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NEMOSHIP

**NE**W **MO**DULAR ELECTRICAL ARCHITECTURE
AND DIGITAL PLATFORM
TO OPTIMISE LARGE BATTERY SYSTEMS ON **SHIP**S

GRANT AGREEMENT No. 101096324

# D1.1: Experiences learnt from Battery Energy Storage Systems (BESS) commercial exploitation and improvement requirements

June 2023

## Report details

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# Disclaimer



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# Project summary

The ambition of the NEMOSHIP project is to develop, test and demonstrate new innovative technologies, methodologies, and guidelines to better optimise large electric battery power technology within hybrid and fully electrically powered ships. The project will act as a key enabler of the new co-programmed European Partnership Zero Emission Waterborne Transport (ZEWT) roadmap to better reach International Maritime Organization (IMO) objectives regarding the reduction of Greenhouse Gas (GHG) emissions from waterborne transport by 2030 and 2050.

To help achieve this ambition, NEMOSHIP will develop a modular and standardised battery energy storage solution that is able to exploit heterogeneous storage units and a cloud-based digital platform to enable data-driven, optimised, and safe exploitation. The project will demonstrate the maturity of these innovations at TRL 7 for hybrid ships as well as their adaptability towards fully electric ships thanks to the observations collected from a retrofitted hybrid Offshore Service Vessel (OSV) (Diesel/electric propulsion), a newly designed hybrid cruise vessel (LNG/electric propulsion) and a semi-virtual demonstration of two additional fully electric vessels employed in tasks such as ferrying and short-sea shipping.

The NEMOSHIP consortium estimates that these innovations will contribute to the electrification of about 7 % of the European fleet by 2030 and the reduction by 30 % of EU maritime GHG emissions compared to a business-as-usual scenario.

The NEMOSHIP consortium is composed of 11 partners (3 RTO, 1 SME, 7 large companies) from six European countries and covers the whole value chain, from research-oriented partners to software developers, energy system designers, integration partners, naval architects, and end-users.

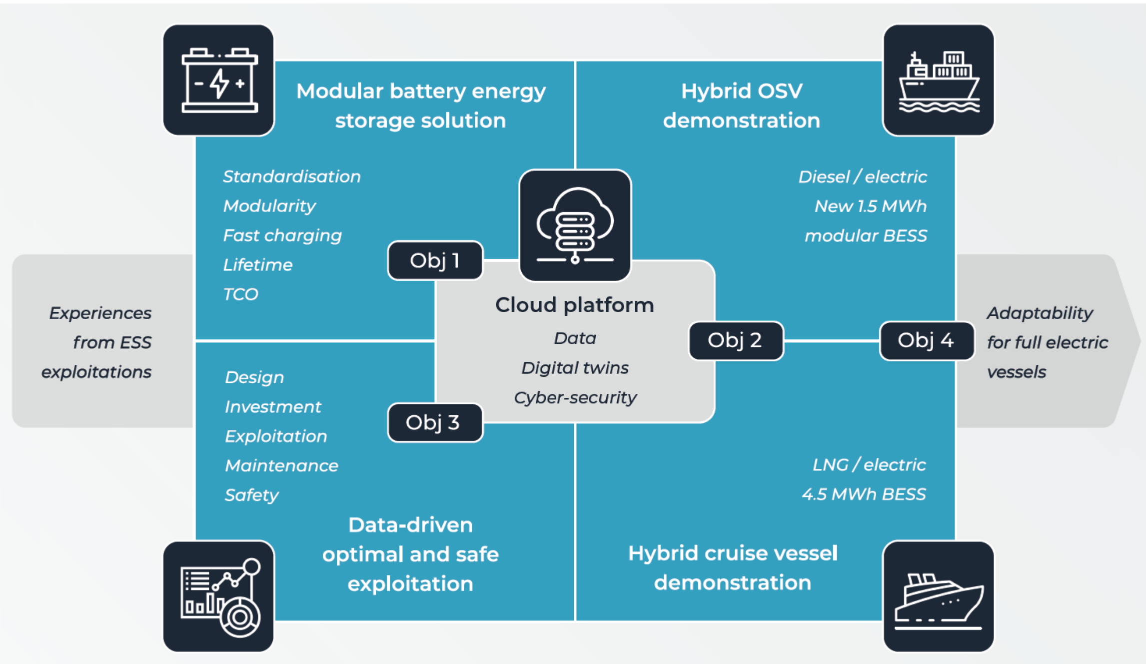



*Figure 1. The NEMOSHIP objectives at a glance*

# Public summary

Task 1.1 named “Experiences learnt from installation and operation of battery energy storage systems (BESS) on vessels”, is one of the five tasks in WP1 titled “Experiences learnt and requirements” which provides a foundation for NEMOSHIP development. This deliverable (D1.1) presents the main results produced from Task 1.1.

This deliverable has kicked-off excellent initiatives towards sharing large amounts of first-hand experience and lessons, which were gathered from the extensive study of more than 750 BESS commercial applications on vessels. All NEMOSHIP industrial partners, namely Equinor, Corvus Energy, Solstad and Ponant, Elkon, and Siemens, have shown extremely positive attitudes towards sharing latest BESS installation and operational experiences with the public. The BESS experiences from these important industrial partners can be summarised in five aspects as follows.

Firstly, this industry-driven study reviews the industrial approaches necessary to achieve $CO_2$ emission reduction targets. Equinor has reached 46 % greenhouse gas (GHG) emission reductions in 2021 compared to 2008 levels for its vessels currently working for offshore oil and gas installations through a combination of policy, technological and managerial actions. However, further GHG emission reductions are more complex and costly to achieve. BESS effectiveness on 18 offshore supply vessels (OSVs) was quantified with regards to the increase in efficiency, total fuel saved and $NO_x$/$CO_2$ emission reductions.

Secondly, this study presents the reported and estimated benefits collected from more than 750 BESS installed on board vessels by Corvus. With installed BESS, the operation and maintenance (O&M) cost reductions have reached 80 % for fully electric vessels (e.g., car ferry) and more than 35 % for hybrid vessels (e.g., OSVs with Diesel-battery) compared to equivalent vessels powered by conventional Diesel engines. The fuel and emission reductions have achieved 95-100 % for fully electric vessels and more than 15 % for hybrid vessels.

Thirdly, a deep dive into the retrofitting of one 630 kWh BESS onto a commercially operating OSV shows that the retrofitting involves many different custom designs, and the total installation cost for the chosen example was 3.4 M€ (5397 €/kWh); this was 10 times the price of equivalent battery systems used by EV within the automotive sector in 2018. The standardisation of interfaces, including mechanical, thermal, electrical grid and communications, between BESS and vessels, is urgently required to reduce installation costs and to increase safety.

The full cycle equivalents (cycles) have been used to measure the BESS usages towards degradation. The 630 kWh BESS yearly operational results display an experienced cycles of 80 versus (vs) its originally designed specification of 480 yearly (0.22 vs 1.3 daily) — it was essentially under-used from BESS degradation perspective. One comparison between the actual BESS cycle vs the designed number of cycles on 19 OSVs shows that the actual BESS cycles are much lower than the designed cycles planned for on 16 of the OSVs.

The number of cycles experienced do not really reflect the effectiveness of BESS operation with regards to the fuel savings and emission reductions. There is thus a need to define more evaluation criteria to assess the effectiveness of actual BESS operation. For example, fuel saving per kWh of BESS yearly and fuel saving per full cycle equivalents yearly. The fuel saving per kWh of BESS yearly has been

used to calculate the effectiveness of the operation of BESS installed onto 10 OSVs, which is effective to evaluate the BESS impact.

Fourthly, two ship owners/operators, Solstad and Ponant, have shared their experiences publicly with the first-of-their-kind BESS installations on their vessels. The experiences and lessons learnt include the BESS installation decision processes, choices made, integration constraints, regulatory and operational challenges, safety concepts, crew feedback, fuel and emissions savings, firefighting strategies, and improved recommendations for BESS integration details and for crew training.

Solstad installed BESS (from 0.5 to 1 MWh) onto 10 vessels providing typical annual savings of 10-15 % on OSVs when combined with shore power (about 1000 tons of $CO_2$/year reduction per vessel). After five-years of operation the installed 500 kWh BESS on Normand Sun provided total fuel savings of 1784 tons and $CO_2$/$NO_x$ reductions of 5718/54 tons respectively. Furthermore, Solstad has provided an overview on the effectiveness of the operation of BESS installed onto 10 OSVs.

Ponant has presented its experience in both installing and acquiring operational battery datasets gathered from two years of monitoring of its exploration vessel, Le Commandant Charcot, which was equipped with a BESS of 4.5 MWh. Ponant notably shared lesson learnt in terms of integration constraints in a newly design vessel, safety and regulatory challenges, operating benefits and feedback. Ponant also shared the lessons learnt from its purchase of an 800 kWh BESS which could not be installed onto its first vessel Le Ponant due to a lack of flag approval.

Fifthly, the joint team has provided concrete suggestions to improve BESS installations and operations and to further BESS development pathway. Equinor has proposed increasing the integration of BESS from the current level aboard vessels towards integrating alongside power supply/charging at onshore/offshore ports, dealing with increasing safety requirements, requirements towards further $CO_2$ emission reductions, and has urged publicly the acceleration of BESS development across sectors/regions in Europe. Corvus has addressed that the development of marine systems BESS must further reduce the footprint, volume, and weight of the installed systems and further increase C-rates and cycles to help move BESS towards being a sustainable enabler for green shipping. Solstad and Ponant have made high-value recommendations regarding integrating BESS onto vessels and provided recommendations towards a training program for crew based on their first-hand experiences.

In conclusion, the amount of BESS installation and operational experiences, as well as lessons learnt from more than 750 commercial BESS projects presented by all NEMOSHIP industrial partners in this deliverable is unprecedented. This report, together with other four tasks in WP1, have provided a solid foundation for the NEMOSHIP consortium to develop, test and successfully demonstrate new innovative technologies aimed towards achieving high TRL, methodologies, and guidelines.

# List of acronyms

| Acronym | Definition | Acronym | Definition |
|---|---|---|---|
| **AC** | Alternative Current | **AHTS** | Anchor Handling Tug Supply |
| **BESS** | Battery Energy Storage Systems | **BMS** | Battery Management System |
| **BOL** | Beginning of Life | **BPMS** | Battery Power Management System |
| **BV** | Bureau Veritas | **CA** | Consortium Agreement |
| **CBA** | Cost Benefit Analysis | **CCTV** | Close Circuit Television |
| **DC** | Direct Current | **DG** | Diesel Generator |
| **DNV** | Det Norske Veritas | **DoD** | Depth of Discharge |
| **DP** | Dynamic Positioning | **E/E** | Electrical and Electronics |
| **EOL** | End of Life | **ESS** | Energy Storage System |
| **EU** | European Union | **EV** | Electric Vehicle |
| **FMEA** | Failure Mode and Effects Analysis | **FSA** | Formal Safety Assessment |
| **GA** | General Assembly | **GHG** | Greenhouse Gas |
| **HAZID** | Hazard Identification | **HE** | High-Energy |
| **HiL** | Hardware in the Loop | **HP** | High-Power |
| **HV** | High Voltage | **IA** | Intelligence Artificial |
| **ICE** | Internal Combustion engine | **IMO** | International Maritime Organisation |
| **KPI** | Key Performance Indicator | **kg/kWh** | Kilogram per Kilowatt Hour |
| **kW** | Kilowatt | **kWh** | Kilowatt Hour |
| **LNG** | Liquefied Natural Gas | **LTI** | Lost Time Incident / Lost Time Injury |
| **MiL** | Model in the Loop | **MVDC** | Medium Voltage Direct Current |
| **MW** | Megawatt | **MWh** | Megawatt Hour |
| **O&M** | Operation and Maintenance | **OSV** | Offshore Service Vessel |
| **OWF** | Offshore Wind Farm | **PC** | Project Coordinator |
| **P-HiL** | Power Hardware in the Loop | **PMS** | Power Management System |
| **PSV** | Platform Supply Vessel | **R&D** | Research and Development |
| **ROI** | Return on Investment | **RTO** | Research and Technology Organisations |
| **SCADA** | Supervision Control and Data Acquisition | **SFC** | Specific Fuel Consumption |
| **SiL** | Software in the Loop | **SME** | Small and Medium Enterprises |
| **SoA** | State-of-the-Art | **SoC** | State of Charge |
| **SoH** | State of health | **SOV** | Service Operation Vessel |
| **SRL** | Software Readiness Level | **TCO** | Total Cost of Ownership |
| **TRL** | Technology Readiness Level | **WP** | Work Package |
| **ZEWT** | Zero Emission Waterborne Transport | | |

# Table of Contents

# 1 Introduction

The International Maritime Organization (IMO) greenhouse gas (GHG) strategy envisages a reduction in the carbon intensity of international shipping by up to 50% by 2030 through intensified, collaborative research activities (compared to ship emissions in 2008)[1]. This, in turn, helps pave the way towards net-zero GHG emissions in Europe by 2050.

Large battery energy storage systems (BESS) are emerging as great enablers of $CO_2$ emission reductions through the electrification of the maritime sector, although integrating BESS onto vessels for ship propulsion remain an emerging technology. It has already been proven that ferries, some short-distance freight services, and inland waterway vessels can be successfully fully electrified[2]. However, a large-scale commercial roll-out across the spectrum of waterborne transport faces a different set of challenges from that experienced by the automotive sector, including:

- Lower numbers, but many different types of vessels;
- Long vessel life times (decades) resulting in the number of retrofits to existing vessels being approximately 10 times higher than the numbers of new vessels being built;
- Very different installation and operational conditions for water-based fuel-saving solutions compared with theoretically similar land transport scenarios;
- A need for advanced technologies and large investments to establish onshore and offshore vessel power supply/charging infrastructure.

With recent large government investments, many BESS projects have been initiated. However, there are large gaps appearing between the BESS initiatives and the actual BESS integration results achieved on vessels. For the installation of the same BESS onto the same type of vessel, the operational results achieved can vary greatly depending on the skills of individual ship operators (e.g., 6 % to 32 % variation in energy savings for ferries of the same application[3]). Only approximately half of ship owners/operators installing BESS have currently achieved their expected fuel-saving results according to the observations of several experienced marine experts. Very few R&D efforts exist that are dedicated to reducing BESS installation costs and optimising their operations, since research institutions often have difficulties accessing the practical experience and operational data generated from BESS integrated onto vessels.

The overall objective of NEMOSHIP is to develop (i) a modular and standardised battery energy storage solution which is enabled to exploit heterogeneous storage units and (ii) a cloud-based digital platform enabling a data-driven, optimal, and safe exploitation, as well as a demonstration of its TRL 7 maturity (regarding the TRL Handbook) for deployment on hybrid ships, and their adaptability for operation onboard fully electric ships.

WP1 provides a foundation for NEMOSHIP solutions while this deliverable (D1.1) presents the main results from Task 1.1 - "Experiences learnt from installations and operations of BESS on vessels". The

[1] International Maritime Organization (imo.org). Available online: https://www.imo.org/en.
[2] DNV. Available online: https://www.dnv.com/expert-story/maritime-impact/Batteries-gain-momentum-in-the maritime-sector.html.
[3] Boveri, A.P.; Silvestro, F.; Molinas, M.; Skjong, E. Optimal Sizing of Energy Storage Systems for Shipboard Applications. *IEEE Trans. Energy Convers.* 2018, *34*, 801–811, https://doi.org/10.1109/tec.2018.2882147.

experiences learnt from high impact R&D projects undertaken by ZEWT and other sectors are presented in D1.2. Other three deliverables in WP1 are D1.3 - “Use cases definition and demonstration requirements”, D1.4 - “Requirements to develop NEMOSHIP modular BESS” and D1.5 - ”Requirements to develop NEMOSHIP digital platform”.

After an introduction highlighting the challenges of emerging BESS, this report has been divided in six sections as follows.

**Section 2** is a review of industrial approaches towards reducing GHG emissions and an overview of the fuel savings achieved from the installed BESS on 18 OSVs that support offshore oil and gas platforms under Equinor’s long-term contracts operate in the North Sea.

**Section 3** provides experiences learnt from more than 750 marine BESS projects managed by Corvus Energy, leader in maritime ESS, that took place between 2018 and 2023.

**Section 4** is a deep dive into the retrofitting of a 630 kWh BESS onto a hybrid-electric vessel to quantitively identify improvement requirements in terms of installations cost and operational efficiency. This section also compared the actual number of cycles experienced by BESSs vs the designed number of cycles on board 19 OSVs.

**Section 5** presents Solstad’s experience learnt from a 500 kWh BESS installation in 2018 and five years subsequent operations on one of its OSVs (hybrid Diesel/electric), and an overview of the effectiveness of BESS installed on 10 OSVs.

**Section 6** presents Ponant’s experience gained from the installation of a 4.5 MWh BESS onto its exploration vessel, Le Commandant Charcot (hybrid LNG/electric) in terms of integration constraints, safety and regulatory challenges, operating benefits and feedback.

**Section 7** summarises concrete recommendations from partners for improving BESS installations and operations and furthering the BESS development pathway, and provide a final conclusion on the experiences learnt and the recommendations.

