical means. When reworking the electronics, one could also analyze the need for such a power hungry driveline. Lowering the energy consumption of the motor scales directly with the estimated range, and the different needs should be weighed against each other.

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## A Survey - Hur använder du din segelbåt?

- Vilken slags segelbåt äger du? Märke, modell och storlek
- Vad har du för motor idag och vilken typ av bränsle använder den?
- Hur stor tank har du idag i liter? Eller om du har en elmotor, hur stort batteripaket har du till den?
- Hur ofta, på ett ungefär, behöver du tanka båten med bränsle per säsong?
- Vilken räckvidd har du idag innan bränslet är slut? Svara i nautiska mil/distansminuter
- Tycker du det är jobbigt att tanka båten med bränsle idag?
- Vad tycker du är jobbigast med att tanka båten med bränsle idag?
- Om du har en förbränningsmotor idag, skulle du kunna tänka dig att byta till en elmotor?
- Om du skulle köpa en ny båt, skulle du vilja ha en förbränningsmotor eller en elmotor?
- Varför skulle du inte vilja ha en elmotor?
- Varför skulle du vilja ha en elmotor?
- Skulle du känna dig trygg, säkerhetsmässigt att ha ett stort batteripaket i båten?
- Vilken är den lägsta räckvidden du skulle kunna acceptera om du skulle ha en elmotor? (M, Nautisk mil/distansminut)
- Hur länge kan du vara ute med din båt idag utan att besöka en gästhamn för att tanka, ladda batterierna, fylla upp vattentanken, etc?
- Hur stort batteripaket har du idag till förbrukningskretsen och vad har du för typ av batterier (Blybatterier, litium-jon, etc)?
- Hur mycket använder du motorn idag? Markera de alternativ som stämmer in på dig
- Om du skulle ha en elmotor, hur lång laddtid skulle du som max kunna acceptera?
- Om du skulle haft en elmotor, skulle du då tycka att det är viktigt att kunna ladda batterierna på något vis när du är ute och seglar?
- Skulle du kunna tänka dig att offra lite av båtens hastighet när du seglar för att ladda batterierna?
- Nu när du har gått igenom alla frågor, har du några övriga tankar eller kommentarer som du vill lägga till?
- Hade du varit villig att vara med i en mer djupgående intervju över videolänk eller telefon? I så fall lämna mail eller telefonnummer nedan så hör vi av oss så snart vi kan!

## B Interviews - Hur använder du din segelbåt?

**Erfarenhet**

- Hur många års erfarenhet av båtliv har du?
- Har du alltid gjort underhållet själv eller anlitat någon?
- Har ditt intresse gett dig möjligheten att öka dina teoretiska kunskaper om båtar gällande exempelvis motorer, bränsletyper, viktfördelning eller liknande?

**Portabel batterilösning**

- Om du skulle haft en elmotor och likt en tankstation, kunna byta dina urladdade batterier mot fulladdade, vad skulle du då tycka är viktigt när du använder ett sådant system?
- Vad skulle du föredra, att byta batterierna manuellt eller att ha något slags automatiskt system?
- Skulle du kunna tänka dig att manuellt byta batterimodulerna, dvs bära dom och hämta nya? Vilken vikt är då maxvikt att bära?
- Skulle du säga att ett sådant system inte skulle få vara jobbigare än att tanka idag?
- Skulle du föredra att kunna byta dina urladdade batterier mot laddade istället för att vänta på att ladda dem? Varför? Varför inte?
- Skulle du kunna tänka dig en mindre räckvidd jämfört med din dieselmotor idag?

**Nutid**

- (Om Elmotor) Vad är de största fördelarna med att använda en elmotor idag?
- (Om Elmotor) Hur fungerar laddningen av batteriet idag?
- Använder du dig av dunkar med extra bränsle ombord på båten? Vad väger dessa? Är det ett problem?

**Framtiden**

- Om du skulle byta till en elmotor, är det då viktigt för dig att det ska gå ungefär lika fort att ladda upp batterierna som att tanka?

**Användarvänlighet**

- Är det viktigt för dig att ha en kort laddtid för att ladda upp batterierna?
- Vad är den längsta laddtiden du skulle kunna tänka dig?

**Underhåll**

- När du gör underhåll på din motor idag, gör du det då själv eller låter du ett båtvarv göra det åt dig?
- När det kommer till el i din båt, är det något som du jobbar med själv eller lämnar du iväg det till ett båtvarv?
- Inom underhållet av din båt, vad är det som du gör själv respektive anlitar någon?
- Förlitar du dig på forum på internet, googlingar och liknande för att göra underhåll på din båt? Speciellt inom elen ombord.
- Upplever du att underhållet av din motor idag är påfrestande?
- Skulle du vilja slippa allt detta underhållet?

- Många båtägare tycker ju att en del av charmen med att äga en båt, är att underhålla, utrusta och reparera. Vad tycker du om detta?
- Hur stort är problemet med dieselbakterier i dagsläget?

**Bekvämlighet**

- Hur många gånger per säsong upplever du oväntat oväder?
- Händer det att oförutsedda problem uppstår med din båt som förhindrar dig får att utnyttja den till fullo? Vad beror det på?

**Säkerhet/trygghet**

- Vilka säkerhetsmoment inom segling upplever du som viktigast i dagsläget?
- Jämfört med en dieselmotor, skulle du känna att en elmotor och batteripaket är mer eller mindre pålitligt? Dvs att räckvidden håller, risken att systemet lägger av och generella tilliten?

**Förväntningar**

- I dagsläget så är det inte möjligt att behålla motorns prestanda, pris, räckvidd och vikt jämfört med dieselmotorerna. Någon eller några av parametrarna kommer behövas kompromissas. Om du fick välja, vilka av parametrarna är det viktigaste för dig att behålla från dagslägets motorer?
- Är det något speciellt som du skulle rekommendera oss att studera för att göra rapporten så bra och omfattande som möjligt?