CHALMERS

Using batteries to store power on vessels for later usage

How battery packs can be used together with an propulsion engine and the advantages of the system

Bachelor thesis for Marine Engineering Program

PHILIP BRÖMS

DEPARTMENT OF MECHANICS AND MARITIME SCIENCES

CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2023

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PREFACE

I am thrilled to have written my bachelors thesis in the spring of 2023 as the last part of my four-year-long marine engineering program at Chalmers University of Technology. As author of this report, I would like to take this opportunity to express my deep appreciation to those who have contributed to this success.

First and foremost, I would like to thank my supervisor, Sami Syrjänen, for his wholehearted commitment and unwavering support throughout this project. Sami's insightful guidance, constructive feedback, and encouragement have been invaluable for this report, and I am grateful for his mentorship.

Lastly, I would like to express my heartfelt gratitude to all the interview participants who agreed to share their valuable insights with me. Their willingness to provide essential information was fundamental in order to write this report. Without their contribution, this project would not have been possible.

In conclusion, I would like to express gratitude to everyone who has helped me along the way, including my supervisor, librarian, examiner, and interview participants. Thank you all for your support, guidance, and contributions to the success. I am honored to have had the opportunity to complete this project and look forward to applying the knowledge and skills gained in my future endeavors.

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SAMMANDRAG (in Swedish)

Sjöfarten står ensam för cirka 3 % av de totala växthusgasutsläppen varje år. Den internationella sjöfartsorganisationen, som ansvarar för att reglera sjöfarten, har som mål att minska växthusgaserna med 50 % före år 2050 jämfört med 2008 års referensvärde. I denna rapport presenteras några alternativ för att minska dessa utsläpp och några andra fördelar som kommer med att använda batterier ombord på fartyg. Studien är baserad på kvalitativa intervjuer med fyra olika medverkande. Deltagarna har erfarenhet inom olika områden inom sjöfartsindustrin men de arbetar alla med batterier som är installerade på fartyg. Studien har genomförts i Göteborg, men de fartyg som deltagarna refererar till har sina rutter inom norra Europa.

När batterier installeras som antingen huvud- eller sekundärkälla för framdrivningen av fartyget minskas fartygens utsläpp men det blir också mer driftsäkert. Att ha ett redundant system är en viktig del inom sjöfarten eftersom besättningen ombord kan vara de enda som kan få motorn att starta igen ifall de har blivit strömlöst ombord. Om det blir strömlöst driver fartyget utan kontroll.

Fördelarna med att använda batterier ombord är många, men batterierna har också nackdelar som kommer att tas upp. Att installera batterier har en kostnad, men detta kommer inte att beräknas i denna rapport och det samma gäller för de totala utsläppen om batterierna laddas från land.

Nyckelord: Batterier, Dieselelektrisk framdrivning, Fartyg, Utsläpp

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ABSTRACT

The shipping industry alone stands for around 3 % of the total GHG emissions yearly. The International Maritime Organization which is responsible for regulating shipping has a goal to reduce GHG emissions by 50 % before 2050 from the 2008 baseline. In this report there are some alternatives to lower these emissions and some other advantages that come with using batteries onboard vessels. The study is based on qualitative interviews with four different respondents. The participants have experience within different fields in the shipping industry, but they are all working with batteries onboard vessels. The study was conducted in Gothenburg but the vessels the interviewees refer to have their routes in Northern Europe.

When installing batteries as either main or secondary source of power for the propulsion the system will lower the emission and it will make the system more redundant. Having a redundant system is a key factor in the shipping industry since the crew onboard may be the only people that can get the engine started again if it has lost power. No power means that the vessel will drift without control.

The advantages of using batteries onboard are many but the batteries also have some concerns, and they will be addressed as well. Installing batteries has a cost but this will not be calculated in this report, the same goes for the total emission when the batteries are being charged from shore.

Keywords: Batteries, Diesel-electric propulsion, Emissions, Vessel

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND TERMINOLOGY

CO2	Carbon dioxide
DEP	Diesel-electric propulsion
DE	Diesel engine
DG	Diesel generator
DP	Diesel propulsion
EMSA	European maritime safety agency
GHG	Greenhouse gas
ICE	Internal combustion engine
IMO	International Maritime Organization
Nm	Nautical miles
NOx	Nitrogen oxides
PMS	Power management system
rpm	Revolutions per minute
STA	Swedish Transport Agency
SDS	Ship power system
SOx	Sulfur oxides

1. INTRODUCTION

In 2018 the shipping industry emitted around 1056 million tonnes of CO_2, which is 2.89 % of the anthropogenic around the globe (IMO, 2021, p. 112). International maritime organization (IMO) have a goal that is to reduce the global emission with 50 % in the shipping industry before 2050 compared to the 2008 emission baseline.

A critical factor for this is to phase out all the older vessels with newer ships where the engine can run on low-carbon fuels. By combining these engines and an aftertreatment system the NO_x can be reduced by up to 90 % and with an increase in the fuel efficiency (MAN Energy Solutions, n.d.).

Another solution to reduce the emissions is to use diesel-electric propulsion (DEP) (Elkafas & Shouman, 2022). This configuration is popular in the car industry where 5 % of the fleet in USA is hybrid cars (Hyunjoo, 2022). The car and vessel hybrid system are not the same, but they have similar technology, the system requires an internal combustion engine (ICE), batteries and an electric motor (Riswick, 2019).

Hybrid systems on vessels for propulsion will optimize the load on the ICE, they can run on steady revolutions per minute (rpm) which will increase the efficiency of the engine. The ICE will be used for propulsion through the generator and if the propulsion does not need all the power the batteries will be charged. The batteries can also be charged from shore when in port. Not all systems can be charged from shore, it all depends on the port the vessel stays in. (MAN Energy solutions, 2018).

The diesel engine (DE) has been used on ocean going vessels since 1912. Selandia which was the first vessel equipped with DE had 1240 horsepower (HP) and a deadweight of 7000 tonnes (MI New Network, 2019). A lot has happened since that vessel and the first vessel built with hybrid drivetrain was in 2012, that vessel was built for passengers and cars (Ship Technology, 2013).

1.1 Background

IMO have set a goal that by the year 2050 to reduce the emissions by 50% compared to 2008 baseline (IMO, 2021, p. 112). To reach this the shipping companies all around the world needs to make a lot of changes to their fleet of vessels.