Eight Appendices present supplementary details to the main report:

(A) Operational data analysis of the BESS described in section 4 with regard to the fuel saving
(B) Lessons learnt from Corvus concerning battery safety
(C) Crew interview results from Solstad’s 500 kWh BESS installation on Normand Sun
(D) The decision-making process defined by Ponant before installing 4.5 MWh BESS
(E) The BESS safety plan for installation and exploitation of Ponant’s 4.5 MWh BESS
(F) Interview report and feedback from crew of the Ponant fleet
(G) ELKON’s recommendations based on its BESS integration projects
(H) Siemens BESS experience learnt from the automotive sector

# 2 Reviewing industrial approaches for reducing GHG emissions

## 2.1 Equinor's approaches for reducing GHG emissions

Very few detailed industrial approaches for reducing GHG emissions are publicly available. This section presents Equinor's $CO_2$ emission reduction results and approaches. The maritime vessels that support offshore oil and gas platforms under Equinor's long-term contracts operate in the North Sea, thus representing a very challenging sector in which to achieve fuel savings and emissions reductions. The marine operation group at Equinor is at the forefront of international efforts to measure and manage fuel consumption and emissions from its contracted vessels since 2011.

The $CO_2$ emissions are classified in four categories: (i) offshore service vessels (OSVs), (ii) extra OSVs, (iii) anchor handling tug supply (AHTSs), and (iv) standby vessels. The total annual $CO_2$ emissions from 2011 to 2021 shown in Figure 2 are the calculated results based on the actual measured fuel consumptions from the four types of vessels together with their efficiencies. It shows that OSVs have the highest $CO_2$ emissions every year from 2011 to 2021. The total annual $CO_2$ emissions for 2021 was estimated to be 236,000 tons based on the actual fuel consumption while $CO_2$ emissions of 436,000 tons were calculated for 2008 based on the best estimates provided by all the vessel suppliers. Accordingly, Equinor has reached $CO_2$ emissions reductions of 46 % in 2021 when compared to 2008. Equinor aims to achieve 50 % reduction in emissions several years ahead of the IMO target of 2030 (218,000 tons in 2030 compared to 436,000 tons to 2008).

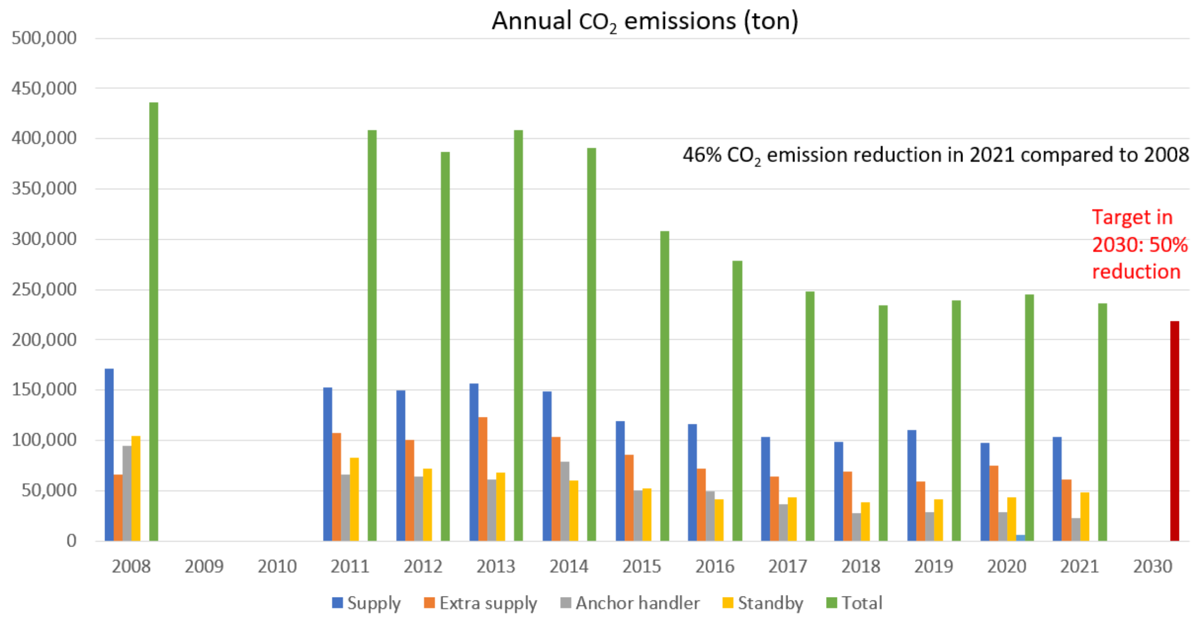



*Figure 2 - Annual CO2 emission results from Equinor's contracted vessels from 2008 to 2021*

Figure 3 illustrates the range of diverse approaches available for $CO_2$ emission reductions, showing that effective actions need to combine many different aspects including policy and finance (governmental level and company level, e.g., fuel incentive agreements), technology (electrification/clean fuels, accurate measurements, and digitalisation tools), and managerial (briefing, awareness, ship owner meeting, monthly fuel reporting and effective training programs). More learning from other sectors (e.g., automotive) and their high-impact projects were explored during this study. The experiences and lessons learnt from real operational data has resulted in real fuel savings for vessels and other sectors, thus establishes the basis for this study which aims to deploy more BESS to further achieve fuel savings and emission reductions.

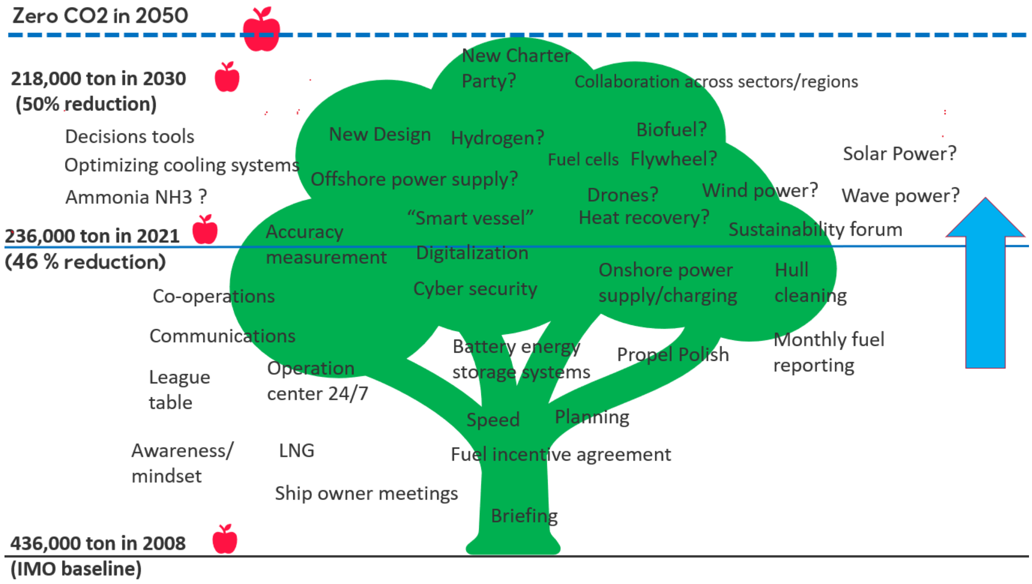



*Figure 3 - Equinor's practical CO2 emissions reduction approaches*

There are strong incentives for enabling the innovative green solutions developed across the oil/gas sector to be transferred to other sectors, e.g., offshore wind farms (OWFs). The experience of the Norwegian maritime green program from 2011 to 2021 has also shown that further $CO_2$ emissions reductions are costly and need collaboration across sectors and regions to be more effective. One sector or one country alone cannot achieve the required $CO_2$ emissions reductions. For example, onshore and offshore power supply/charging infrastructure requires a minimum volume of vessels to be successful, something the offshore oil and gas industry alone cannot provide, but which multiple industries working together can. Successful upscaling and commercialisation of effective green solutions consequently depends on the efforts of the whole supply chain. For maximum socioeconomic effect, five companies reducing emissions by 10 % each might be more effective than one company reducing emissions by 50 % (since further reductions always cost more). The electrification of waterborne transport can also apply effective energy efficiency solutions from other sectors such as the automotive.

## 2.2 Effectiveness of BESS operations onboard OSVs

This section presents the operational results of 18 BESS installed onto 18 OSVs using data collected from the MarESS[4] operation system which reports the BESS effectiveness concerning the efficiency increased, total fuel saved and NOx/$CO_2$ emission reductions due to the BESS installation. The MarESS software identifies periods of excessive consumption and proposes the most effective fuel saving initiatives to make the most of potential cost and emissions savings for the company. It does this by combining data on fuel levels with other information such as weather information and ship tracking. Offshore companies use MarESS daily on more than 150 ships.

[4] Global Opportunity Explorer. Software Drives Fuel Efficiency Improvements For Maritime Industry.

BESS on hybrid OSVs currently have two functions: (i) Peak shaving of the power from diesel generators—using the BESS to ensure the generators operate at optimal efficiency, and (ii) BESS capacity serving as a spinning reserve during dynamic positioning (allowing one generator fewer to operate). Without BESS, an OSV must have two Diesel generators in operation (one for supplying power and another one for spinning reserve). With BESS, only one Diesel generator needs to be operational, and the BESS capacity serves as the spinning reserve; this is assuming that the BESS has been sized to offer sufficient power and energy for this purpose. This reduces fuel consumption by avoiding the need to run an additional generator inefficiently (at part load).

Table 1 gives a list of the installed BESS capacity. The fuel consumption per nautical mile (NM), total operational days, efficiency increased, fuel saved, and the reduction of $NO_x/CO_2$ for each BESS installed on the 18 OSVs are from the data collected by MarESS. The fuel savings include the use of onshore power supply. The installed BESS on 16 of the OSVs achieved fuel savings as expected, however, the BESS on two of the OSVs saw an outcome involving more fuel consumption instead of fuel savings; this might result from both the lack of onshore power supply used and the losses experienced by the BESS and should be further investigated. The vessel nr. 18 is Normand Sun from Solstad and its own detailed analysis will be presented in section 5.

*Table 1 – Overview of the effectiveness of the BESS installed on 18 OSVs*

| Ship | Installed BESS capacity kWh | Fuel consumption tons/NM | Days | Efficiency increased % | Fuel saved tons | $NO_x$ saved tons | $CO_2$ saved tons |
|---|---|---|---|---|---|---|---|
| **1** | 625 | 0.045 | 1737 | 2.77 | 236 | 7 | 755 |
| **2** | 875 | - | 1464 | 4.38 | 310 | 9 | 992 |
| **3** | 875 | 0.045 | 853 | 12.43 | 492 | 10 | 1147 |
| **4** | 875 | 0.041 | 1037 | 21.9 | 1212 | 32 | 3815 |
| **5** | 497 | 0.048 | 1829 | 12.76 | 1417 | 43 | 4544 |
| **6** | 565 | 0.050 | 672 | 2.25 | 89 | 3 | 284 |
| **7** | 621 | 0.053 | 1128 | 12.18 | 947 | 28 | 3036 |
| **8** | 746 | 0.026 | 1188 | -3.47 | -184 | -6 | -591 |
| **9** | 621 | 0.048 | 1200 | 14.42 | 1019 | 1 | 2752 |
| **10** | 621 | 0.038 | 1341 | 19.36 | 1142 | 34 | 3661 |
| **11** | 621 | 0.042 | 1403 | 12.98 | 846 | 25 | 2711 |
| **12** | 746 | 0.038 | 1219 | -3.41 | -188 | -6 | -602 |
| **13** | 621 | 0.049 | 1890 | 10.99 | 1070 | 32 | 3430 |
| **14** | 621 | 0.06 | 1890 | 7.62 | 781 | 23 | 2505 |
| **15** | 568 | 0.024 | 1798 | 24.8 | 2514 | 75 | 8060 |
| **16** | 870 | 0.049 | 456 | 15.24 | 301 | 9 | 965 |
| **17** | 621 | 0.049 | 1159 | 15.77 | 1600 | 48 | 5129 |
| **18** | 497 | 0.045 | 1857 | 13.7 | 1784 | 54 | 5718 |

# 3 Experience learnt from large BESS commercial projects

Corvus Energy is the market leader in maritime ESS with almost 800 units installed worldwide since 2011. From this strong experience, Corvus Energy has defined a process ok selecting the right technology and product for a dedicated application (Figure 4).

Installing large BESS systems on hybrid or fully electric vessels is still an emerging approach. Hands-on experience of these BESS enables Corvus to perform portfolio analysis across different components and their applications to improve both production development and data monitoring.

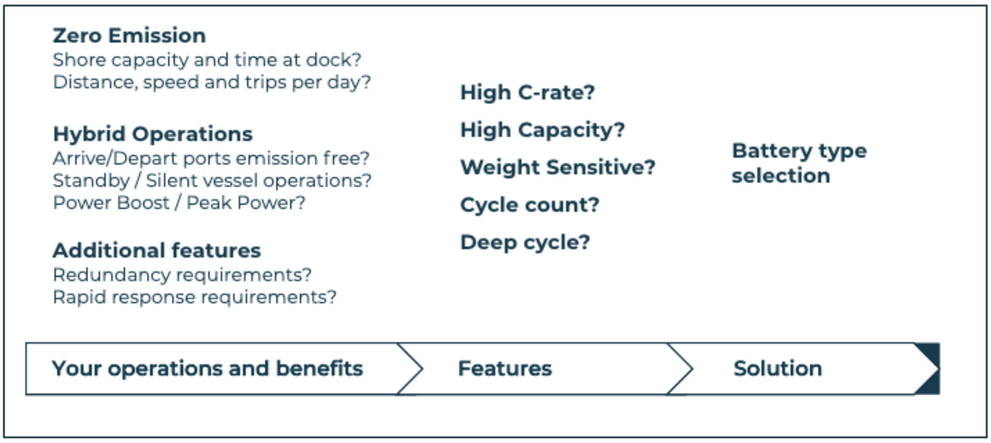



*Figure 4 - Corvus process for selecting the right BESS technology*

## 3.1 Reviewing large BESS commercial projects delivered by Corvus

This section shared the experiences learnt by Corvus from above 750 projects. Those commercial BESS projects are distributed in six vessel types (Table 2) and seven applications (Table 3). This represents a total operational capacity of more than 650 MWh and the total operational hours have exceeded seven million. The estimated reduction in $CO_2$ emissions are around two million tons.

Table 4 summarises the impact of the BESS installations undertaken by Corvus onboard various vessels, with their reported/estimated O&M costs and fuel and emission reductions. Emissions savings are, in the first instance, proportional to the MWh of the batteries installed. Every effort should therefore be made to ensure the installation and integration of batteries are as easy, inexpensive and low-risk as possible.

With newly installed BESS systems, the O&M costs for fully electric vessels (e.g., car ferry) can be reduced by 80 % compared to similar vessels powered by conventional Diesel engines. The O&M costs of hybrid vessels can also be significantly reduced by the installation of large BESS systems thanks to the reduction of the operational hours and start-up/shut down times of the rotation machines (e.g., Diesel generators) and the improvement of the operational conditions of the rotation machines (e.g., increasing its operational low load to its design load). These O&M cost reductions decrease when the BESS systems degrade over time and need replacement after several years of operation. The design lifetime for most of these BESS systems is approximately 10 years. Large BESS system installations onto vessels have been effective at generating fuel and emission reductions on all types of vessels.

*Table 2 – Corvus BESS projects divided into six vessel types*

| Car & passenger ferries | Cruise & yachts | Offshore & subsea | Tugs/Workboat/ Fishing/Research | Merchant vessels | Port equipment/shore stations etc. |
|---|---|---|---|---|---|
| **158** | 42 | 142 | 152 | 78 | 186 |

*Table 3 - BESS applications*

| Application | Effectiveness |
|---|---|
| **Spinning reserve** | Backup energy, reducing number of running engines, increasing fuel efficiency |
| **Dynamic performance** | Instant power supply, mitigate slow engine response |
| **Peak shaving** | Reduce power peaks, optimising engine load |
| **Zero emission** | No running engines, No emissions/noise |
| **Enhanced ride through** | UPS like functionality, like spinning reserve in local subsystem |
| **Strategic loading** | Optimise energy generation, reduce fuel consumption |
| **Energy regeneration** | Optimise use of energy from lifting operation, fuel saving |

*Table 4 - Reported and estimated O&M, fuel, and emission reductions per vessel type*

| | Fully Electric Car ferry | Hybrid Car ferry | Hybrid PSV | Fully electric Tug | Hybrid Fishing vessel | Hybrid Shuttle tanker |
|---|---|---|---|---|---|---|
| **Operation and maintenance cost reductions** | 80% | 35–50 % | 35–50 % | 80 % | 50-75 % | 35-50 % |
| **Fuel saving** | 100% | 15–40 % | 15-20 % | 100 % | 20-25 % | 20-25 % |
| **$CO_2$ emission reductions** | 95% | 15–40 % | 15–20 % | 95 % | 20-25 % | 20-25 % |
| **$NO_x$ emission reductions** | 95% | 30–60 % | 30–40 % | 95 % | 30-40 % | 30-40 % |

## 3.2 Learning from large BESS commercial projects

In addition to cost and emission reductions, the learning from Corvus BESS installations can be completed concerning investment, certification, optimal exploitation and safety.