To use renewable energy in its different sources is one solution to reach the goal. Energy is hard to store and that’s where diesel-electric vessels are great, they can be charged from shore when the electricity are cheap and easy to receive and when the vessel isn't charged from shore the diesel generator DGs can be run on diesel and move the vessel forward (EPA, 2022).

The advantages of using DEP are many and varied by which industry the vessel operates in. The offshore industry can use batteries in order to turn of DG and still have the same redundancy. The batteries are used for peak shaving, the load goes up and down fast. This saves fuel since the batteries take load that the extra DG would have otherwise, and this expands the service intervals on the DG (Ulstein, 2019).

The ferry industry operating on shorter routes and with a high demand for manoeuvrability can also take advantages of the DEP system as well as tug vessels (Maritime News, 2009).

For a vessel to be optimal for DEP they need at least one of the following criteria: (DST, 2019, p. 2)

- High electrical power demand with high degree of varying loads
- High degree of partial load for propulsion
- High comfort demands
- High demands towards redundancy
- High demands towards manoeuvrability

Since the DEP system are relatively new in the shipping industry the regulations are updated frequently. The regulations are about how the batteries can be mounted in case of a fire but also what will happen if the batteries are empty.

The regulations are from IMO, but the Swedish transport agency (STA) also has some guidance on how the batteries can be installed, this however only concerns the vessel sailing with the Swedish flag.

If batteries are installed on vessels, it will increase the redundancy of the electrical system and will make the vessel safer. In case of a blackout, where all the power is lost on board, the emergency generator must be started and from that all the necessary system will be started by an engineer on board. If instead batteries are installed, they can directly power all the consumers until the DGs are started again. (Moore, 2020)

1.2 Aim of the study

The aim is to get an understanding of how the DEP system can be used on board. The advantages of this system compared to conventional diesel propulsion (DP). How the DEP and DP system are configured and installed depends on the application and the traveling route.

On shorter sea voyages it´s possible to install batteries that will be the main propulsion for the vessel, this is done by installing large batteries that are being charged from shore. That system is common and will be mentioned in this report, but the focus will be how to use similar technology on longer voyages. The ICE will be the main propulsion on the longer voyages and the batteries will be installed and used under shorter periods on the voyages when the load is increased, this can happen when strong winds occur or when it is high waves.

1.3 Research questions

The first question is the main question and the second one is a sub question, both of them will be answered in this report.

– The advantage of using battery packs on vessels?
– How to use battery packs on board vessels?

1.4 Delimitations

The central point will be from either the DG or the shore side charging to a battery. The battery by itself or with the DG balance the total load that the propulsion require.

If the batteries are being charged from shore and not from the DGs the report will not look deeper into where the electricity is from, this means that the electricity can be made from either renewable sources or from non-renewable sources. Why this delamination is made is because the report will only look into the advantages of the batteries starting from the vessel.

In this report no calculations on the emission will be made and no calculations on the cost for installing the batteries either.

2. THEORY

Elkafas & Shouman, (2022) concludes in their report that DEP is the cheapest, most environmentally friendly and energy efficient way compared to diesel propulsion. In the environmental case the NOx, SOx and CO2 emissions were thought about since they are related to IMO regulations.

Previous studies have been made on the topic and shown that DEP are worth installing in order to reduce the emissions and fulfil the IMO regulations already now. Even if the vessel constructed now may not be in service in 2050 some great economic aspects will play a crucial role when ship owners decide to buy new vessels.

The great economical aspect is that the vessel will receive financial advantages on port fees if they are green vessels. This means that vessels that release less air emissions than the regulations state will obtain financial benefits in harbor fees already now. (ESI, 2023)

To lower the fuel consumption, extend the service interval and keep down the running hours on the engines, the DEP system can be installed (MAN Energy solutions, 2023). Combining all of this, the advantages of the DEP system are many and the negative aspects are few.

2.1 Propulsion systems

The different propulsion systems that are commonly used for vessels will be described and how the systems are designed.

2.1.1 Diesel-electric propulsion system

When talking about DEP, some different arrangements are considered. One system is with DGs that charge batteries for later consumption. The other one is still DGs, but they are directly connected to a switchboard for distribution straight to the electric propulsion motor (see figure 1). The generators can also be turbine or steam driven generators but in the marine industry they aren't common. (Anish, 2019)

The system used depends on what configuration is needed on the specific vessel type. Cruise liners have a particular route they travel on and are built for. Tanker vessels can have different routes every time and are hard to build or convert to DEP (Maritime News, 2009).

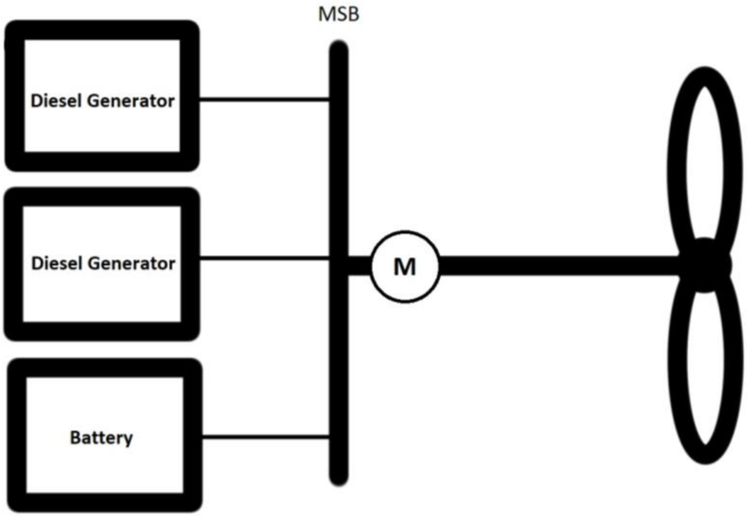

Figure 1. Battery parallel with diesel generators.
Note. Electric motor (M), Main switchboard (MSB)

2.1.2 Diesel mechanical propulsion system

The diesel engine (DE) has a low power output, at the best the large propulsion diesel engines will have close to 50% efficiency. (Takaishi et al., 2008) This means that half of the fuel doesn't even move the vessel forward but is still being emitted into the air. This is the biggest concern with the internal combustion engine (ICE), but the combustion engine has heat generated from it compared to the electrical engine. That heat can be reused for heating cargo or for heating the accommodation onboard without losing any efficiency from the power output. (Rai et al., 2018)

The diesel mechanical propulsion consists of a main engine that is either directly coupled to the propeller (see figure 2) or through a gear box if the revolutions need to be changed.

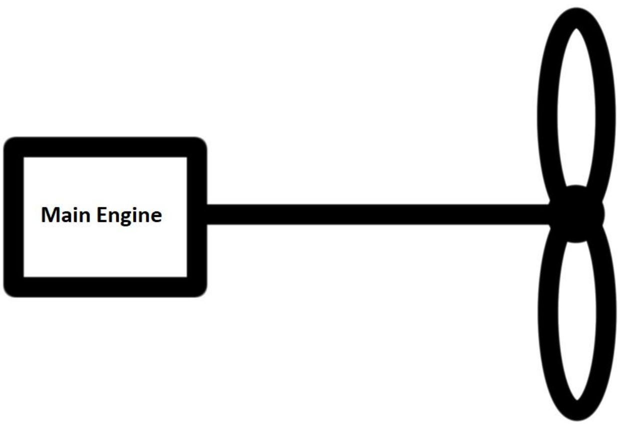

Figure 2. Main engine connected to a propeller.

2.3 Types of engines

Engines come in a variety of sizes and makers. The configurations are either V-engine that have the cylinders in a V shape; the other is a straight engine where the cylinder or cylinders are arranged in a line. Both these engines can have different number of cylinders and power output but also be run on gasoline or diesel (Fenske, 2014). This makes the engine a complex machine with a variety of applications.

Engines manufactured today specifically for the marine industry often have dual fuel systems. This means that the engine can be run on both diesel and another types of fuel, often some type of natural gas (Wärtsilä, 2023). Why natural gas is used is because of the lower emissions emitted into the air. The natural gas can lower the energy efficiency measures by 20%, the NOx will be reduced by up to 80% and the SOx will almost be eliminated (DNV, 2023).

2.3.1 Two stroke engine

The two-stroke engine is a common machinery today when talking about ships engines, this is because of the dual-fuel solution. Dual-fuel engines are used onboard vessels that run on diesel or gas for the main propulsion (Wärtsilä, 2018). In figure 1 the cylinder is open (cross section) from one end and the four different cycles are shown.

The two-stroke engine only needs one revolution to complete the combustion cycle (intake, compression, ignition, combustion and exhaust)

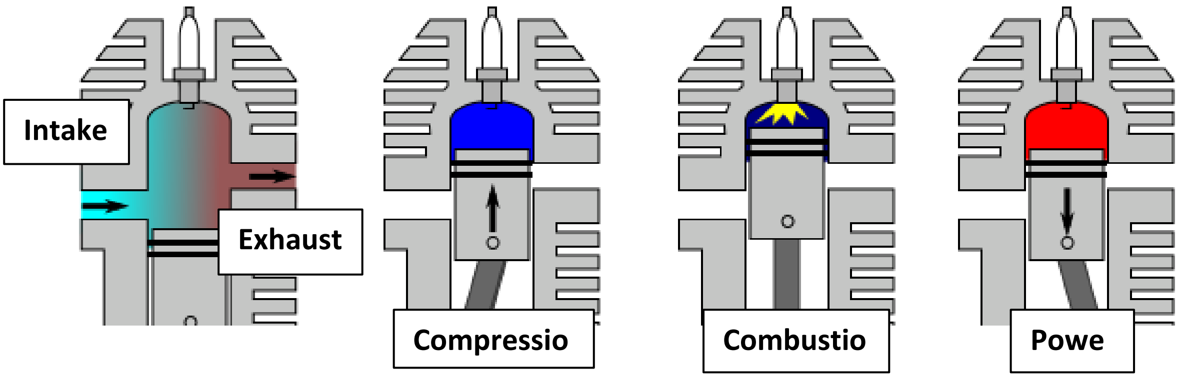

Figure 1. Cross section of two stroke engine. (Tucvbif, 2014) CC-BY-SA

2.3.2 Four stroke engine

The four-stroke engine is even more complex than the two-stroke engine, this is because of more parts and the four cycles on one combustion compared to two on the two-stroke.
The four-stroke engine has cleaner combustion, this means that no excess fuel escapes from the chamber. It is done by controlling the intake (incoming air) and exhaust valve (outgoing air) (Prime Source, 2023).

The four-stroke engine needs two revolutions to complete one combustion cycle (intake, compression, ignition, combustion and exhaust). See figure 2 where all four piston strokes are shown.

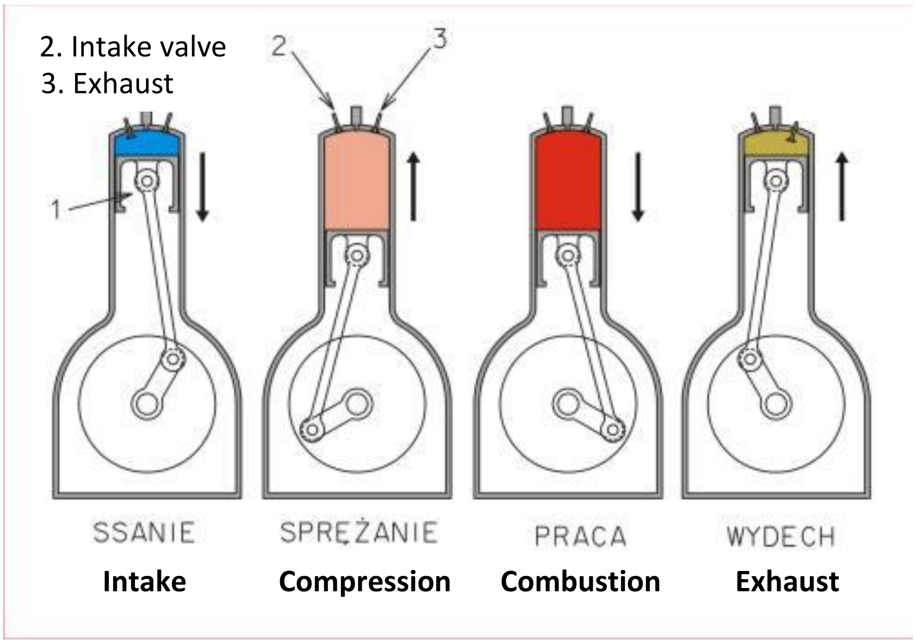

Figure 2. The four different strokes. (Jonasz, 2003) CC-BY-SA

2.4 Engine speed

The engines are divided into three different categories when talking about speed. They are low speed engines, operating up to 400 rpm. Medium speed engines working between 400 – 1200 rpm and the high-speed engines operating above 1200 rpm (Mathcad, 2006).