The installation of BESS is still expensive and time-consuming. The installation cost of retrofitting a BESS onto an OSV is often twice as much as the cost of the container containing the BESS itself, and it can take months or years of preparation before the actual installation is carried out. Reducing the installation costs of BESS through standardisation of overall interfaces between BESS and vessels is urgently required (electrical, thermal, management systems, …).

One of the industry's affordable BESS installation criteria is return on investment (ROI). Most of the Corvus BESS projects (in the range of 500 kWh to several MWh) have reached ROI (annual) of 26-45% with a payback time of 2.2-3.9 years. To maximise ROI, collaborative efforts from many aspects shown in Figure 5 are required.

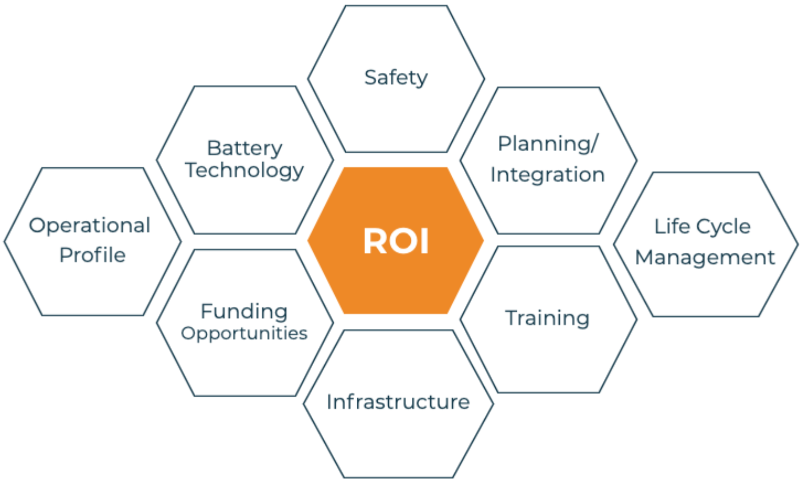



*Figure 5 - Collaborative efforts towards maximising ROI of a BESS project*

One of the largest technological barriers slowing down BESS installations is the increasingly demanding safe operational requirements required for certification and re-registration of flags, especially for retrofitted vessels. Many certifications are required after BESS installation including comprehensive failure mode and effects analysis (FMEA)[5]. The re-registration of flags might also become a showstopper for BESS installations. For example, Ponant purchased an 800 kWh BESS, but could not install it onto its vessel Le Ponant due to the requirements of the flags not being met.

More R&D efforts are required to optimise installed BESS operations. Many vessel owners and operators are conservative regarding BESS operational modes hence there are large potential benefits still to be unlocked from installed systems. When larger capacity BESS are installed onto hybrid-electric vessels, their optimised operations are becoming increasingly important. Furthermore, extending BESS integration from on board only to include the port power supply and charging infrastructure could have a high impact on reduction of emissions from vessels.

Finally, Corvus learned from its long experience in maritime applications. Corvus has a well proven built in safety system from cell to system level to avoid thermal propagation, validated by a thermal runaway test protocol defined with DNV and the Norwegian Maritime Authority, but also learned safety must be considered at vessel level. All stakeholder needs to collaborate and be responsible to ensure good conditions in the battery rooms and a built-in robustness in systems and installations. Training the crews and fire brigades on many different scenarios is important to be able to tackle all types of events.

[5] Failure Mode and Effects Analysis for Classification, Document: 12009.408.910.00 FMEA, DNV. ID: D31005. Available online: https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/design_and_analysis/215_fmea/FMEA_GN_e-Mar18.pdf

# 4 BESS installations and their operational results

This section takes a deep dive into the BESS installations and their operational results from the on-going OMB6 project[6] of which Equinor is the project manager and Corvus is a project partner. The installation costs and operational results of retrofitting a 630 kWh BESS system onto a commercially operating OSV are presented. Furthermore, a comparison of BESS actual operational cycles vs the designed cycles on 19 OSVs is performed. The objective is to show and quantify BESS installation costs and the gaps between the battery actual usages and the design usages on board.

## 4.1 Vessel retrofit with a 630 kWh BESS

A 630 kWh BESS comprising the Corvus Orca Energy Storage System was installed on board a commercially operating OSV in March 2018; four-years of operational data (2018-2022) has since been collected. Orca ESS is a large-scale lithium-ion battery product, designed for hybrid and fully electric ferries, tugs, cruise ships, superyachts, and port cranes. The OSV was originally built with four Diesel generators each having a power generation capacity of 2100 kW. The goal of this section is to present the system installation and subsequent operations and to show the need for improvements that were learnt from this example.

Actual BESS implementation approach, timescale, and costs depend on many factors, including the ship owners' interests, their financial situation, and the technology suppliers, and can vary substantially from case to case. Installation of a 630 kWh BESS onto one commercially operating OSV in 2018 is illustrated in Figure 6.

*Figure 6 - The installation of one unit of a 630 kWh BESS onto an OSV in March 2018*

**The installation has been analysed in terms of costs breakdown as listed in Table 5 and summarised in Figure 7.** The total cost of a 630 kWh BESS installation retrofitted onto an OSV was 3.4 M€ (5397 €/kWh) of which the installation costs were 2.4 M€ (71 %) and the containerised BESS itself was 1 M€ (29 %). The BESS retrofitting cost of 5400 €/kWh calculated for the installation of BESS systems onto this vessel is 10-fold more expensive than retrofitting the equivalent battery systems onto electric

[6]OMB6 (Optimizing marine battery operations using 6 years' operational data from two commercially operating vessels), https://www.sintef.no/en/projects/2021/omb6-optimizing-marine-battery-operations/(accessed on 4 April 2023).

vehicles (EV) in the automotive sector[7,8]. This is due to the retrofitting of vessels currently requiring many unique customised designs that are time consuming to source and install and have high failure risks. The standardisation of interactions between the BESS and ship systems, including mechanical, thermal, electrical grid and communications is thus urgently required to reduce the installation costs and to increase safety standards.

Firstly, the development of safe and cost-efficient installation plans is crucial. The plans include (i) the type and size of BESS, based on economic feasibility (CBA: cost and benefit analysis) and the identity of the BESS supplier (who typically has a one-year delivery time), (ii) arranging contracts with the suppliers, and (iii) defining the necessary requirements from the shipyard to undertake the OSV retrofitting. Secondly, negotiation with different shipyards and the selection of one for the undertaking of the retrofitting project. Thirdly, four sub-contracts were signed, covering the interactions between the BESS and the OSV's systems (including mechanical, thermal, electrical grid and communications) during the installation process. Fourthly, the delivery of a 630 kWh containerised BESS to the shipyard at a cost of 1 M€. Fifthly, the installation and commissioning of the BESS took one-month of work time. This involved multidisciplinary actions at a further cost of approximately 1 M€. For the ship owner, there will be also a 0.6 M€ loss incurred due to the vessel losing commercial rental income for one month while it is out of service being retrofitted. The renting loss can be reduced if the ship owner can effectively combine the installation period with its existing ship O&M plans. Sixthly, after the BESS is installed, comprehensive testing including FMEA is required, and new flag registration is required before the ship can return to service.

*Table 5 - The six major costs when retrofitting a 630 kWh BESS on an OSV*

| Major Aspects | Description | Time | Costs |
|---|---|---|---|
| **Installation plans** | Development of installation plans (CBA study and contracting BESS supplier, booking shipyard and OSV retrofitting plans, arranging contracts, etc.) | 1 or 2 years | Two persons for half year<br>0.1 M€ (3 %) |
| **Preparation at shipyard** | Booking shipyard for retrofitting OSV | Several months | 0.1 M€ (3 %) |
| **Preparation on OSV** | Preparing BESS interactions (including mechanical, thermal, electrical grid and communications) | Several months | 0.2 M€ (6 %) |
| **Delivery of a 630 kWh containerised BESS** | Battery pack production, system integration and containerised BESS | Several months | 1 M€ (29 %) |
| **Installation and commissioning** | Execution of retrofit of BESS on OSV | One month | 1 M€ (29 %) + 0.6 M€ (18 %), in loss of OSV commercial income |
| **Tests, certifications, and flag registrations** | Tests including FMEA and new flag registration | One week | 0.4 M€ (12 %) |
| | | **Total costs**: 3.4 M€ | |

7 European Battery Alliance, Internal Market, Industry, Entrepreneurship and SME. Available online: https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en

8 Ioannis, T.; Dalius, T. *Li-Ion Batteries for Mobility and Stationary Storage Applications-Scenarios for Costs and Market Growth*; EUR 29440 EN; Publications Office of the European Union: Luxembourg, 2018.

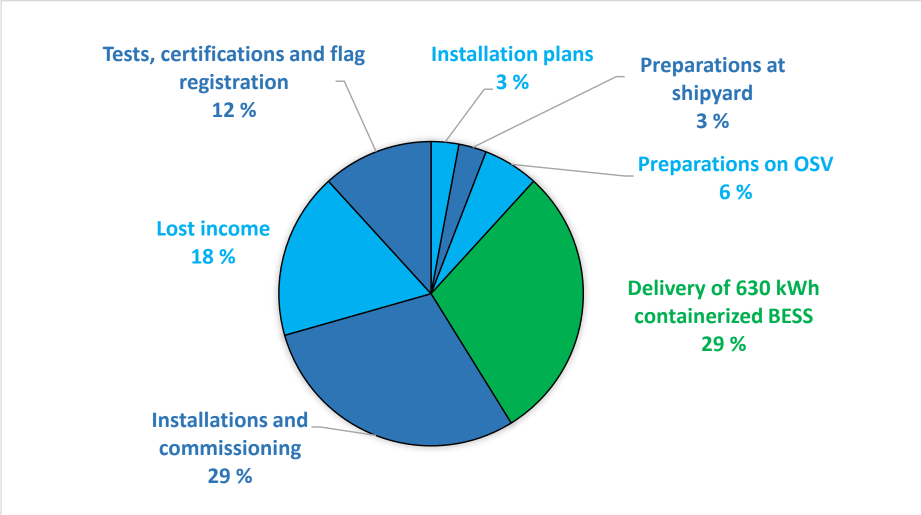



*Figure 7 - The main costs breakdown (%) when installing a 630 kWh BESS onto one OSV*

## 4.2 Operations of a 630 kwh BESS on a hybrid OSV

The operation of a battery system aims to minimise the total fuel consumption from OSVs that have a hybrid micro-grid consisting of Diesel generators, batteries, and green power injections from onshore and future offshore stations. As mentioned, the example OSV for this project has four Diesel generator units (each with 2100 kW) and one installed BESS unit (630 kWh, 1890 kW).

A 630 kWh BESS was integrated into the Diesel–battery hybrid system on board the OSV as shown in Figure 8. The main BESS functions were to serve as (i) a spinning reserve to reduce the number of engines running during dynamic positioning (DP) operations, (ii) peak shaving and (iii) for use when vessels are approaching and staying in the port.

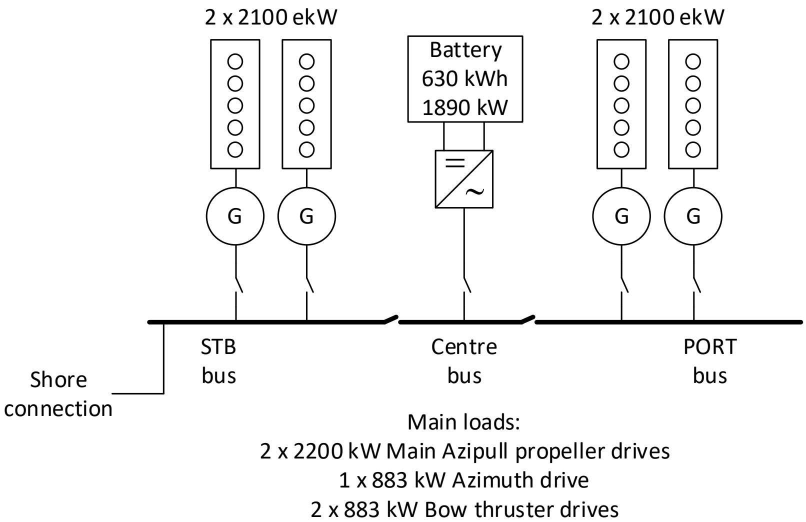
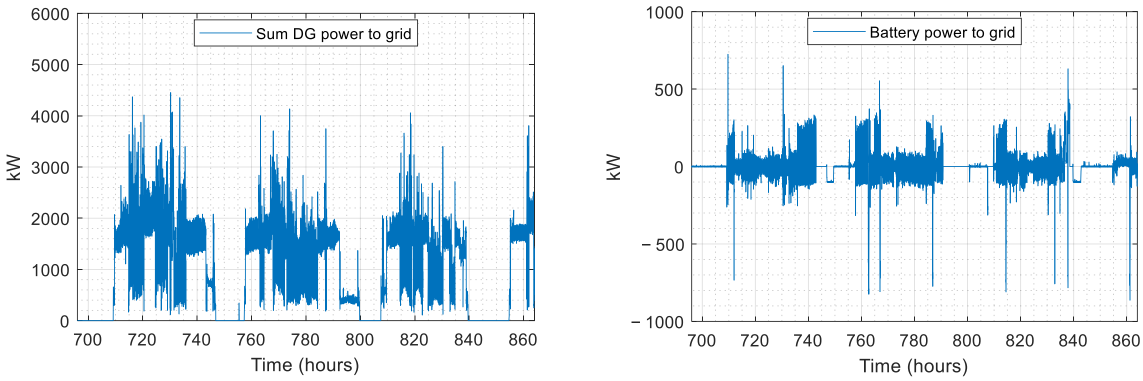



*Figure 8 - Simplified one-line diagram of the vessel power system on an OSV*

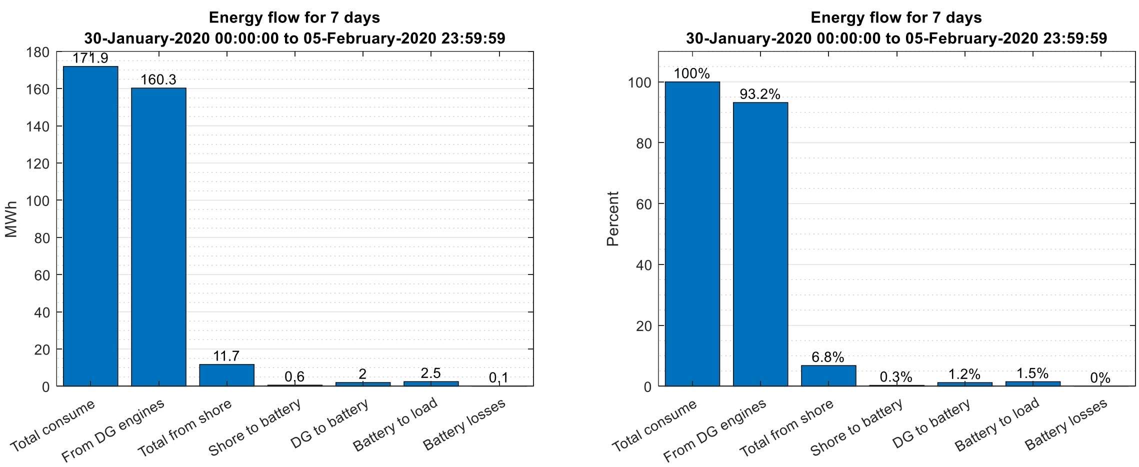
The 630 kWh BESS has operated for five years since its installation in March 2018. The available operational data includes 165 parameters measured at the system level per second (including power generation from Diesel units, actual power, and rate of charging from BESS) and battery internal performance parameters per second via the lighthouse port (e.g., cell state of charge, voltage, state of health and temperature, pack voltage and current).

**The total DG and battery power for the week are shown in Figure 9 for one typical week. The aggregated flow of energy is shown in Figure 10.** The 630 kWh BESS only contributes a small share of energy to the ship propulsion while the Diesel engines are the key source of propulsion energy. A significant amount of energy is supplied from onshore, but this is mostly used to supply onboard hotel loads rather than for battery charging. It is therefore reasonable to believe that the current use of the battery only has a minor influence on fuel consumption, except for the potential savings when using the battery to provide a spinning reserve capability.




(a) (b)

*Figure 9 - One week of operation: (a) sum kW power from DG and (b) battery power to the grid*




(a) (b)

*Figure 10 - Comparison of energy flow in one week (a) in MWh (b) and percent*

The vessel logging system also records the operational modes carried out at any time. These registered operations are in port, in port with shore connection, transit, standby and dynamic positioning. Standby implies that the vessel is maintaining a position at a safe distance from an offshore installation, waiting for a loading/unloading operation to begin. Dynamic positioning is used during critical operations close to an offshore installation. In these operations, there are special requirements regarding redundancy in power generation, and in practice, this implies that the vessel needs to run more Diesel generators than would be required normally to provide the necessary load power. As will be shown, the load profiles and resulting engine fuel efficiency very much depend on the actual operational mode that is active at a particular time.

The logged data was analysed to achieve a better understanding of the fuel-saving potential. An analysis of the battery power flow from the 11-month operation shows that the total energy delivered from the BESS was 45.6 MWh, corresponding to 50.9 MWh for the whole year if one assumes that the analysed period is representative of a whole year. **Accordingly, the BESS underwent 80 equivalent full cycles yearly, which is low versus vs the system specification of 480 equivalent full cycles yearly.**

The definition of equivalent full cycles and the comparison between the actual equivalent full cycles vs the designed cycles is discussed in next section. More details of this 630 kWh BESS operational data analysis are given in a paper[9] and in Appendix A.