2.5 Engine output

The output from the engine is how much power the engine can produce; it produces power by converting thermal energy (fuel) into mechanical energy (drive shafts) (Landis, 1997).

Table 1 shows different engines where the red line can be referred to as the auxiliary engine (High-speed DE), the black line can be referred to as the propulsion engine on smaller vessels (Medium-speed marine DE) and the green line refers to the propulsion on big vessels over 50´000 dwt (Large, slow-speed marine DE)

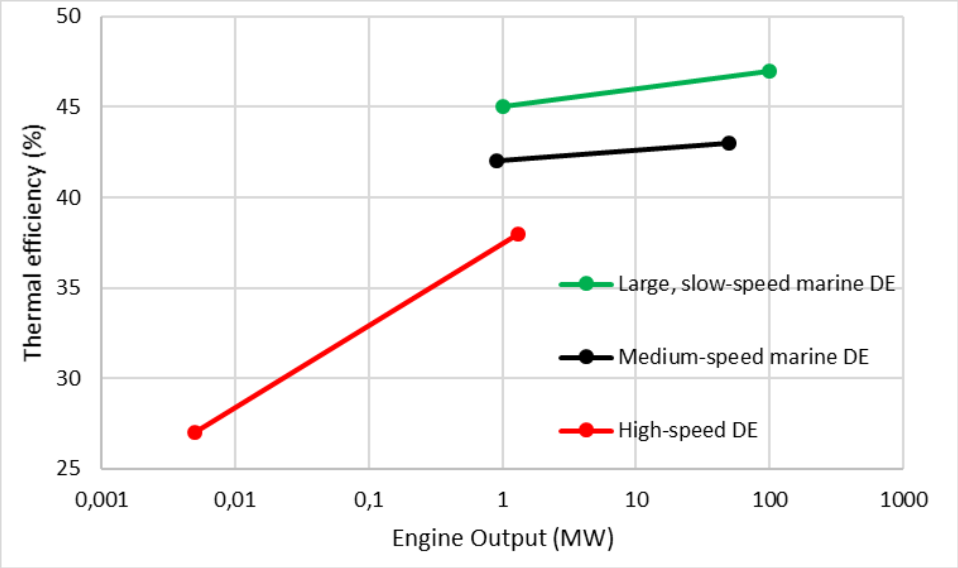

Table 1. Engine output and the thermal efficiency of engines used on vessels.

2.6 Change of load on the diesel generators

The DG are suitable for various loads. The load is how much power the DG generates to the consumers. A DG working at low loads will have poor energy efficiency and higher fuel consumption (Shipsbusiness, 2015).

2.7 After treatment systems

Engines today have after treatment systems (ATS), and they have that in order to compile with the regulations on how much emissions are being let out in the air. The ATS cleans the exhaust gases and while the systems can vary depending on the application the ATS needs to be used in order to pass the emission legislation (Westerhof, 2021). Figure 3 shows how an oxidation catalyst, injection of urea and SCR catalyst after a DE.

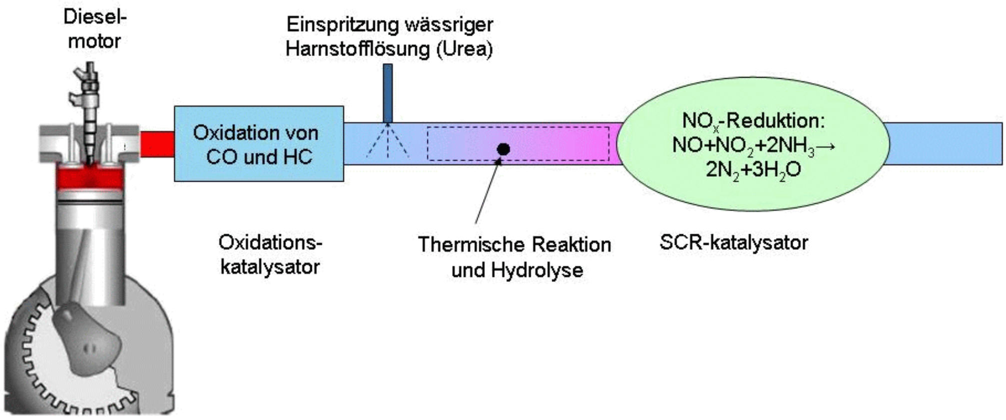

Figure 3. Engine and after treatment system. (Hastdutoene, 2011) CC-BY-SA

2.8 Generator

A generator is a machine that generates electrical power by converting mechanical energy into electrical energy. It does this by using either a two or four-stroke engine, usually diesel, to turn an alternator. The alternator contains a magnetic field created by the rotor and stator, which produces a voltage when the rotor is rotated by the engine. The voltage is then used to produce electrical current that can be used for electrical consumers. (APR Energy, 2018) When referring to DGs in this report this setup with an internal combustion engine and a generator attached to it is meant. Figure 4 shows a typical setup for a diesel generator where the generator, in the orange circle are highlighted.

Figure 4. Generator together with an engine. (Igiritam, 2015) CC-BY-SA

2.9 Lithium-Ion batteries

The lithium-Ion batteries are the ones used daily by a lot of people, they are being used in phones, computers, cars and many more. They are being used because of the high energy density, high power and high efficiency (Minos, 2023).

The deployment of energy storage is rapidly accelerating due to its ability to enhance grid flexibility, provide multiple services, and cater to various applications. To be able to run a vessel 100 percent on renewable sources the batteries are needed, they can be charged with solar or wind power and discharged at sea.

One significant driver for the adoption of energy storage is its capacity to mitigate the energy sources, in this case the DG or from shore. By storing excess energy during periods of high generation and discharging it during times of increased demand, energy storage helps balance the supply and demand, maximizing the utilization of energy and minimizing waste.

Furthermore, energy storage systems offer a range of advantages beyond renewable energy integration. They can provide rapid response capabilities, allowing for quick power discharge or absorption within fractions of a second. This agility is crucial in maintaining grid stability when unexpected spikes in electricity demand occur, providing a reliable and stable power supply (ucsusa, 2015). By providing electricity in response to fluctuations, energy storage systems can help defer or eliminate the need for costly operations when running a DG

In summary, the deployment of energy storage is gaining momentum due to its ability to increase grid flexibility, optimize energy utilization and stabilize grid operations. These systems have become indispensable in modern electricity grids, providing multiple benefits and enabling a more sustainable and reliable energy future.

2.10 Fires in batteries

Lithium-ion batteries possess high energy density but also carry significant risks and hazards, including flammability and potential for fire and explosion. These risks stem from various factors such as overcharging, use of non-compliant charging equipment, exposure to extreme temperatures, physical abuse, short-circuiting, malfunctions, system faults, and manufacturing defects or contamination (dfes, n.d.).

Instances that can lead to the ignition of lithium-ion batteries include:

1. Overcharging or use of non-compliant charging equipment
2. Overheating or exposure to heat or extreme temperatures
3. Physical abuse such as dropping, crushing, piercing, or excessive vibrations
4. Short-circuiting, battery cell malfunctions, or faults in the system
5. Defects or contamination during the manufacturing process

When lithium-ion batteries fail, they may experience thermal runaway, which involves the violent rupture of one or more battery cells. This process is accompanied by hissing sounds, the release of toxic, flammable, and explosive gases, and the initiation of a self-sustaining fire (dfes, n.d.).

2.11 Power management system

The power management system (PMS) is the system that controls the continuous supply of all the electric systems onboard. It controls the load on the generators for the most efficient operation (ABB, 2023).

The PMS typically controls the following systems onboard vessels:

- Load demand monitoring on ship power system (SPS).

Total load is compared with the available generating capacity.

- Generator management on SPS.

If a blackout occurs an automatic restart and connection of the DGs is ensured. This also stops big consumers from being restarted until enough power is ensured.

- Load sharing on SPS.

This shares the load on the different DGs that are connected.

- Frequency control on ship.

Keeps the frequency within the limit by giving signals to the DGs.

3. METHODS

With every vessel currently sailing almost every one of them are unique, so is the system used for propulsion. In order to cover different propulsion system for the result, qualitative interviews, as described by Denscombe (Denscombe, 2018) made it possible to use follow up questions depending on how the interview went. The qualitative interviews gives an open discussion about the topic. Since the people that are working or have worked with the hybrid propulsion systems have more knowledge then the interviewer, this method takes advantage of the expertise and knowledge from the interviewers which will give a better result in the end.

The interviews will be semi-structured, this is done because the participants have a lot of experience of the topic and the questions over time can be changed for the better (Barclay, 2018).

Since hybrid propulsion is a new element in the shipping industry a lot of owners to the vessel and companies that produces these systems don´t want to participate in the interviews it they are not anonymously.

3.1 Background of the subject

In order to have knowledge and understanding of hybrid systems. Reports from marine engine manufacturers as well as peer reviewed reports have been read on the subject. This is because of the amount of research that the manufacturers are doing and share through reports, the reports have been found on companies' websites and the peer reviewed reports have been found on the webpage scopus.com.

Scopus proved to be a valuable resource for obtaining information about batteries installed on vessels, as it provided a unique and comprehensive collection of scientific evidence that was needed for the background to DEP. With its vast database of peer-reviewed journals, conference proceedings, and book series, Scopus offers researchers and analysts advanced search tools and analytics to support the work.

Using Scopus allowed access to a broad range of relevant scientific evidence that might have been difficult to find using other search tools, such's as google.

3.2 Interviews

To allow the interviewees to elaborate on their answers and ensure that the outcome of the study is comprehensive, the interviews will be conducted in a semi-structured format (Höst et al., 2006). This approach will also help to address the issue of participants using different terms to refer to hybrid propulsion systems. By using this approach in conjunction with the information gathered from the literature search, the study aims to gain insights into the benefits of using batteries together with DG and their impact on the vessels.

The semi-structured interviews consisted of five questions and lasted between 25 and 40 minutes. The initial contact with the interviewees was made through email or phone, and the interviews were conducted either online, through phone or in person, depending on the preference of the interviewee. Overall, this approach provided valuable insights into the use of hybrid propulsion systems and their benefits for vessels operation.

The interviews were conducted in Swedish. In table 2 the date and how the interview was done is shown.

Table 2

When the interviews were conducted and what type of communication used.

Interview	Type of interview	Date
1	In person	2023-04-12
2	In person	2023-04-12
3	Microsoft Teams	2023-04-12
4	Phone	2023-04-25

3.2.1 Participants

The participants have a minimum of five years of expertise in how a vessel should be designed to obtain a well worthy sea standard.

The people that have been chosen to participate in the interviews are people who are working or have worked with vessels that use hybrid propulsion. They are all familiar with how the system works and what's needed in order to have a good working vessel. Some of them are engineers and others work in the office with technical questions regarding the vessels.

The involved individuals have been found suitable for the interviews and they have some relation to the marine programs at Chalmers.

The attendees listed in Table 3 have been selected for their knowledge and experience in the field of hybrid propulsion. Each person brings a unique perspective to the table, based on their background and expertise. By interviewing them, they'll able to gain a comprehensive understanding of the current state of hybrid propulsion technology, as well as the challenges and opportunities associated with its development and implementation.

Table 3

The individuals interviewed

Interview	Position	Experience
1	First Engineer	Around 5 years
2	Former Chief Engineer	Over 10 years
3	Technical inspector	Around 20 years
4	Maritime professional	Over 35 years

Comment: The different individuals, their position and their experience

Interview 1.

Working right know on a vessel equipped with battery packs that are being charged from the DG when the power is not being used for the propulsion.

Interview 2.
Have from time to time been a teacher with specific knowledge of electrics. Referring to batteries on board the same way as the first participant with batteries being charged when the extra power from the DG is not being used for the propulsion. Have worked at sea for over 10 years and with batteries on vessels for close to 5 years.

Interview 3.
Working at the office for a vessel owner with expertise in vessels equipped with batteries. Have had a major role when ordering and building vessels with batteries onboard. Technical knowledge comes from both working as a captain and as a technical inspector. The vessel this participant referred to was vessels using batteries as their main propulsion and the batteries could be charged from either shore or from DG.