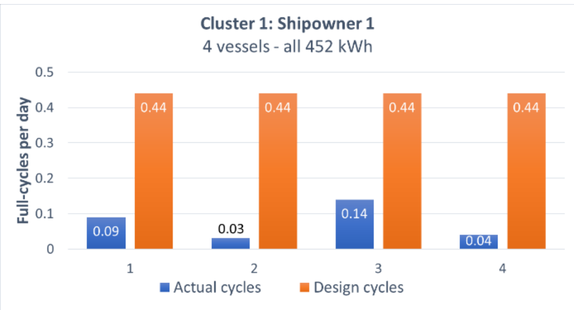
## 4.3 Comparing BESS actual cycles vs the designed cycles onboard 19 OSVs

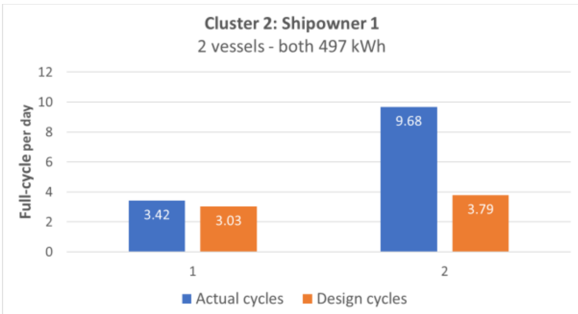
Corvus has compared the actual number of cycles experienced by BESSs vs the designed number of cycles on board 19 OSVs. The comparison is based on the four conditions as follows:

- Containerised BESS with a capacity varying from 452 kWh to 1424 kWh
- Operational modes including DP, transit and at port
- Only periods with quality lighthouse data (Corvus battery monitoring system)

The comparison uses Equivalent Full Cycles (EFC) which considers two main factors affecting the lifetime of the batteries: (i) the number of cycles experienced by the BESS and (ii) the depth of each of the cycles. In order to analyse how battery lifetime is affected by multiple and variable cycles occurring within the same day, the cycles are converted to cycle equivalents, where the original cycles are weighted against their contribution to the aging of the BESS. The limitations of this methodology are detailed in Appendix C.

The comparisons between the actual BESS cycles experienced vs the originally designed cycles can be divided into seven clusters according to the ship owners as shown in Figure 11 and Table 6.




[9] He, W.; Mo, O.; Remøy, A.; Valøen, L.O.; Såtendal, H.; Howie, A.; Vie, P.J.S. Accelerating Efficient Installation and Optimization of Battery Energy Storage System Operations Onboard Vessels. Energies **2022**, 15, 4908.


*Figure 11 - Comparison of the BESS actual usages vs designed usages on 19 OSVs*

*Table 6 - A comparison of actual full cycle equivalents vs the designed full cycles on 19 OSVs*

| | | Actual daily full cycle equivalents (ratio of the actual to designed) | Designed daily full cycle equivalents |
|---|---|---|---|
| **Cluster 1 (ship owner 1): 4 vessels: 452 kWh** | 1 | 0.09 (20 %) | 0.44 |
| | 2 | 0.03 (7 %) | 0.44 |
| | 3 | 0.14 (32 %) | 0.44 |
| | 4 | 0.04 (9 %) | 0.44 |
| **Cluster 2 (ship owner 1): 2 vessels: 497 kWh** | 5 | 3.42 (113 %) | 3.03 |
| | 6 | 9.68 (225 %) | 3.79 |
| **Cluster 3 (ship owner 2): 2 vessels: 565/1424 kWh** | 7 | 0.80 (24 %) | 3.27 |
| | 8 | 0.50 (8 %) | 6.25 |
| **Cluster 4 (ship owner 3): 2 vessels: 621 kWh** | 9 | 0.31 (16 %) | 1.97 |
| | 10 | 0.32 (16 %) | 1.97 |
| **Cluster 5 (ship owner 4): 2 vessels: 678/994 kWh** | 11 | 0.30 (11 %) | 2.80 |
| | 12 | 1.50 (18 %) | 8.49 |
| **Cluster 6 (ship owner 5): 3 vessels: 621/994/994 kWh** | 13 | 0.35 (11 %) | 3.28 |
| | 14 | 0.27 (3%) | 8.49 |
| | 15 | 0.60 (7 %) | 8.49 |
| **Cluster 7 (various ship owner): 4 vessels: from 525 to 870 kWh** | 16 | 2.35 (24 %) | 9.81 |
| | 17 | 0.69 (10 %) | 6.85 |
| | 18 | 4.64 (129 %) | 3.60 |
| | 19 | 0.13 (2 %) | 5.60 |

The actual BESS cycles observed on the 16 OSVs are mostly lower (16/19) than the designed number of cycles. Six of the BESS have even experienced a ratio of the actual cycles vs the designed cycles being lower than 10%. This low number of actual cycles are consistent with the actual number of 80 cycles observed vs the designed number of 480 cycles annually (0.22 vs 1.3 daily) as presented in section 4.2 "Operations of a 630 kwh BESS on a hybrid OSV”.

The installed BESS capacity on these OSVs is small and the total discharging power from the BESS is expected to be less than 1% of the total power consumption of one typical offshore trip. The low number of actual full cycle equivalents results from the three main usages of these BESS as follows:

- Spinning reserve capacity. When a BESS is used as spinning reserve capacity, it does not actually discharge and charge very often and the full cycle equivalents experienced are, as a result, very low since the BESS experiences minimal degradation. The BESS is in an efficient operational mode since the BESS experiences almost no losses and suffers minimal degradation.
- Load levelling. The BESS charges during low demand and discharges power during periods of high demand**.** Since the BESS has a small capacity, it mainly improves upon the operational conditions of the Diesel engines. The BESS often operates at 40 to 60 % state-of-charge (SOC) while undergoing shallow operational cycles which results in a low number of full cycle equivalents.

- Port mode. When there is green power available at the port, the BESS should discharge to the minimum SOC it has when it approaches the port and charge to its maximum SOC before its parent vessel leaves the port. However, it has only been about 40 % of the time that these 19 OSVs have had access to green power while visiting ports. As a result, these BESS have not consistently discharged to their minimum SOC when approaching ports and then charged to their maximum SOC before leaving the port. This then results in a low number of full cycle equivalents.

Discussions towards further investigation of the actual operations of the BESS onboard the 19 OSVs:

- The BESS suppliers should define the criteria used to calculate full cycle equivalents and these criteria should be verified and published for public examination and criticism or improvement. R&D entities and ship owners/operators can then use these criteria to calculate full cycle equivalents to thus evaluate their BESS usages and to predict the levels of BESS degradation amongst their own assets. When the BESS operates in a spinning reserve capacity mode, its number of full cycle equivalents should be low but not zero.
- The cycles do not really reflect the effectiveness of BESS operation with regards to the fuel savings (emission reductions). More evaluation criteria towards assessing the effectiveness of actual BESS operations should be defined. For example, fuel saving per BESS kWh yearly and fuel saving per full cycle equivalents yearly. The fuel savings resulting from the BESS installation onboard the 19 OSV respectively will be further investigated. OSVs operate different types of offshore trips of varying duration under different met ocean conditions. It is therefore necessary to have operational data of more than one year or longer to allow for a better analysis.
- The three BESS which experienced actual cycles that are higher than the designed number of cycles should be further investigated to determine if the differences observed are indeed real observed differences or simply an artefact of the available data.

# 5 Learning from Solstad's BESS installations and operations

Solstad has already installed batteries (from 497 kWh to 996 kWh) onto 10 vessels out of its 90-vessel fleet. Solstad learnt that existing battery systems typically show annual savings of 10-15 % on offshore supply vessels when combined with the use of shore power (about 1000 tons of $CO_2$/year reduction per vessel). Larger systems may provide even more $CO_2$ reductions (around 5-10 %) and could allow for zero-emission sailing close to shore and within ports. However, in order to enhance vessel electrification in this way, it is critical to get the unit cost of BESS systems down so that they are a commercially attractive option for both ship owners and operators.

This section will focus on the learning from the vessel "Norman Sun" retrofitted in 2018 with a 500 kWh BESS from Corvus Energy, and whose characteristics are listed in Table 7.

*Table 7 - Characteristics of the Normand Sun*

| | Normand Sun |
|---|---|
| **Owner & operator** | Solstad Offshore ASA |
| **Type** | Offshore Supply Vessel (OSV) |
| **Built** | 2014 |
| **Dimensions** | LOA: 94,65 m - Deck: 1170 $m^2$ |
| **Operational route type** | Offshore installation supply service (oil/gas and wind farm) |
| **Operational route distance** | 100 to 300 nm |
| **Required autonomy** | 24 to 72 hours |
| **Accommodation** | 28 persons |
| **Propulsion mode** | Hybrid Diesel/electric |
| **Propulsion Power** | Diesel: 4 Diesel gen sets with total electric power of 8000-10000 ekW |
| **DC bus voltage** | 800 – 1100 VDC |
| **AC bus voltage** | AC grid voltage 690/440/230V. ESS connected at 690V AC with both transformer and inverter |
| **Battery Capacity** | 497 kWh (Corvus Energy) |
| **Use of battery** | Spinning reserve and peak shaving during both approaching / port stay and transit |
| **C-rate** | Orca energy on Normand Sun has a C-rate of max 3. |
| **Charging infrastructure** | 2x350 kW charging system on board |

## 5.1 The key facts of the 500 kWh BESS installation on Normand Sun

Figure 12 shows the installation in 2018 of a 500 kWh BESS from Corvus on board the vessel "Norman Sun". The key facts of the installations are listed in Table 8.

The total installation cost was 1.3 M€ (2600 €/kWh) and Solstad received Norwegian government NOx funding of 0.5 M€ to support the BESS installation. It is noted that the total installation cost of 2600 €/kWh for this BESS is lower than the 5400 €/kWh from the 630 kWh BESS retrofitting on another SOV in 2018 presented in section 4.1. The delivery of these two containerised BESS is estimated at the same price level since both BESS were retrofitted in 2018.

The lower BESS retrofitting costs on Normand Sun result from the following five aspects:

(i) Installation plans,
(ii) Preparation at shipyard,
(iii) Preparation on OSV,
(iv) Installation and commissioning (Normand Sun used three weeks vs four weeks of 630 kWh plus loss of commercial renting income.),
(v) Tests, certifications, and flag registrations (Normand Sun performed tests by itself vs 630 kWh was tested by the class society).

The total delivery time was six months from the BESS ordering to the completion of BESS installation on the Normand Sun. The BESS installation and commissioning on board was three weeks.

There were no requirements for testing from the class certification society during the installation work. Solstad did take measurements which became class requirements later.

*Table 8 - The key facts of the 500 kWh BESS installations on Normand Sun*

| | Value | Comment |
|---|---|---|
| **Total installation cost** | 1.3 M€<br>(2616 €/kWh) | Received Norwegian government funding of 0.5 M€ |
| **Delivery time** | 6 months | From the initial order to completion of installation |
| **BESS installation commissioning on board** | 3 weeks | Including the sea trials and FMEA |


*Figure 12 - The 500 kWh BESS retrofitted onto the "Normand Sun" vessel in 2018*

## 5.2 Learning from the 500 kWh BESS operations onboard Normand Sun

MarESS operation system has been used to monitor Normand Sun offshore routes, speed and the fuel consumption as shown in Figure 13. It can also generate summary reports to help the ship operator to meet legislative requirements and cut fuel consumption (reducing fuel costs and greenhouse gas emissions) as shown in Figure 14.


*Figure 13 - One display picture from the MarESS monitoring system*


*Figure 14 - MarESS summary report of Normand Sun operational results*

Table 9 shows the effectiveness evaluation of the installed BESS on Normand Sun from the indicators compute by MarESS operational system and provide in the summary report.

After five-year of operation, the total fuel saved is 1784 tons and $CO_2$/$NO_x$ reductions are respectively 5718/54 tons. The average of the fuel saving per BESS kWh yearly is around 700 kg/kWh.

The fuel consumption reductions achieved from installing the 500 kWh BESS on board the Normand Sun during different operational modes are summarised in Table 10 and Figure 15. The BESS installation resulted in significant fuel consumption reductions during all four operational modes (DP, standby, transit and port). The large average fuel usage reduction of almost 50 % at port includes the use of onshore power supply.

*Table 9 - Effectiveness of the 497 kWh BESS installed on board the Normand Sun*

| Ship | Fuel consumption tons/NM | Days | Efficiency increased | Fuel saved tons | NOx saved tons | CO2 saved tons | Average fuel saving per BESS kWh yearly kg/kWh |
|---|---|---|---|---|---|---|---|
| Normand Sun | 0.045 | 1857 | 13.7% | 1784 | 54 | 5718 | 706 |

*Table 10 - Fuel consumption reductions during different operational modes on board Normand Sun*

| Ship | Change in DP tons/day | Change in standby tons/day | Change in transit tons/day | Change in port tons/day |
|---|---|---|---|---|
| Normand Sun | -6.14 % | -12.59 % | -12.74 % | -47.83 % |

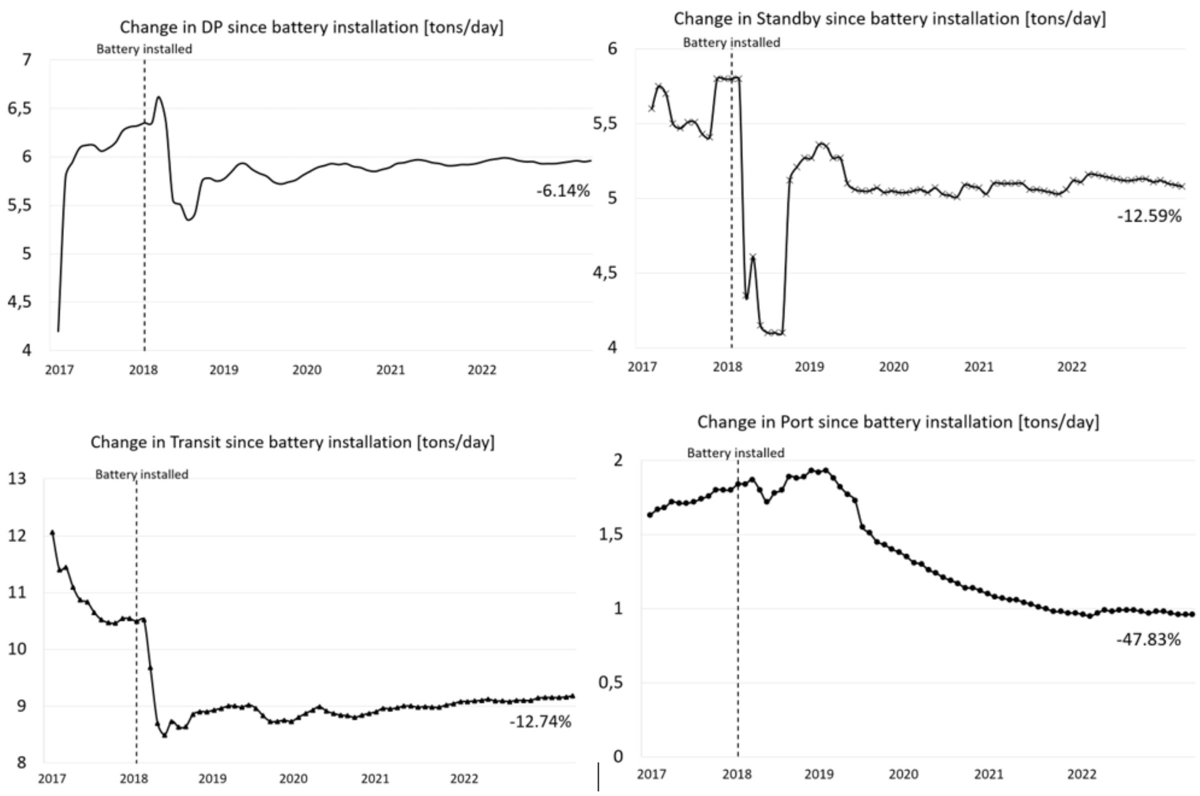



*Figure 15 - Fuel consumption changes during DP, standby, transition and port modes on Normand Sun*

Furthermore, the crew interview about the installation of the BESS on Normand Sun was conducted on 27 February 2023. The questions to captain/chief engineer and their answers are given in Appendix D. It reveals that BESS is considered useful above all to facilitate the manoeuvrability of the ship, in particular in the dynamic positioning phase. They are aware of energy management but the availability of power seems to take precedence. It must be noted that a common recommendations is to have a good understanding of battery system safety and knowledge in case of fire.

## 5.3 The effectiveness of BESS operations on 10 OSVs

Table 11 shows the operational results of the effectiveness resulting from the use of installed BESS on 10 OSVs collected from the MarESS operational systems installed on these vessels. The installed BESS capacity is in the range of 497 to 996 kWh and the operational days of the BESS vary from 307 to 1857 days. The average efficiency increased (%), DP fuel usage reduction (%), the fuel saved (tons) and the $NO_x/CO_2$ reductions (tons) are listed in Table 11. The DP fuel usage reductions confirm the significant contributions provided by the installed BESS as spinning reserving capacity. Please note that the effectiveness includes the use of onshore power supply.