Interview 4.
Been working on ships for around 10 years and 25 years with projecting and on site at shipyards. Specialist in liquid gas carriers and with prospecting newbuilding vessels. Also works with insurance companies on site when something has happened with the vessel, it can be a collision or an oil spill for example.

3.3 Generalization, reliability and validity

In order to achieve high reliability, the selected people have been chosen because they have great knowledge of the hybrid system. The same goes for the reports read on the topic in order to gather relevant information.

The shipping companies that have been contacted are not willing to give out data gathered from their vessels. This means that the result won't be as reliable as it could possibly be. The interviews will be the only source of information that has been gathered in order to answer the research question.

3.4 Ethical considerations

With regards to the owners of the vessels, no names that can disturb the company or the company's interest in the daily work will be called out. This also means that the interviewed people will not have to give out their name.

Under the interviews notes were taken and after the interview was done a full text was transcribed which was later sent to the participants so that human errors wasn´t made but also to inshore that everything was according to how they formulated the information under the interview.

4. RESULTS

The results are presented in the relevance order, this means that in the beginning the results are for all vessels and later more specific for different vessel types is mentioned. In the end some thoughts are stated about what the interviewees mentioned were problems and why batteries at the moment are not more common in the shipping industry.

4.1 Service intervals and fuel consumption

Whit the batteries installed the advantages are both time and money. The money saved from using batteries onboard vessels is high because DGs can be turned off and the running hours will not keep on going, the DGs have service intervals depending on the running hours and here both interviews 1 and 2 had experienced less work when the batteries are installed compared to before they were installed.

Another benefit of using batteries onboard vessels is the saving in fuel consumption. Running two DGs on part load compared to one at higher load and with the extra load when needed coming from the batteries will reduce the total fuel consumption.

According to interview 2 which said the following regarding how the batteries had changed the planned weekly work onboard.

When the installed batteries were used the planned maintenance on the DG was more precise. We had fewer unexpected things that happened to the DG compared to when not having batteries installed.

Interview number 3 charged from shore when possible so the running hours and fuel consumption on the DG was low. The DG only needed a service every 2000 hour.

4.2 Redundancy

Interviewees 1 and 2 had experience with batteries installed on vessels. The batteries are in fact something necessary for the daily operations onboard. Without the batteries the DGs could not balance the extra load needed for the propulsion system and an extra DG would need to run. If another DG was started both interviews 1 and 2 said that it will result in either one DG running at high load and the other at low load or that two DG running at half load. It is the PMS controlling this and both the solutions regarding how to balance the DGs are inefficient. Why more DGs would need to run is for redundancy, the high loads are not there all the time but when the propulsion needs more power it needs to be fast and often only for short periods.

To use batteries that instead are being loaded and discharged when propulsion needs it will instead lead to a DG running at higher load, since it will need to charge the batteries and give power to the propulsion. This is compared to not charging the batteries. However, the solution with batteries that help the DG to balance the extra load will be more efficient compared to using another DG on standby.

Regarding other solutions that the batteries had solved, interview one said regarding the usage of gas instead of diesel as fuel.

During the time when the batteries were out of service for maintenance, the generators were affected by something called "knocking". When the engine is running, it needs a certain amount of fuel and air to function properly. If the engine doesn't get the right amount of fuel or air, it can cause knocking in the cylinders, which is a bad thing. The gas used to power the engine may have difficulty adjusting the amount of fuel needed to avoid knocking. This can cause a sensor to detect the knocking and cause the engine to switch over to diesel which will lead to more emissions let out in the air.

The knocking happens easier when the engine runs on gas and is exposed to rapid change of load, to instead have the batteries take this change of load and have the engine run on steady load will not expose the engine for the knocking problem.

The second participant specifically mentioned how important a good working PMS is when using batteries for the extra load changes. Without a good working PMS, the load could not be handled by the DG and as a result another DG would need to run. A bad installed and programmed PMS and the load can´t be balanced and a black out will occur.

The third interview had multiple vessels, some using only diesel and others using batteries as the main propulsion. The battery powered vessels had a lot of advantages over the diesel fueled ones, the fact that the vessel was almost impossible to lose power made if safer for the crew and passengers onboard.

Interview 3 mentioned that the battery powered ones also had full power ready for the propulsion at all times compared to the diesel-powered vessels which had to raise the speed on the DGs before the propulsion could use it. The negative aspects of having high power output at all times was according to interview 3 that it could be a rapid change when for example going forward and rapidly change to backwards when mooring.

4.3 Emissions

The third interview had knowledge of batteries as the main power source for the propulsion of the vessels. With this system the PMS controlled when the DGs needed to start in order to charge the batteries, the charging then stopped when the batteries had enough power, but the main part of the charging was done with electricity from shore and through cable, this was to further reduce the emissions. The vessels had high expectations of becoming net zero in emissions and in the future, they would only be charged from shore.

Interview number 1 and 2 said that the batteries help the DG to have a more optimal load that reduces fuel consumption and lowers the emissions. With optimal load on the DGs the after-treatment systems worked better and less emissions were let out in the air.

4.4 Risks with batteries

Regarding the risks of using batteries onboard vessels, the fire hazard is a concern all the interviewees had. Person 1 said regarding question four and five.

The fire hazard that occurs with batteries installed onboard are not possible to withstand. Also, it differs from the classification society what type of extinguishing equipment is needed when having batteries installed onboard.

The batteries installed onboard all the interviewees' vessels were lithium-ion batteries and they have become increasingly popular due to their high energy density (Minos, 2023). The interviewees explained that lithium-ion batteries can store more energy in a smaller space than other types of batteries. However, there are some safety concerns associated with their use, including the risk of fire and that it is almost impossible to stop the fire when it has started.

One of the main causes of fires in lithium-ion batteries is overheating. When the battery is charged or discharged too quickly, it can generate heat, which can cause the battery to overheat and potentially catch fire. Additionally, if the battery is damaged or punctured, it can also cause a short circuit, which can lead to overheating and fire.

Interview 1 said that they stored the batteries in a separate room without any camera surveillance over them, this could potentially be a hazard if the fire alarm started but the crew couldn't see if a fire occurred or if it was a false alarm.