The proposed criteria fuel saving per BESS kWh year was calculated. The smallest 497 kWh BESS on vessel No. 10 has the highest annual fuel savings per kWh BESS installed: 706 kg/kWh. The largest 996 kWh BESS on vessel No. 4 has low annual fuel savings per kWh BESS installed: 295 kg/kWh. The large BESS is used to pursue new functions e.g. zero-emissions at port. The fuel savings in Table 11 include both the effect from BESSs and the use of onshore power supply. For example, the 620 kWh BESS on vessel No. 9 have experienced very low fuel savings which might result from its low access to onshore power supply.

*Table 11 - An overview of effectiveness of the BESS installed on 10 OSVs*

| Ship | BESS capacity kWh | Days | Efficiency increase % | DP fuel usage reduction % | Fuel saved tons | $NO_x$ saved tons | $CO_2$ saved tons | Fuel saving per BESS kWh yearly kg/kWh |
|---|---|---|---|---|---|---|---|---|
| **1** | 565 | 1067 | 12.44 | 15.06 | 607 | 18 | 1956 | 368 |
| **2** | 560 | 1553 | 10.48 | 12.03 | 950 | 29 | 3046 | 399 |
| **3** | 565 | 1067 | 11.16 | 7.35 | 537 | 16 | 1720 | 325 |
| **4** | 996 | 398 | 7.65 | 10.86 | 320 | 10 | 1026 | 295 |
| **5** | 497 | 1829 | 12.76 | 12.78 | 1417 | 43 | 4544 | 569 |
| **6** | 560 | 1494 | 15.11 | 10.02 | 1545 | 46 | 4953 | 674 |
| **7** | 745 | 307 | 7.80 | 16.03 | 154 | 5 | 494 | 246 |
| **8** | 560 | 1525 | 8.70 | 6.25 | 834 | 25 | 2674 | 356 |
| **9** | 620 | 672 | 2.25 | 5.66 | 89 | 3 | 283 | 78 |
| **10** | 497 | 1857 | 13.70 | 6.14 | 1784 | 54 | 5718 | 706 |

# 6 Learning from Ponant's BESS installations and operations

Ponant is a French cruise company with 13 cruise ships in currently active, and has a target to complete the retrofit of its entire fleet by 2030.

Ponant built in 2021 a new hybrid vessel, "le Commandant Charcot", equipped with a large 4.5 MWh BESS from Corvus Energy. Sections 6.1 to 6.4 will present the learning respectively about the decision-making process, the BESS installation (integration constraints and regulatory challenges), the current operational results, and the feedbacks from the crew.

Ponant also shared the lessons learnt from its one purchase of an 800 kWh BESS which could not be installed onto its vessel "Le Ponant" due to a lack of flag approval in section 6.2.2.

The details in this Section are supplemented by Appendix E, Appendix F and Appendix G.

## 6.1 Decision-making process to a newly design

Ponant's newly built vessel, Le Commandant Charcot (Figure 16), is a Polar Exploration Passenger Vessel built in 2021 by the Norwegian shipyard VARD and equipped with the latest technologies to help reduce its carbon footprint. This is a unique Polar Class 2 vessel, sailing in the most remote areas of the world and built with a high level of safety and environmental care. The vessel is equipped with 6 dual fuel engines using LNG as fuel stored into membrane tanks of 4500 $m^3$ to supply an electrical propulsion system.

At the beginning of the project during the concept design phase, many questions had to be clearly posted and answered to help in defining the needs and the proper dimensioning of the BESS. One set of the original critical questions used in Ponant's decision-making process behind the BESS installation is listed in Appendix E. This process led to the installation of a **4.5 MWh BESS of the ORCA series manufactured and delivered by Corvus Energy to support the electrical grid.**

A detailed description of the characteristics of the vessel is available in the deliverable D1.3 "Use cases definition and demonstration requirements".


*Figure 16 - Le Commandant Charcot in operation in ice*

## 6.2 The key facts of the BESS initiatives and installations

### 6.2.1 Lessons learnt from the 4.5 MWh BEE installation on Le Commandant Charcot

**BESS integration on board**

Two BESS of 2260 kWh each have been connected on each side of the 11 kV main switchboard in two dedicated Energy storage rooms. A detailed description of the integration of the BESS system is available in the deliverable D1.3 “Use cases definition and demonstration requirements”.

The footprints, weight, and costs of the 4.5 MWh BESS installation on Le Commandant Charcot are listed in Table 12. It is noted that the total installation cost of the 4.5 MWh was nearly 5 M€ which results in 1100 €/kWh, which is much lower than the 5400 €/kWh observed from the retrofitting of a 630 kWh BESS onto an OSV in 2018 as presented in section 4. **It is as expected that new installations of BESS are much cheaper than retrofitting BESS onto an existing vessel. In addition, the larger the capacity of the BESS, the lower cost per kWh it usually results in.**

*Table 12 - Key parameters of 4.5 MWh BESS installation on Le Commandant Charcot*

| Parameter | Value | Total and normalised values |
|---|---|---|
| **Footprints** | BESS room A plus converter & transformer room: 72 $m^2$ | Total surface: 161 $m^2$ |
| | BESS room B plus converter & transformer room: 89 $m^2$ | 35 $m^2$/MWh |
| **Weight** | Total weight: 85 tons | 19 kg/kWh |
| **Costs** | Battery purchasing costs: 3.8 M€ for 4520 kWh (4 x 1130 kWh) | Total costs: 4.894 M€ |
| | Transformer and converter costs: 962 k€ for 2 units of 11kVA/717V, KVA 3500//1750/1750 Transformers, 4 units of ACS 880 Water cooled AC/DC converters | 1100 €/kWh |
| | Installation costs: 150 k€. Including mechanical and electrical installation, and foundations | |
| | Studies costs: 21.5 k€. Including studies and Class society fee | |

**Safety measures, planning and procedures**

The safety of BESS installations and operations are always the top priority of all ship owners/operators.

Ponant has shared its implementation of the 4.5 MWh BESS safety planning and procedures on board Le Commandant Charcot including the energy storage room layout, ventilation, firefighting and emergency plans detailed in Appendix F.

In the Energy storage rooms, the batteries are located at the center, allowing easy movement around and the rooms are also equipped with a CCTV system for a video surveillance. The Energy storage room has a non-hazardous category 10 assigned to it. Indeed, it is considered essential that the battery racks are enclosed within a gas-tight enclosure and that a dedicated exhaust vent is the sole way of venting all potential hazardous gases to the outside. Only this exhaust gas vent ducting is considered to be a hazardous zone 2 in case of thermal runaway and those ducts are routed respectively to the forward mast for battery room A, and to the aft mast for battery room B.

The optimal working temperature for the battery is within the range of 10-15 °C. The room temperature should be maintained within this range all the time under any condition (external temperature -25°C + 35 °C, battery charging / discharging). An AHU unit is supplying treated, dry, fresh air (six times air change per hour) into the ESS room and the thermal balance is controlled through a fan-coil unit which has a full back up through a self-contained unit. A local temperature sensor is present monitoring the ESS room temperature and gives an alarm if the temperature deviate from the optimal range. In addition, the ventilation of the battery racks is separated from the room ventilation.

In case of fire, redundant fixed firefighting systems have been installed in each ESS room following the recommendations from Corvus and DNV-GL: Fixed NOVEC extinguishing system and pressure water mist system.

Finally, the BESS installation required the definition of emergency plans and procedures for the crew and operators. Those plans gave important warnings to the crew and define an assessment and response plan in case of fire or thermal event. Procedures have been defined for emergency stop, entering in the Energy storage room, removing the equipment.

**Flag and Class regulations applicable to Ponant's Vessel**

At the time of the vessel construction, there was no specific rules for the implementation of BESS onboard a vessel. The classification society Bureau Veritas (BV) oversaw the vessel survey and certification and created the regulations required for the equipment (BESS) integration on board and BV approval based on the following two certifications:

- TYPE APPROVAL CERTIFICATE 52350_A0 BV (Appendix 25)
- H887 593OSL20_-_Certificate - Battery System (Appendix 24)

The BESS was certified compliant with BV NR 467 rules requiring type approval for battery cells, battery pack and testing following IEC 62619 and IEC 62281. Those standards describe several tests to be performed under extensive use conditions on the batteries cells such as, external short circuit, shock, fall, over-temperature, over-charge and on the Battery Management System BMS such as overcurrent, over-voltage, overheat. Those tests should not result in fire or explosion of the cells.

There are clear rules concerning the approbation of battery Energy storage systems in general but concerning the integration of such a system onboard a vessel, no dedicated rules were written. Battery integration onto the vessel has been based on the following three processes leading to three documents submitted to the review of the French Flag for approval:

- Recommendations and conformity matrix: Battery Compliance Report
- Risk analysis HAZID
- Flag analysis and recommendations

The intention of the Battery Compliance Report is to verify that the shipyard meets the design requirements according to the class society (BV) related to the energy storage rooms. The assumptions related to the installation, design, and control of the ESS are commented and evaluated and the class requirements are presented and evaluated in the BV compliance matrix.

About the HAZID, the battery cells typically require additional protection for safe usage in an industrial environment. The integration of the related Battery Packs must be performed properly, and safety precautions shall be considered at all stages. A risk assessment study has been carried out focusing on the storage of batteries, operation, ventilation, passive fire protection, efficiency of fire systems, loss of ventilation and emergency situations. The result being a list of recommendations which are then implemented.

Before the HAZID, the French Flag issued a list of recommendations:

- A risk assessment must be carried out to quantify the risks linked to batteries integration.
- This risk assessment must relate in particular to the risks linked to the ventilation of the battery compartments, the independence of the explosive gas extraction ducts, the fire insulation of these compartments and the effectiveness of the fire extinguishing system of these compartments.
- Submit the battery management and maintenance manual established by the supplier and approved by BV. This manual must contains: description of the batteries and their installation on board, their operation, the limitations of this installation and the procedures for emergency.
- The personnel on board must be trained in battery management and intervention.
- A representative of the administration will participate in this assessment.

### 6.2.2 Lessons learnt from the BESS initiative on vessel Le Ponant

In 2020, Ponant initiated a major retrofit of its first vessel, Le Ponant, an 88-meter-long sailing motor cruise vessel that was 30 years old. The intention was to integrate a BESS of 800 kWh to allow the ship to reach zero emissions at anchor or alongside at pier by discharging the batteries. Battery recharging was planned at sea during its transition mode.

Ponant implemented a HAZID study for BESS integration onboard the vessel with a positive approval result from the vessel classification society Bureau Veritas (BV). Unfortunately, this risk analysis and battery installation plans were then rejected by the flag society. It stated that it was not safe to integrate the 800 kWh BESS onto a 30-year-old vessel within a compartment below the water line and inside a narrow space. The batteries were to be located at the aft part of the bow thruster room, well behind the collision bulkhead.

The main risk highlighted by the flag society was the risk of collision and flooding, and the potential consequences of a battery explosion onboard such a small vessel. However, BV approval certificates did not indicate such risks beforehand. In the end, the purchased 800 kWh BESS could not be installed onto its vessel Le Ponant due to the lack of flag approval.

The lessons learnt is that the feasibility study should be presented to the flag society for comment and approval at a very early stage of the studies to better integrate their remarks and recommendations and to better mitigate the costs should rejection occur.

## 6.3 Operational results of 4.5 MWh BESS

After two years operation of this 4.5 MWh BESS, the preliminary analysis of the results gathered by the crew on board are presented in this section. Additional details concerning operating modes and expected benefits are given in the report D1.3 as far as this deep analysis drive the demonstration requirements for the development of the a cloud-based digital platform to enable data-driven, optimised, and safe exploitation.

### Global efficiency

The first analysis that has been done is regarding efficiency balance of the full charging and discharging cycle as detailed in the one line diagram below (Figure 17) showing the different electrical losses of each of the components.

<u>Discharging mode total efficiency</u>: with batteries at BOL about 87.8 %, with 10 years old batteries: 85.4 %.

<u>Charging mode total efficiency</u>: Generator losses have to be taken into account in addition to other losses: with batteries at BOL 85.3 %, with 10 years old batteries: 82.9 %

When batteries are in use, we should record and quantify those losses and display an overall grid efficiency value and compare it to a threshold. As this network efficiency is a major indicator to guide the crew into the best usage of the BESS, The way to compute this threshold has to be defined and should be part of a dedicated study in the project.

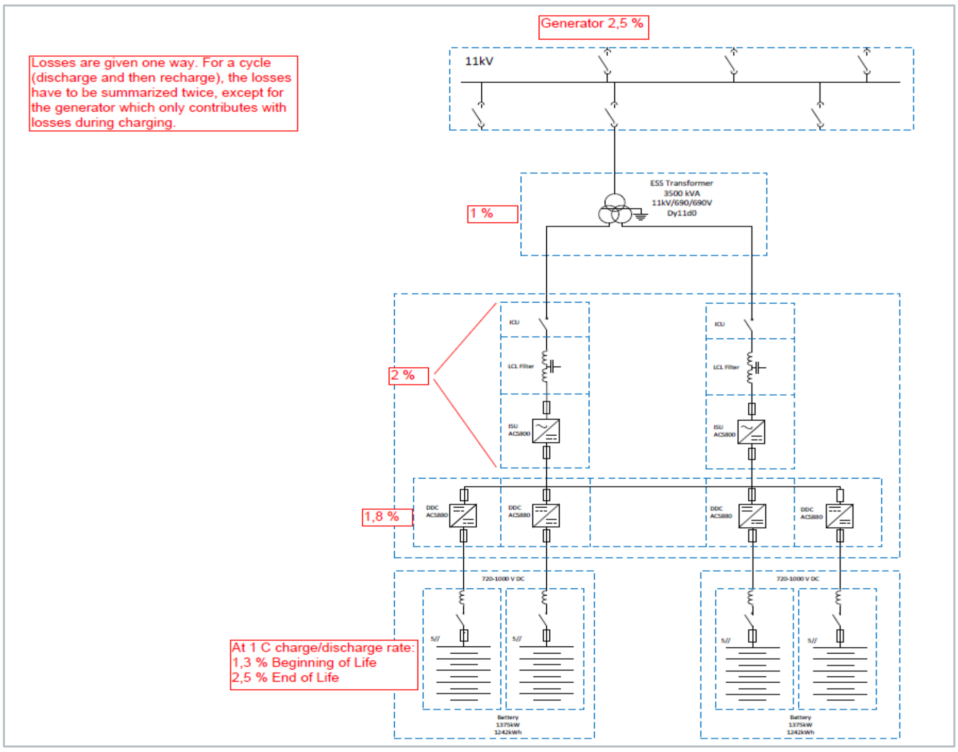



*Figure 17 - One single-diagram and efficiency of major components*

### Overall efficiency assessment

The operational profile time sharing for Le Commandant Charcot is summarised in Figure 18.

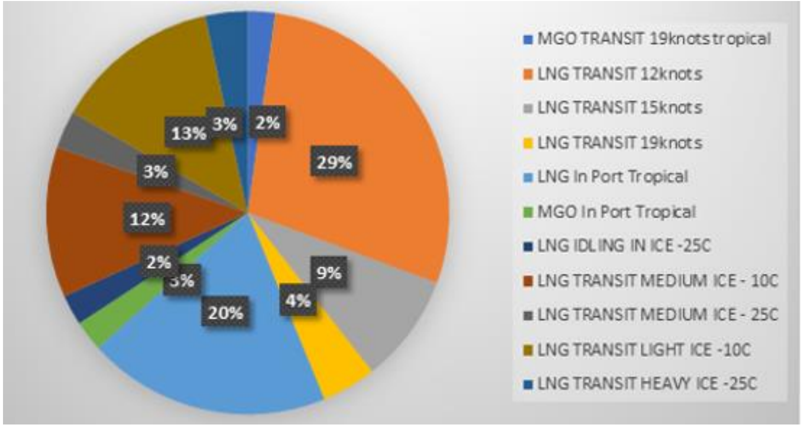



*Figure 18 - Operational profiles of the time sharing for Le Commandant Charcot*

An estimation of the operational benefits from the 4.5 MWh BESS, in terms of fuel saving, is summarized in Table 13. The results are weaker than expected and do not yet meet the qualitative expectations summarised in the Table 14.

The energy efficiency of the installation remains to be demonstrated but at the environmental level there is a benefit in terms of a reduction in exhaust gas emissions. For this specific subject, sensors and/or measurement records are missing on board: sensors for methane slip, NOx, CO, $CO_2$.

A major conclusion of this analysis is that the benefits of BESS on a cruise vessel are difficult to measure and quantify. A methodology and tools to better understand the potential savings and benefits and notably compute fuel saving quantities is missing. Ponant will develop during the project, with the support of partners, an energy audit analysis tools to better quantify the benefits of the 4.5 MWh BESS, including fuel savings, increasing level of operational safety and GHG emission reductions.

In addition, standardisation of the use of the BESS is necessary. Today, there is no operational directive describing the correct PMS and BESS parameters according to the operating modes. Today each operator uses the BESS differently.