To minimize the risk of fire, it is important to use lithium-ion batteries only with compatible devices and chargers, and to follow the manufacturer's recommendations for charging and storing the batteries. It is also important to inspect batteries regularly for signs of damage or wear. Both interview 2 and 4 mentioned this but also that they preferred the batteries to be cooled with air instead of water to not risk a leakage of water near the battery room.

Overall, while lithium-ion batteries can pose a fire hazard if not used or stored properly, these risks can be minimized by taking appropriate safety precautions. Onboard all vessels the interviewees had been on they had these precautions in mind and everyone in the crew was careful with the handling of the instruments and the batteries.

Interview 4 also mentioned that the risks with batteries today are how to use them so they will be in operation for as long as possible. The producers of batteries are specifying that batteries should not be charged over 80 % and not discharged to lover than 20-30 % in order to keep the lifespan as long as possible (Bonnet, 2023). Smaller batteries can be changed out relatively easily and cheaply, but vessels are often built in layers which can make this harder.

4.5 Using only batteries

The negative aspects regarding batteries as the only type of propulsion are according to the interview three.

On colder days, up to 40% of the battery's capacity is used for heating the passenger area compared to around 5% on normal days. The two different vessels can run six to seven hours on one charge and up to ten hours straight on the other vessel. This is significantly reduced on the colder days as mentioned earlier.

The output of this is that the problem wasn´t there often but the days they were a significantly higher usage of the DG was used for charging the batteries.

The other two interviewees, 1 and 2, could run 100% on the batteries as well but only for up to 20 minutes, hence the problem with the heating never occurred for them. This type of propulsion with only the batteries was not used frequently since at least one DG needed to be started again shortly after.

All interviewees mentioned that the problem with only using batteries and no DG installed onboard at all, will lead to problems when the vessel is going to shipyards for repair or inspection. The vessels will be designed and built with the specifications needed for the specific route they will be used on. If used on another route or the speed is increased for example, the batteries will be discharged faster, and the vessel will lose all its power.

4.6 Infrastructure of charging

Even if not all the interviewees had vessels operating with batteries that were charged from shore and discharged under voyages, they all mentioned charging infrastructure and a standardization of the charging cable as a problem.

Ports are relatively often placed away from power sources and that is a problem when the charging will be from shore instead of from DG. The time when the vessels are not running is costly which means that the charging needs to be fast.

For ferries going front and back between two places which interview 3 referred to. The stays are too short, and the costs are too high to install chargers at both places.

4.7 Advertising

In the interview with 1, 2 and 4 they all mentioned that by installing batteries onboard, even if it was only a small battery. The vessel could use this for marketing and show that they had taken steps towards being ecofriendly even if they did not use the batteries, they only had it installed for backup power if needed.

5. DISCUSSION

The aim of this study was to investigate the usage of batteries on board vessels, both alone and together with DGs. However, there was not enough prior knowledge about the technical solutions used on different types of vessels. Initially, the intent was to analyze the efficiency of the system, but the collected data became unusable due to incorrect calibration of the tool and the data was of no use.

To address these challenges, the research question and the methodology needed to be revised. Starting by gathering more background information about the technical solutions used on different types of vessels to better understand the study design. By taking these steps, the study could yield valid information from the interviewers to answer the research questions.

A believed statement considered it necessary to gather extensive information regarding how the charging was made and how the batteries work together with the DG but also that the acknowledged scope of the investigation might have been too broad, resulting in general findings that lacked depth. Despite this, the founding of the discoveries is compelling, indicating that batteries onboard will likely become increasingly common on various vessels in the future.

Overall, the statement emphasizes the significance of continuing research to better understand batteries onboard and their potential use in various applications.

5.1 Interviews

In the interviews the result was clear. They all saw potential in using batteries to reduce emission, help the DG work better and for improved redundancy. This report does not involve any calculations on what the cost for installing batteries are but that is something that later needs to be taken into account for, interview number 4 told that the calculation for installing batteries on a newbuilding for them would have been 10 percent extra on the total price of the vessel. In their case that was too much, and other environmental improvements were taken in order to reduce the emissions.

5.1.1 Service intervals and fuel consumption

The use of batteries onboard vessels provided several advantages. The installation of batteries on vessels can result in significant savings in terms of time and money. This is because the use of batteries can reduce the running hours on the DGs, which have service intervals based on the running hours. Therefore, the maintenance cost and workload associated with servicing the DGs can be reduced with the use of batteries. On the other hand, more systems are required when using batteries onboard. The space needed is on cargo vessels lost income for the owners. Smaller battery installations like interviews 1 and 2 talked about will also take up a lot of space even if it for them was achievable.

Another advantage of using batteries onboard vessels is the lower fuel consumption, the DGs can be operated to reduce their fuel consumption. This is a significant advantage, as fuel is one of the major expenses in the operation of vessels.

Furthermore, the use of batteries can also improve the precision of planned maintenance on the DGs, as mentioned by interviewee 2. Reducing the load on the DGs and ensuring that they operate within their optimal load range. As a result, the DGs can be serviced based on their running hours, and the probability of unexpected breakdowns can be reduced.

Interviewee 3 highlights the advantage of charging batteries from shore whenever possible, resulting in a reduction in the running hours and fuel consumption of the DGs. This approach can also reduce the frequency of service intervals required for the DGs, resulting in additional savings in terms of maintenance costs.

In conclusion, the use of batteries onboard vessels provides significant advantages in terms of time and money saved, as well as a reduction in fuel consumption and maintenance costs. Therefore, it is essential to consider the installation of batteries when planning the operation of vessels to optimize their performance and reduce their environmental impact on the vessel.

5.1.2 Redundancy

The batteries are constantly providing better redundancy compared to having an extra DG running all the time, this would not work long term either with another DG running just for redundancy. The fact that losing power will be almost impossible will be an extra protection for the crew according to interview 1. Regarding the redundancy provided with batteries installed there is no downside to the installation.

5.1.3 Emissions

This goes hand in hand with batteries, the emissions that the exhaust pipe is letting out when using DG are higher than when combined with batteries. To only use batteries will reduce the emissions to zero from the vessel. The fact that a lot of energy is needed to produce batteries and that batteries do not have an infinite lifespan needs to be taken into account when choosing batteries in order to reduce the emissions. But even the dirties extraction method will emit lower CO_2 than not installing batteries at all (Crawford et al., 2022). In the future the methods for extraction will probably be even better for the environment and the total emissions from extraction to recycling of the batteries will be lower than today.