*Table 13 - Fuel saving estimations for different operation modes*

| Operations | Frequency | Saving |
|---|---|---|
| **Maneuvering** | 2 % | 9.50 % (back-up mode) |
| **Port/ Anchor** | 20 % | 0 % to 5 % to be evaluated with dedicated software (Zero Emission cycles mode) |
| **Ice Navigation** | 16 % | 0 % (peak shaving mode) |
| **Transit** | 62 % | to be evaluated (enhanced dynamic support mode) |
| **TOTAL** | 100 % | 1 to 2 % at this stage of analysis. More savings could be expected by proceeding to accurate measurement and data analysis that would lead to a specific software, smart tool device to measure batteries efficiency and guide the crew to better operate the batteries |

*Table 14 - Operational benefits from operating a 4.5 MWh BESS on Le Commandant Charcot*

| | Design objectives | Actual operational results |
|---|---|---|
| **Fuel saving** | 5 % of fuel saving was expected and a ROI of 10 years | Potential saving have been almost deleted by the electrical losses |
| **Operational safety** | Secure the vessel operations by preventing black out and stabilising the grid frequency, optimising the use of dual fuel engines running on gas mode | Not measurable |
| **GHG emission reduction** | Improving the engine load and reducing fuel consumption and methane slip emissions | BESS contributes to less GHG emissions (difficult to measure) |

## 6.4 Crew interview and feedback

A questionnaire was sent to the Ponant fleet of 13 ships to the captains (group 1), staff captains (group 2), chief engineers and chief electricians (group 3). 17 replies were received (32 %), including ten people having sailed on ships with batteries installed.

The detailed report is presented in Appendix G where replies were grouped according to following categories:

- Risk and reliability level
- General knowledge about the batteries
- How the batteries are used on board
- Technical issued encountered
- Crew proposals on design and exploitation improvements

**A deeper analysis of this report will be achieved in D1.3 to help defining the demonstration requirements on Le Commandant Charcot, taking into account in particular the recommendations about the improvement of the operating modes and knowledge/training**

Nevertheless, the most important feedback about current exploitation can be summarised as follows.

It must be noted that a majority of the participants are confident to very confident (12/17) about the use of batteries. It is also to note that in this pool of participants, there is no obvious relation between the confidence level and the experience with ESS.

Despite the high confidence levels, all the participants in group 2 which had experience with batteries, deem the batteries of high risk. On the other hand, almost all the participants consider high reliability of the battery systems.

From the 10 participants having sailed on ships equipped with battery systems, half considers having received sufficient training regarding the operation or safety management of the batteries.

These expectations about the batteries systems can be grouped into four main focuses:

- Increase the safety of the systems
- Optimize the use of Diesel Generators
- Reduce environmental footprint, locally or globally
- Direct fuel consumption reduction

It shows that in general the participants feel that their expectations of the batteries are met. In particular, it can be underlined that the batteries perform well for the zero emission mode, but less in the expectation of fuel economy or environmental impact. In addition, it has been noticed that the capacity of swift reaction of the batteries to load variations, especially in ice conditions is beneficial and was not foreseen.

However, some drawbacks arise listed by number of mention in the survey:

1. Safety, fire, risk of thermal runaway
2. Efficiency: electrical losses in the ESS.
3. Price and low ROI
4. Size and Weight

While the fuel economy and $CO_2$ emissions reduction were ones of the highest expectations, the participants are not confident on the possibility to measure the ESS impact on fuel consumption.

# 7 Recommendations for BESS integration and further development

This section has collected Equinor's recommendation for BESS further development, Corvus BESS development roadmap, and Solstad and Ponant practical BESS integration and training suggestions. Elkon's recommendations for BESS integration and Siemens BESS experience learnt from automotive are supplemented by Appendix H and Appendix I.

## 7.1 Equinor's recommendations for BESS further development

Equinor has proposed furthering the integration of BESS from the current level on vessels to level on ports with power supply/charging from onshore/offshore ports. It is also crucial to deal with the increasing of safety requirements, to further $CO_2$ emission reductions, and to accelerate BESS development and uptake across sectors/regions in Europe as follows.

**Onshore/offshore power supply/charging**

Further integration of BESS from the current level on vessels towards integrating alongside power supply/charging from onshore/offshore ports can maximise the benefits from using onshore green power. The onshore power supply covers the vessel's typical hotel load (e.g., approximately 250 kW at port for the selected OSV in section 0, whereas one Diesel generator might normally need to remain in operation if there is no BESS installed on board the vessel. In order to fully use green power at port, the battery will need to be discharged to a minimum level before arrival at port and will then be charged back up to its maximum capacity whilst at port. With a fully charged BESS, spinning reserve is also available to prevent starting additional Diesel generator during trip.

Significant benefits could also be available from the future provision of offshore stations supplying green power including BESS charging (e.g., from offshore wind farms). However, the loads required during stand-by or DP at offshore sites are typically much higher than the loads experienced at port.

**Increasing safety requirements for operation of BESS on vessels**

There is an increasingly demanding set of safety requirements for the installation and operation of BESS on board all types of vessels. Work is required to document the experiences learnt whilst preparing for the changes required by newer safety requirements, including extending BESS integration on board to both onshore green power supply and charging infrastructure and preparing for unexpected new risks (such as cyber-attacks). The recommendation is to continue to update safety training programs to build up the long-term skills needed by the crew to follow/support the safe electrification of ships.

**Further $CO_2$ emission reductions**

To achieve further $CO_2$ emission reductions, new operational strategies are required to unlock the potential of larger capacity BESS or greater number of individual BESS units on hybrid OSVs. In NEMOSHIP, the newly BESS installed will provide significant ship propulsion power during offshore trips and proposed operational strategies will able to optimise the operations and to evaluate the potential combinations amongst BESS alongside the use of alternative fuel solutions.

**Acceleration of BESS development**

The reviewing of Equinor's industrial approaches towards reducing GHG emissions in section 2 shows that further $CO_2$ emissions reductions are both costly and require collaboration across industrial sectors and geographic regions to be more effective and efficient. One sector or one country alone cannot achieve the required $CO_2$ emission reductions. For example, onshore and offshore power supply/charging infrastructure requires a minimum volume of vessels to be commercially successful.

Table 15 shows four proposed scenarios towards accelerating BESS development in Europe for both hybrid and fully electric vessels towards the 2030 and 2050 deadlines. The first three scenarios are for technical and operational transferability among similar vessels, across sectors and across regions in Europe. The digital platform development deals with not only the barriers to incorporating BESS such as policy, management, and technology but also the increasingly demanding safety requirements for operating BESS on board all types of vessels including dealing with new, unprecedented, or unexpected risks (such as cyber-attacks). The fourth scenario addresses technology advancements towards zero emissions.

*Table 15 - Four scenarios to accelerate BESS development in Europe*

| Scenario | Description |
|---|---|
| **S1: Similar vessels** | Facilitating technical and operational transferability among similar vessels including safety and training program assessment. |
| **S2: Across sectors** | Applying the electrification experience of both vessels (OSV for oil/gas industry and cruise ship) to other sectors promoting blue growth, such as offshore wind industry. |
| **S3: Across regions** | Transferring the experiences gained from electrification in Scandinavian countries to all regions in Europe. |
| **S4: Towards future** | Advancing large hybrid and full electric ships to further lower emissions and to pave the way towards longer zero-emission routes above 300 nm. |

## 7.2 Corvus BESS development roadmap

According to experience gained by Corvus from delivering more than 750 large BESS projects, its BESS development roadmap includes the following four aspects: performances, safety, standardisation and digitalisation.

**Marine systems performances and modularity**

Marine system development of BESS must further reduce the footprint, volume and weight of the systems whilst also increasing C-rates and cycles to help achieve the goal of BESS being a sustainable enabler for green shipping. Corvus has achieved two BESS advancements through reducing the footprint/volume by 50% and the weight by 30% in 2016 and 2019 respectively as shown below.

Maritime battery installations must see further standardisation and modular approaches to both mechanical and electrical integration with onboard and onshore power supplies.

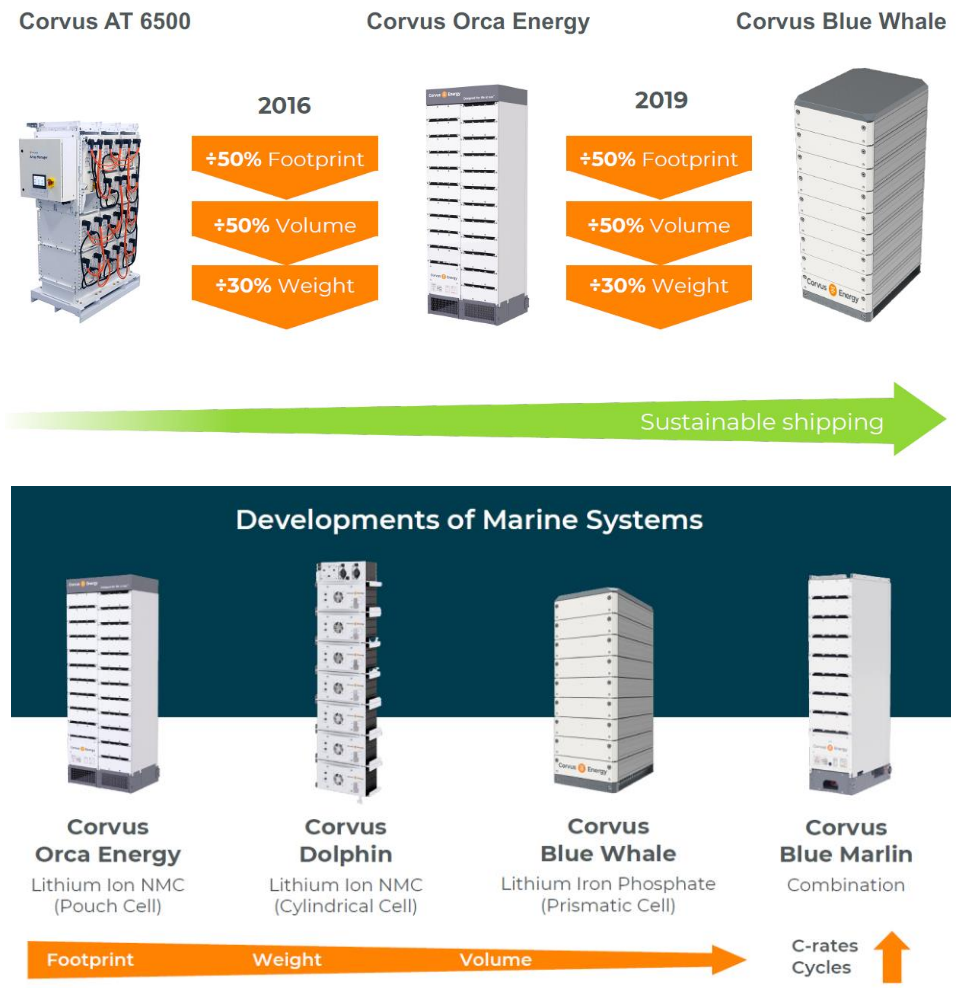



*Figure 19 - Corvus evolution towards achieving sustainable shipping*

**Driving safety**

Corvus is further driving safety through six aspects: (i) Emergency management, (ii) Continuous improvement, (iii) In-house competence, (iv) Continuous monitoring, (v) Quality control and (vi) Information sharing, as shown in Figure 20.

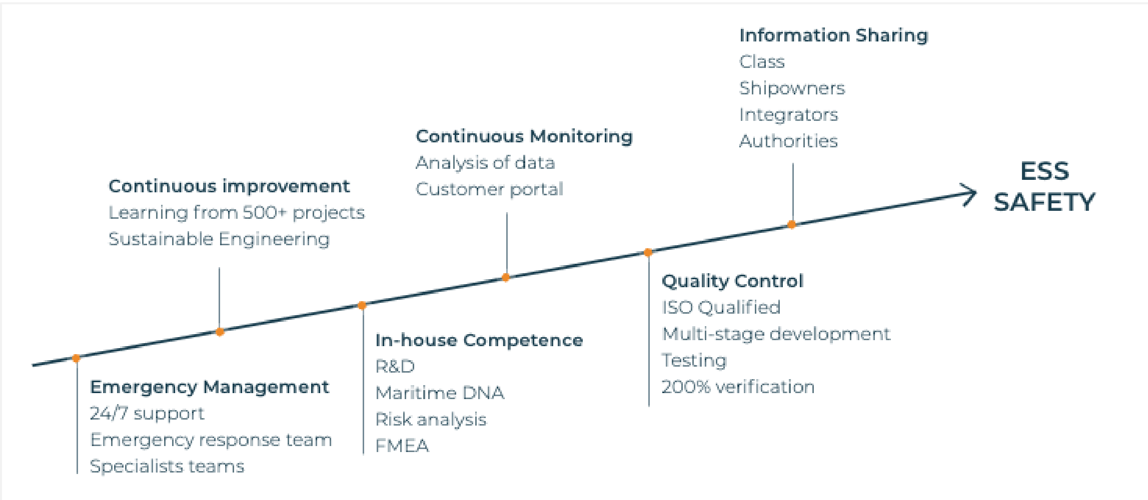



*Figure 20 - Corvus driving safety further roadmap*

**Driving digitalisation**

Fourthly, Corvus will drive digitalisation further and it will further enhance its monitoring technology through the Corvus customer portal.

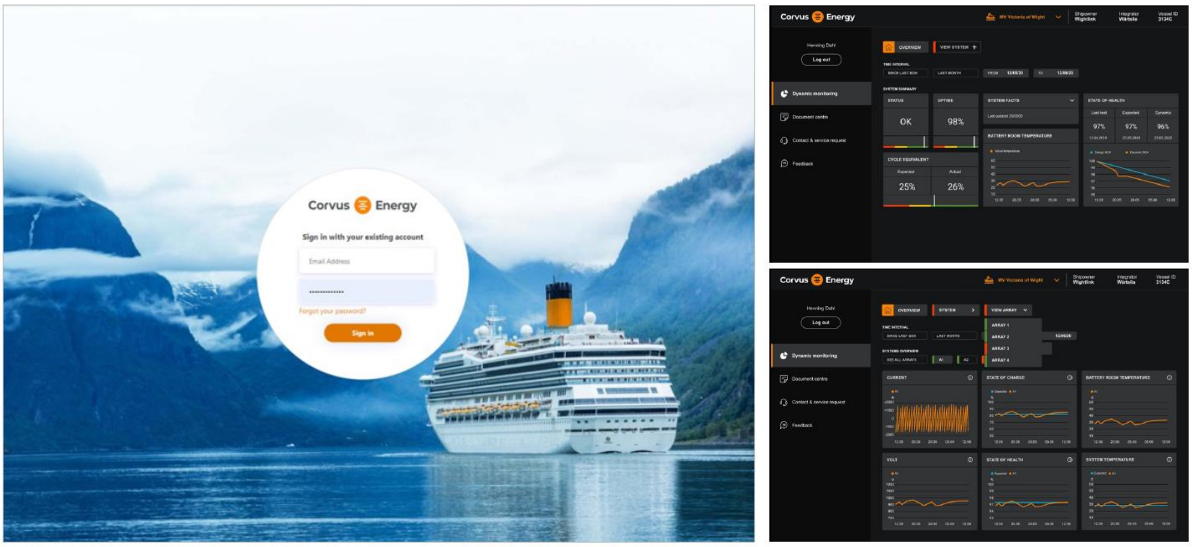



*Figure 21 - Corvus Customer Portal*

## 7.3 Solstad's recommendations for BESS integration and training

According to its first-hand experiences from 10 BESS installations and their operation the recommendations from Solstad are given as follows:

- For retrofit projects, it is recommended to install the BESS in container form on the deck (if deck space is available). This will make it easier to both finalise the battery pack and test it onshore before its installation onto the vessel. It will allow the installation to be plug-and-play which will then reduce the overall installation time and costs.
- It is recommended to consider Integration with the vessels firefighting equipment and systems. Freshwater deployed in a water mist form is the main fire-fighting equipment within the battery room alongside a NOVAC firefighting gas system.
- It is recommended to consider integrating the onshore power system with the battery; this then allows the battery to help with power peaks while connected to onshore power.
- In addition, the courses and training for efficiently and safely operating new BESS on board are important including:
- Dedicated course for crew on board vessels fitted with batteries to specifically handle firefighting in the battery room on board.
- Proper training of the crew to learn the new onboard battery system and to understand the opportunities offered and risks posed by the BESS.

## 7.4 Ponant's recommendations for BESS integration and training

**Ponant's recommendations based on Le Commandant Charcot integration feedback**

Based on their experience of the 4.5 MWh BESS installation, the following lessons learnt are formulated:

- Nothing should be placed above the battery racks (cable trays, pipe, duct …) to prevent any loss of functionality in case of fire in the batteries.
- A60 insulation should be considered in the ceiling of battery rooms regardless of the category assigned to the adjacent rooms to prevent overheating in the above compartment.
- Exhaust fan and fan starter cabinet should not be located inside the ESS room.
- Exhaust fans should be made spark free regardless of the battery rack system to be able to extract combustion gases without any risks to the installed equipment.
- Dedicated exhaust ducts should be in place to prevent any diffusion of smoke into other compartments.
- Structural steel exhaust ducts should be used (not galvanised thin steel duct).
- Build a return to normal situation plan to be followed after a battery fire occurs. An example being: nitrogen network/connection for gas flushing of the battery room, damaged battery safe evacuation routes, etc.
- Specific firefighting protection equipment (hydrofluoric acid) and specific medical treatment (hexafluorine) should be readily available and accessible.
- Separation between racks should be in place to improve air-cooling efficiency and to prevent battery rack fires propagating to the next battery rack.
- Avoid any water pipe passing through the ESS room to avoid any risk of water spray or leak onto the batteries.
- Only noncombustible material should be present in the ESS room.
- Battery room doors should be gas tight.
- Steel exhaust ducts should be fitted.
- ESS room should not be close to accommodation or permanently manned areas.