5.1.4 Risks with batteries

One major risk with the installation is the fire hazard that the lithium-ion battery has. If lithium-ion batteries catch on fire, toxic and explosive gases are being released interview 2 said. These need to be ventilated away from the compartment in order to not injure someone onboard. Regarding the solutions the interviewees had in order to reduce the risks of fires, the compartment where the batteries were standing was equipped with a fixed installation of fire extinguishing if a fire occurred.

All participants in the interview were not afraid that the batteries would start to burn but they showed concerns that if the batteries would start to burn, they were aware that they could only try to stop the fire from spreading. Since people that work on vessels are the ones that are the firefighters a special training for battery fires could be a great feature to add to the existing training that is being held every time a new certificate is being renewed, something that helps the crew if a fire would break out in the batteries.

5.1.5 Using only batteries

The risks of only using batteries and not installing a DG onboard will be devastating. According to Transportstyrelsen "4 §30 The machinery must be able to be started without help from the outside" (Transportstyrelsen, 2019, p. 18). This applies to all vessels that have been built under and after 1986 which means that a DG or something similar must be installed on the vessels.

Regarding the fact that by using batteries and only a DG as backup the problem with a lot of power being used to heat the personal compartments still stands. This can be solved by using smaller doors and in pairs so that two doors have to be used to get in or out. This traps warmer air inside the accommodation and less heat needs to be heated every time the doors are being opened.

5.1.6 Infrastructure of charging

The problem with vessels that are charging high voltage under short periods from shore to the batteries is the infrastructure of the power. A lot of cities don't have the power needed to charge these vessels and that is something that has to be solved as well as how the charging should be done.

The charging cable is only a matter of money to solve that aspect. An automatic robotic arm has been installed in some places to be able to get the charging going fast (ABB, 2018).

Regarding how to solve how much power that is needed to the place where the charging will take place needs to be calculated. Concerns that may arise are that the power cables need to be of a bigger size which is a lot of money only for a vessel to be able to being charged.

5.1.7 Advertising

By installing batteries onboard vessels, the owner can advertise this on the vessel, and it means good publicity. But the fact that only a small battery is needed in order to write "Battery powered" on the side is greenwashing. For the companies that instead use batteries as part of their main propulsion the meaning of the advertising is not the same when other companies "don't play by the same rules" as interview 2 said. Even if the advertising should not be why the owner decides to install batteries onboard it will still be a reason to install batteries.

5.2 Discussion of method

A lot of time was used in the beginning to do a scientific investigation, as the installation of batteries onboard was not familiar at first. The author had to conduct a literature search using scientific databases and university-provided tools to evaluate sources, which helped to obtain relevant sources and build a background and theory. However, early in the process some reports were found outdated and that was realized when there was more knowledge on the topic, this indicating that something might have been missed out on other relevant information that was inaccessible through the database.

The author also had to adjust the theory successively as the interviews opened up new aspects that had not been considered before. Despite the effort, the literature search was far from perfect even to it brought some useful information. Semi-structured interviews were read about before conducting the interviews, which was a new experience. Books on the topic helped to plan and present the results effectively. Although the limited knowledge of batteries for propulsion, the decision to cover as many areas as possible within the advantages of using diesel electric propulsion was made.

Initially, the aim was to contact only one company regarding the data that needed to be collected but later that data was not accurate. Therefore, to broaden the perspective and have something to work with interviews were established. However, the interviews provided a better understanding of DE installations. In-person interviews were more in-depth and interactive than email interviews, allowing for follow-up questions and better conversations.

The interviews were conducted with people that were in different positions in the vessel company they worked for, this together with the fact that they were anonyms generated great material from the interviews. If data collection had been the method, the outcome would not have been relevant for other vessel types than the one collected from. Instead, by doing interviews and with people in different segments of shipping, the outcome of the research covered more vessel types.

5.3 Validity and reliability

Trost has identified potential issues with reliability and validity in qualitative studies and interviews (Trost, 2010). Throughout this study, I prioritized addressing this concern. Interview-based collection can yield different results on different occasions, so steps were taken to maintain consistency during the different interviews. No own opinions during discussions from the intervener but when there was uncertainty around a particular piece of information, the participants were asked to provide further explanation to ensure that we fully understood each other.

The validity of the articles used in this study has been strengthened by the fact that they have all been peer-reviewed. Additionally, specifically targeted individuals that were responsible for the daily operations with DEP, which enhances the validity of the sources.

6. CONCLUSION

The goal for this research was to look into the use of batteries installed onboard and how they could be used, both alone and together with DG. Different vessel types can use batteries completely different but the advantages of using batteries are the same. The reduced emissions when using batteries by them self or together with a DG are significant and on top of this, the DG will work better which means less time when the DG are out of service.

How the batteries will be used is related to what the vessel is in need of, a ferry working on short voyages for commuting can charge the batteries from shore either every time they are in port, or they can charge them when they are not in traffic. The regulations state that a DG or similar is needed on board if the vessel loses power, that power source may not often be used but it is installed, and it makes the vessel more redundant since two power sources are available on short notice.

Vessels using the DG as a prime source of power for the propulsion, the batteries will be charged when the engine has a low load request for propulsion. The stored power in the batteries will then be used when a lot of load is needed for the propulsion, this is called peak shaving and the only downside to this is the fire risk that occurs with batteries. That fire risk is low, which makes the system with batteries together with a DG a great installation to lower the fuel consumption and furthermore reduce the emissions.

6.1 Recommendations for further research

Some recommendations for further research are to:
Make a case study with at least two different vessels where one operates with diesel electric propulsion and the other with only diesel propulsion.
This will have a more concrete result, but it will also be hard to find two vessels that have the same design but with different main power systems.

To look into retrofitting an older vessel with DEP and the cost for that are another great future research. In the newspaper it’s often an article of vessels under 500 gross tonnages that are being retrofitted with DEP and the only mention is the saving in fuel consumption every year, but the articles never mention what the cost are for installing the batteries and if the savings in fuel are worth the money invested.

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APPENDIX 1

Questions for the interviews.

How are the batteries being used onboard your vessels and why did you install them?

How long do the batteries last (hours)?

What are the benefits of installing batteries?

What are the disadvantages of installing batteries?

Have you had any problems with the authorities regarding the installation of batteries?

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