**In terms of crew training,** to the following recommendations apply:

- Knowledge of the risks of such an installation.
- Knowledge of the safeguards in place.
- Emergency procedures to be carried out in case of fire.
- Firefighting systems and how to use it/them.
- Specifics behavior and actions to be taken after an emergency situation has ended.
- Return to normal: which procedures should be followed in which order.
- Restricted area, only authorised crew member can have access.

# 8 Conclusions

This deliverable has presented a comprehensive review of experiences from more than 750 BESS installations and operations, and the recommendations derived from that. The NEMOSHIP industrial partners have shown extremely positive attitudes towards sharing the latest BESS installation experiences, operational results, and recommendations with the public. The experiences learnt and recommendations presented in this report can be summarised with the following three aspects.

**Supporting BESS installation decisions.**

In Section 2, Equinor has addressed that emerging BESS are a great enabler towards achieving Equinor's emission reduction targets, but further GHG emission reductions are more complex and costly to achieve. An overview of the operation of BESS onboard 18 OSVs has quantified the effectiveness with regards to the efficiency increased, total fuel saved and $NO_x/CO_2$ emission reductions due to the BESS installation. This then increases the confidence for the investors and ship owners/operators towards installing more BESS onto their vessels.

In Section 3, more than 750 BESS with a total operational capacity of more than 650 MWh have been installed on various vessels and at ports globally. The installed BESS have effectively reduced the O&M costs for both fully electric and hybrid vessels and reduced the fuel consumption experienced causing a reduction in all emissions.

In sections 5 and 6, the leading green ship owners/operators Solstad and Ponant have presented the installation costs they experienced and the operational results of a 500 kWh and 4.5 MWh BESS installation respectively. An overview of the BESS operations on 10 OSVs show that all of the installed BESS (capacity from 500 kWh to 1 MWh) have achieved efficiency increases and fuel savings over a long commercial period of few years. The crew interviews on the operation of the 500 kWh and 4.5 MWh BESS installations have been presented respectively in Appendix D and section 6.4. Appendix E also includes the set of original questions used by Ponant in the actual 4.5 MWh BESS decision-making process.

**Safe and cost-efficient BESS installations.**

Section 4 presents a deep dive into the retrofitting of one 630 kWh BESS from the OMB6 project in which Equinor and Corvus are participating together and shows that retrofitting involves many different custom and unique designs. The total installation costs for the chosen example was 3.4 M€ (5400 €/kWh), which was 10 times the price of equivalent battery systems used by EVs within the automotive sector in 2018. The standardisation of interfaces, including mechanical, thermal, electrical grid and communications, between BESS and vessels, is urgently required to reduce installation costs and to increase safety through standardisation.

In sections 5 and 6, and in Appendix D to Appendix G, Solstad and Ponant have shared their experiences publicly with the BESS installations on board their vessels. The experiences and lessons learnt include aspects of the BESS installation decision processes, choices made, integration constraints, regulatory and operational challenges, safety concepts, crew feedback, fuel and emissions savings, firefighting strategies, and recommendations for BESS integration details and for crew training.

Ponant successfully installed a BESS of 4.5 MWh with an overall cost of 5 M€ (1100 €/kWh) on its new exploration Vessel, Le Commandant Charcot which was delivered in 2021. It was as expected that the 1100 €/kWh installation cost during the construction of the new vessel is much lower than the 5400 €/kWh cost experienced when retrofitting a 630 kWh BESS onto an existing OSV.

**Optimising the operation of installed BESS**

In section 4, during the OMB6 project, the 630 kWh BESS yearly operational results display an actual number of equivalent full cycles of 80 vs its originally designed specification of 480 cycles yearly (0.22 vs 1.3 daily) - the BESS was essentially under-used from an energy perspective.

In Section 5, the proposed criteria of yearly fuel saving per BESS in kWh has been used to calculate the effectiveness of the BESS installed onto 10 OSVs. The calculated yearly fuel savings per BESS in kWh shows that the largest installed BESS with a capacity of 996 kWh has the lowest calculated value, which therefore requires an exploration of new functions when larger capacity BESS are installed on board.

In Section 4, it is recommended to further develop the MarESS operation system from simply reporting the operational results to advanced digital platforms which are able to actively optimise BESS operations based on the operational data collected.

There is a great potential to unlock further benefits from these installed BESS. Great joint efforts amongst R&D entities, BESS suppliers and the end users of manufactured BESS are required. The BESS evaluation criteria including full cycle equivalents should be verified and published for public examination and criticism or improvement. Furthermore, the cycles do not really reflect the effectiveness of BESS operation with regards to the fuel savings (emission reductions). There is a need to define more evaluation criteria on the effectiveness of actual BESS operation. For example, the fuel saving per kWh of BESS yearly and fuel saving per full cycle equivalents yearly.

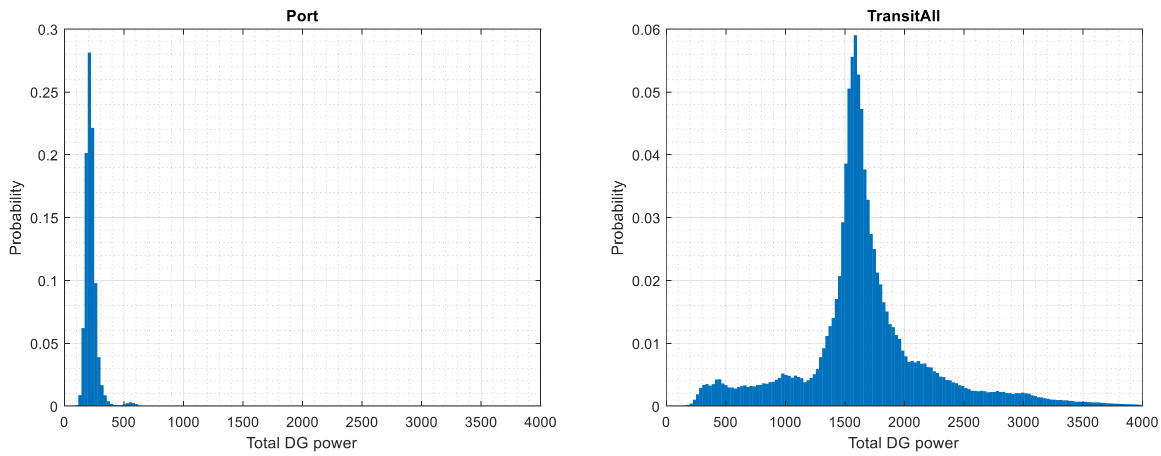
# Appendix A: Operational data analysis to increase fuel-saving

Following the deep dive into the operation of the 630 kWh BESS in Section 4, this appendix presents the data logged from the operation of the BESS previously described during 11 months; the analysis of the data undertaken aims to provide a better understanding of the fuel-saving potential.

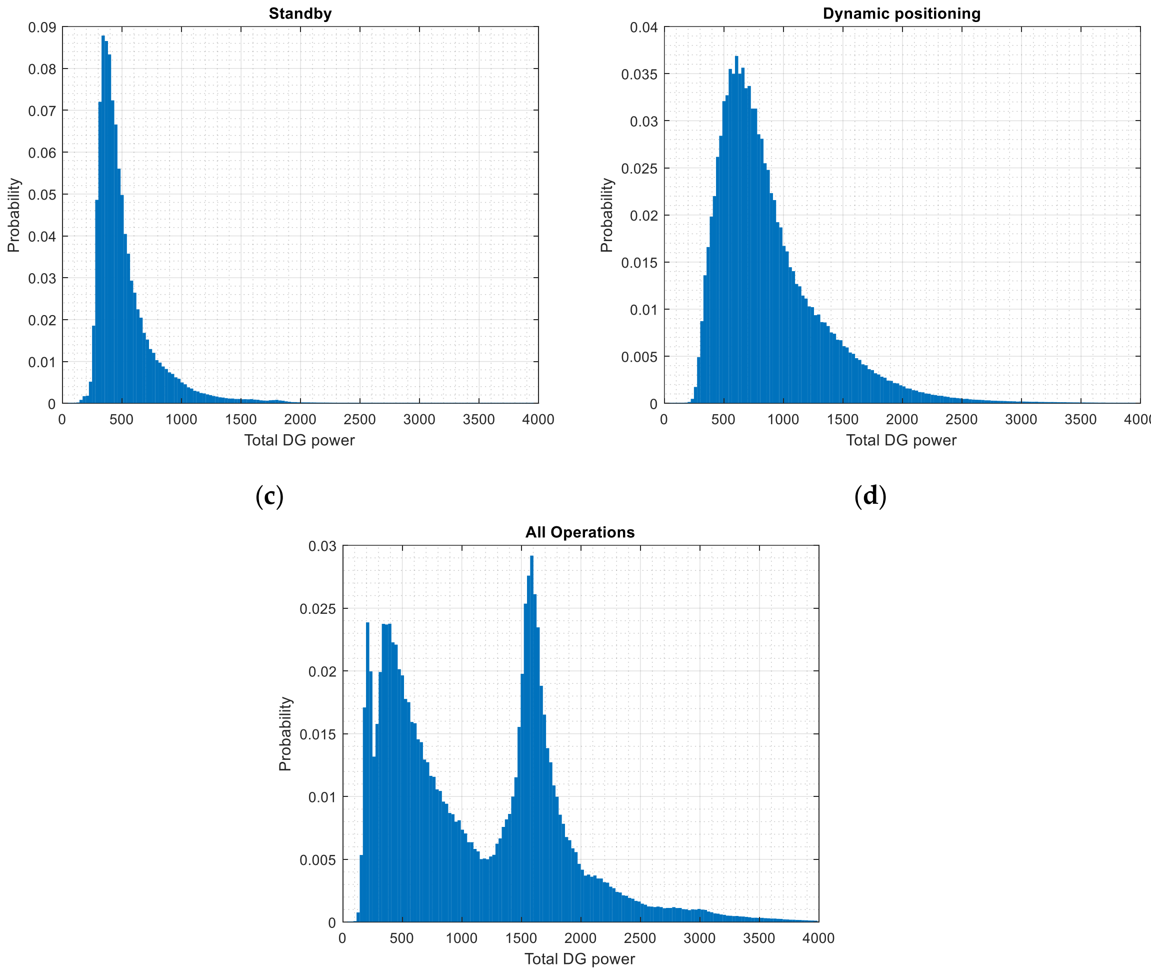
## Operational data from the 630 kWh BESS

The data from the OMB6 project were analysed to obtain a better understanding of the fuel-saving potential. Figure A 1 shows the probability distribution of the time elapsed at a given total level of power production during the analysed period. The distributions are normalised such that the sum of probabilities in each plot is 1. These give significantly more information than the average and peak measurements that are shown in Figure A 2. The plots (a) to (d) show the probability distribution for each operation, and these all show that the observed distributions are unique to each operation. Plot (e) shows the probability distribution of power generation for all operations during the analysed period. The probability distributions are all normalised per mode such that the sum of probabilities in each plot is 1.

Figure A 2 (a) shows the number of hours the vessel has operated in each operational mode within one week. The sum of power delivered from the engines during each of the operational modes is also shown (peak and average). Power from shore is not recorded in the onboard data logging system and is therefore listed as zero in Figure A 2 (b). Figure A 2 (b) also shows that the difference between average and peak load is substantial, and the average load observed can be quite different during different operational modes.



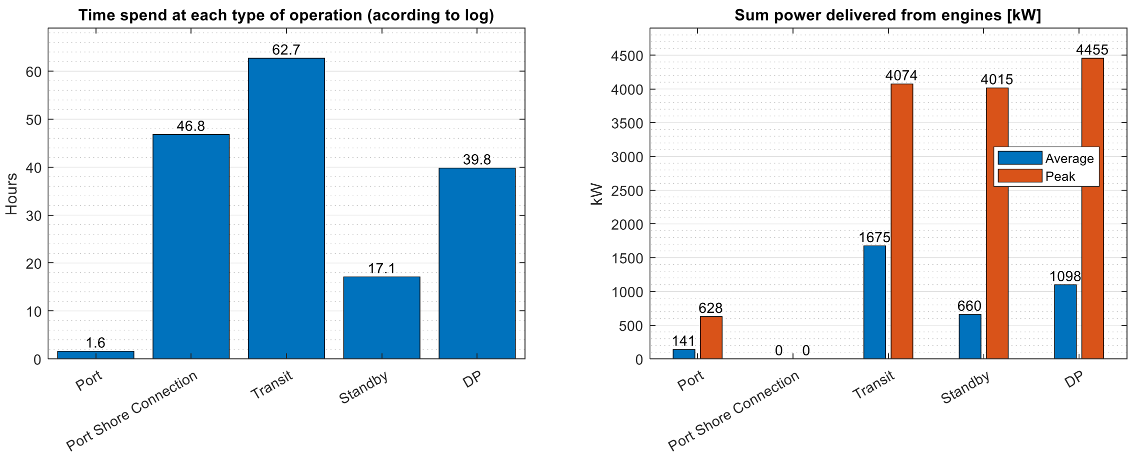

(a) (b)




(c) (d)

*(e)*

*Figure A 1 - The probability distribution for the time elapsed at a given total level of power production (kW) for the OSV for 11 months, for time elapsed in (a) port, (b) transit, (c) standby and (d) dynamic positioning. The probability distribution of all operations is shown in (e).*




(a) (b)

*Figure A 2 - Time spent (a) total average and peak power delivered by the DG engines (b) by operation mode (one week)*

## Analysis of the 630 kWh BESS operational data

In order to identify the fuel efficiency of each Diesel generator, one needs to know the individual load on each engine. The number of running and connected Diesel generators varies, depending on the operations undertaken, the environmental conditions (wind, sea current and waves), as well as onboard operating procedures, safety requirements and crew preferences. The probability distribution of the time elapsed at a given individual loading (kW) of the Diesel generators is shown in Figure A 3, for each operation, (a) to (d), as well as for all operations (e). It is observed that the individual probability distributions are significantly different from the distribution observed for the total power generated.

The red line in the plots shows the most efficient operating load for the engines. An important observation is that the engine load is close to the optimal load during transit mode but is far from optimal during all other operational modes.

The specific fuel consumption curve (SFC) for the engines was deduced from the measurements collected. Measurements of instantaneous fuel consumption (tons/hour) and generator power (kW) were used to find a piece-wise linear approximation of fuel consumption per hour at different loadings. This approximation was then used to estimate the specific fuel consumption curve that shows the tons of fuel consumed per produced MWh, for different loading conditions. The estimated curves were found to align quite well with the curves for the engines generated from the datasheet.

The deduced SFC curve was then combined with the individual loading of the engines to create the probability distribution of the specific fuel consumption (tons/kWh) shown in Figure A 4 (a). The plot shows the probability of a running engine operating at a specific fuel consumption (tons/kWh). The corresponding cumulative distribution is shown in (b). The important observation from Figure A 4 (a) is that the engines operate most of the time at a specific fuel consumption above the minimum and that there is potential for improvement on this. It is, however, important to remember that the periods with the highest specific fuel consumption are those with the lowest power production since the engines have low fuel efficiency at low load. The fuel usage is, therefore, low in these periods, and consequently the fuel-saving potential is not as large as one might expect based on inspection of Figure A 4(a) and (b). Additional insight into the fuel saving potential is found from Figure A 4(c) and (d) which shows the probability and cumulative distribution of the fuel saving potential when running the engines at their best operating point all the time. This is purely theoretical since it will require an ideal, lossless battery system to maintain optimal loading. It however defines the maximum possible fuel saving that can be achieved through optimisation of the engine operating point.

The operation period shows that the total energy delivered from the BESS was 45.6 MWh, corresponding to 50.9 MWh for the whole year if one assumes that the analysed period is representative of the whole year. Accordingly, the BESS underwent the equivalent of 80 full cycles yearly (0.22 cycles daily), which is a low number compared to the system specification for 480 equivalent full cycles yearly (1.3 cycles daily). More significant fuel reductions should be possible by fully using the energy throughput of the BESS, without risk to the battery's 10-year design life. New, integrated and optimal BESS operational strategies and digital platforms are required to achieve this.

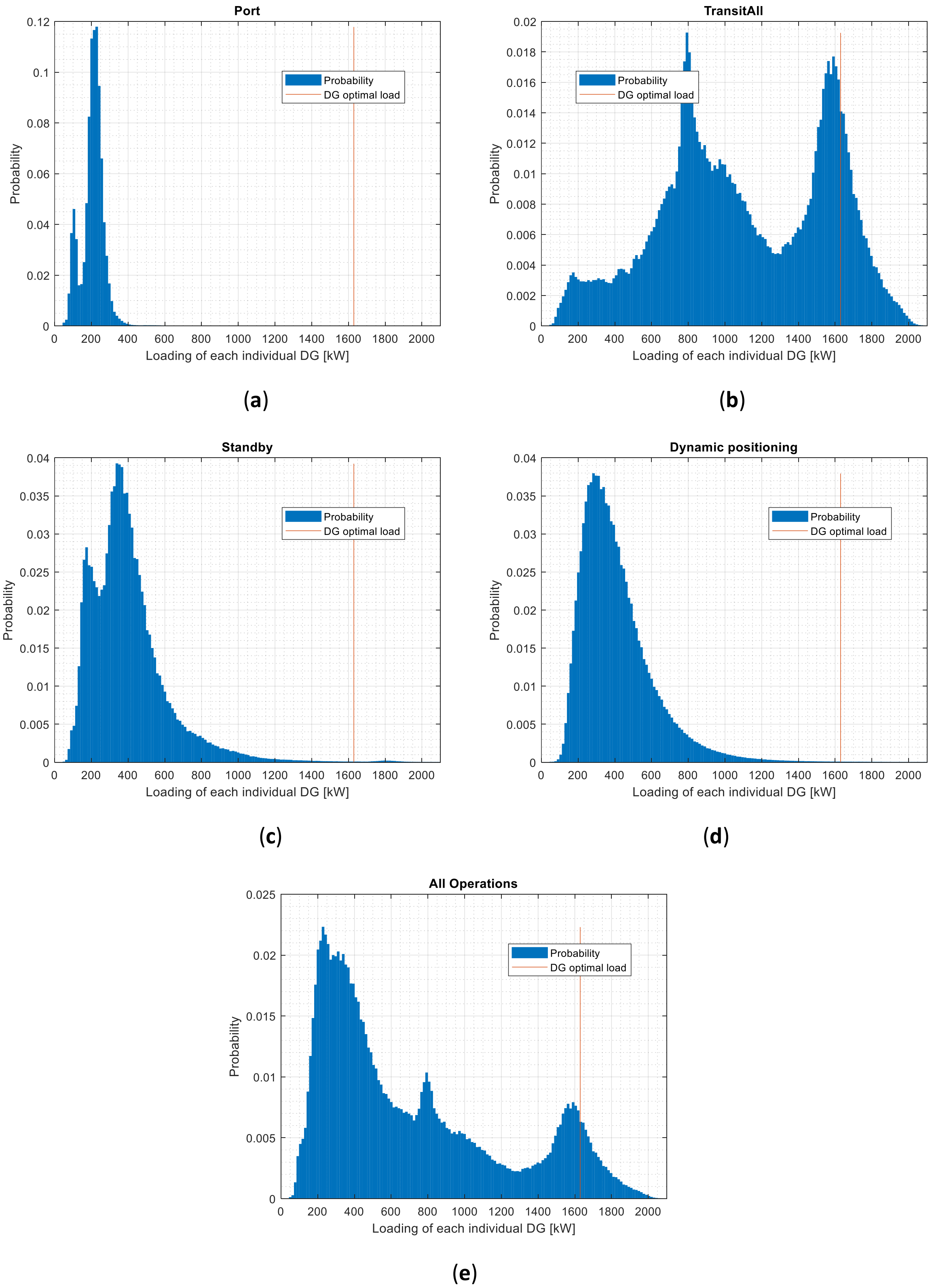
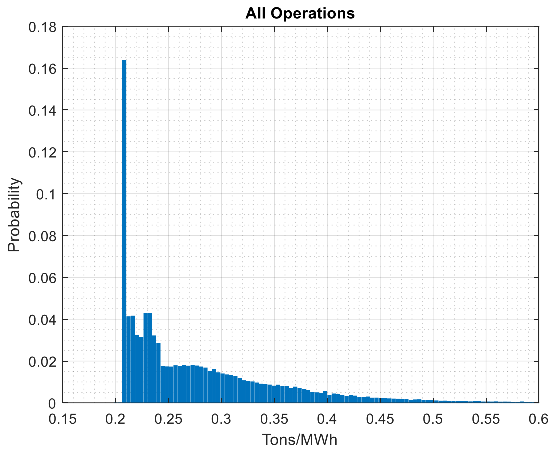
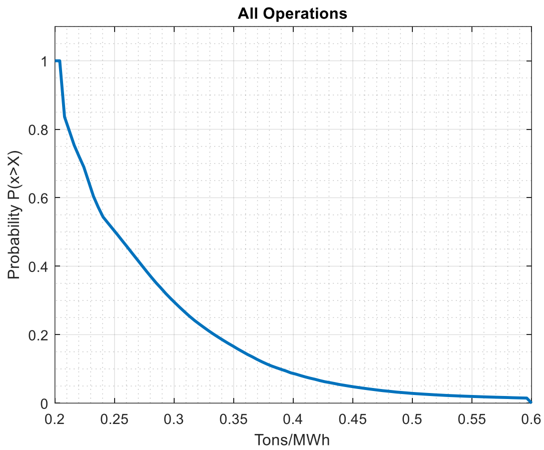


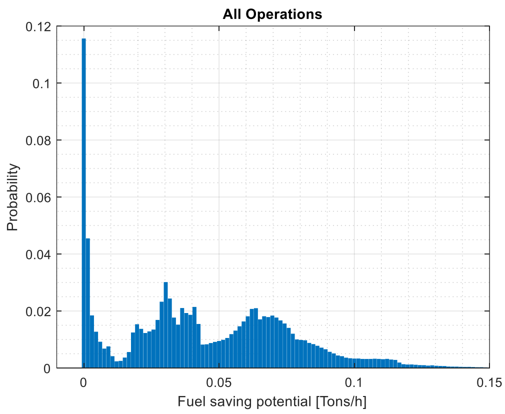

*Figure A 3 - The probability distribution for the time elapsed at a given loading (kW) of the Diesel generator units for the 11 months elapsed in (a) port, (b) transit, (c) standby and (d) dynamic positioning. The probability distribution for all operations are shown in (e). The probability distributions are all normalised per mode such that the sum of probabilities in each plot is 1*

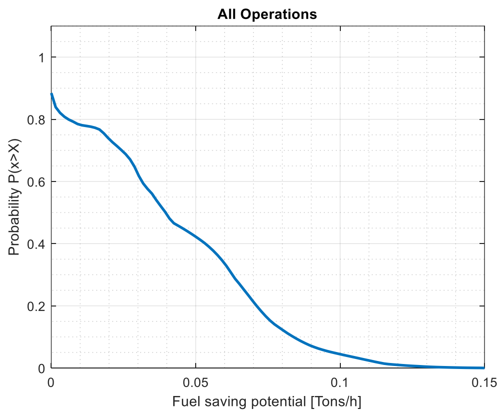



(a)




(b)




(c) (d)

*Figure A 4 - (a) The probability distribution and (b) the cumulative distribution of the time the engines were running at different specific fuel consumption (tons/kWh) during 11-month operation. (c) shows the probability distribution and (d) the cumulative distribution of the time with different fuel (theoretical) saving potential (tons/hour)*

# Appendix B: Battery Safety and lessons learnt from Corvus

## Selected two battery accidents on Norwegian vessels

**Battery fire with subsequent gas explosion on passenger ferry Ytterøyningen[10]:** On the evening of Thursday 10th October 2019, there was a small fire in the battery room on board the Norwegian passenger ferry Ytterøyningen. Firefighting commenced and the ferry reached port under its own engine power. Passengers and crew were evacuated onto land. In the morning of Friday 11th October, there was an explosion below deck, in or adjacent to the battery room.

**Battery-powered excursion vessel overheats in Norway, sparking fear of explosion[11]:** The MS Brim is a 2019-built all-electric excursion catamaran offering excursion tours in Norwegian fjords. The vessel features two battery rooms with 790 kWh of batteries installed and supplied by Corvus Energy.

A fire alarm on board the vessel was first reported on 14th March 2021 as the vessel was located in the Oslofjord near Fredrikstad, Norway. Following the incident, the vessel's four crew were evacuated and the ship was towed to nearby Vallø. There were no passengers on board at the time of the incident. Officials report that although the situation and temperatures on board had stabilised, the fear was that the batteries may had been exposed to heat that could have produced explosive and flammable gases within closed rooms and bulkheads on board the vessel, preventing anyone from boarding or even going near the vessel. A 300-meter safety zone has been established around the vessel and officials report that half of Vallø had been closed to the public over fears of an explosion.


*Figure A 5– Left : Passenger ferry Ytterøyningen / Right : MS Brim excursion catamaran*

**The lesson learnt from the two above battery accidents is before everything that fire brigades must be trained on how to correctly handle battery fires when they occur.** On Ytterøyningen the first responders were not aware of all risks and approached the incident like it was a "normal" fire which resulted in an explosion in a nearby room below deck the following morning. On MS Brim the fire brigade listened to advice from the Corvus personnel present, which resulted in a successful handling of the incident.

## Safety is a joint responsibility

Safety must not be considered only on system level but also on vessel level. The scenario on board MS Brim is outside of what's intended to be covered by propagation testing and battery system safety. This is not incidents caused by a fault on cell level, which is taken care of by single cell thermal

[10] Inthttps://www.sdir.no/en/shipping/legislation/directives/battery-fire-with-subsequent-gas-explosion/ (accessed on 6 April 2023).
[11] Battery-Powered Excursion Vessel Overheats in Norway, Sparking Fear of Explosion (gcaptain.com)/ (accessed on 6 April 2023).

insulation. Battery suppliers and regulations in general have focused too much on single cell and module level safety and not enough on vessel level. As shown in Table A 1, all stakeholder needs to collaborate and be responsible to ensure good conditions in the battery rooms and a built-in robustness in systems and installations.

*Table A 1- A joint responsibility to achieve safety*

| Stakeholder | Responsibility |
|---|---|
| **Battery supplier** | Battery compliant to standards and regulations on all safety aspects |
| **Integrator** | Verified seamless integration of the battery system in the vessel |
| **Shipyard/Designer** | Vessel compliant to regulations and specifications |
| **Approval bodies** | Rules, regulations, product approvals, acceptance tests, inspections etc. |
| **Ship owner/operator** | Follow up on approvals and inspection results.<br>Operation according to specifications and approvals.<br>Training for crew |

## Lessons learned on system level safety

**Battery system integrate single cell passive thermal runaway insulation** and integrated thermal runaway gas exhaust system. Any cell venting and TR exhaust gas are contained and channelled to exhaust via a separate and sealed ducting system in order to easily vented TR gas to external atmosphere.

**Modules are designed with high IP grade on high voltage parts,** this means water will not be able to get inside the module and cause shorting. All power connections are designed to be waterproof, adding an extra layer of protection against ground faults, arcing, and shorting. It allows also for safe use of water FIFI.

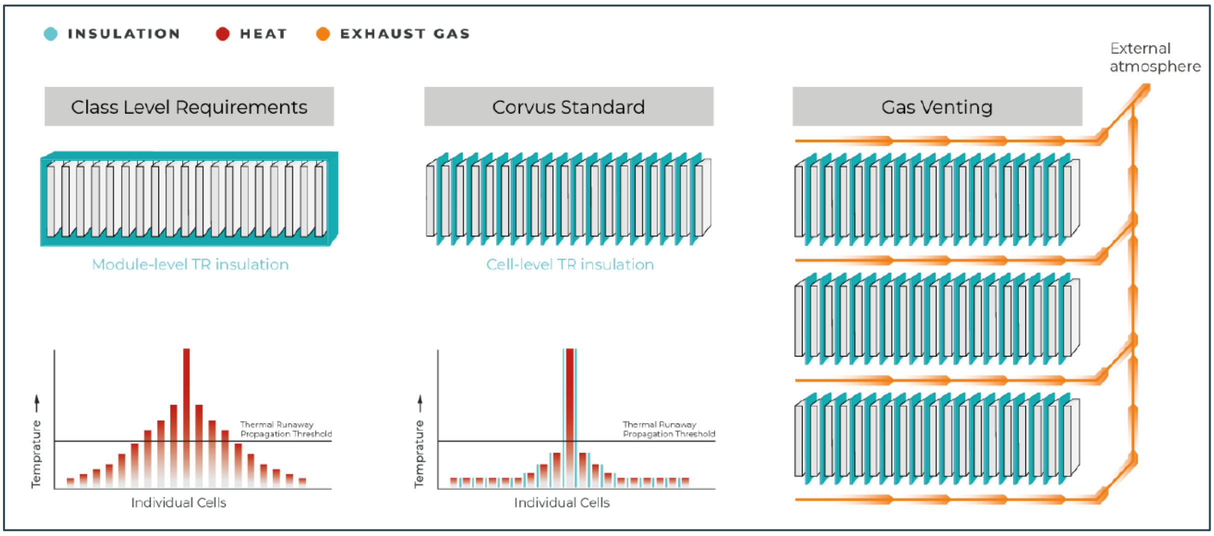



*Figure A 6 - Passive single-cell thermal runaway insulation*

## Norwegian Maritime Authority test protocol

In addition to the standard approval tests, in 2016, the Norwegian maritime authority required Corvus to perform a more severe thermal spread test on their battery pack. The protocol for this test was established by the Norwegian flag with the participation of the DNV and requires that they be presented with undertaking three tests.

This test consists of overloading (3C overcharge) 2 of the 24 cells of a 100 % loaded module until thermal runaway (TR) occurs. Three tests, taking three different pairs of cells (based on their location in the module) are then completed.

The acceptance criteria for this test are as follows: no propagation of the fire from one module to another can occur. Corvus tests exceeded this acceptance criterion by demonstrating in each of the 3 tests that there was no propagation between cells within an individual module (cf. Figure A 7). This performance was achieved through the intrinsic thermal protection built into the cells and was completed without any other external refrigeration system being present.

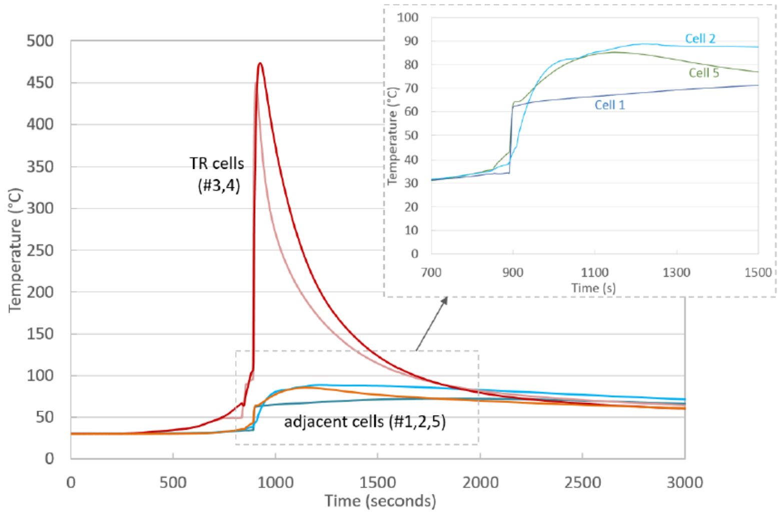



*Figure A 7 - Results of thermal runaway test within Corvus battery module*

This test made it possible to establish, on the basis of the "worst case scenario" of 2 cells in thermal runaway, the defining of the quantities of gas generated, their composition and the temperature generation during this thermal runaway phenomenon and thus allow the definition of the design criteria for the system required for collecting and routing these gases to the outside.

# Appendix C : Equivalent Full Cycles (EFC) computation

**The Equivalent Full Cycles (EFC) is an indicator of battery aging** by considering the number of cycles experienced by the BESS and the depth of each of the cycles. In order to analyse how battery lifetime is affected by multiple and variable cycles occurring within the same day, the cycles are converted to cycle equivalents, where the original cycles are weighted against their contribution to the aging of the BESS. EFC are then calculated summing up the number of part cycles to full cycles. As an example, two cycles for 50% SOC change per cycle makes up one equivalent full cycle.

**The main advantage is that the method is very simple** and straightforward requiring no battery models or particular knowledge to provide a quick assessment.

**But for a detailed assessment the EFC method is not a replacement for a good battery lifetime model** since the EFC method fails to take into account aging stress factors such as temperature, magnitude of current, SOC levels and to some degree micro cycles:

- For vessels where the battery is used as a spinning reserve, no contribution to the number of EFCs will be taken into account
- The EFC method does not account for the temperature effects in battery aging. If the battery temperature is higher than what is assumed for the lifetime calculations, the aging can be significantly worse. If the temperature is below 10-15 °C, higher aging can also be expected
- The EFC method in its pure form is not accounting for the difference in wear and tear in different SOC ranges. Two batteries with the same number of EFCs but in different SOC ranges will exhibit radically different aging profiles.
- The accuracy of current sensors varies with the magnitude of the current. Shunt resistors will become inaccurate at high currents because of heat generation. For operational profiles with large variations in the current, this inaccuracy problem will be prevalent in the entire current range. Magnetic field current sensors are less accurate for small currents. Therefore, regardless of which current sensor that is used, it may be difficult to always know whether the battery is charging or discharging based on the current sensor output. This can lead to significant errors in the EFC. A common workaround is to set a lower cutoff current for calculating EFCs. So, if the current is lower than the EFC cutoff, the battery is considered resting and the wear and tear of the battery from such shallow cycles is not captured. Another challenge is that the wear and tear of the battery from shallow cycles cutoff since different power electronics have different noise levels.

**In summary for a comparison with a planned operational profile:**

- If the real world number of EFCs are larger than the design EFCs and potential current sensor inaccuracies are corrected for, the wear and tear of the battery system is larger than it is designed for and the battery system may not reach its design life
- If the real world EFCs are lower than the design EFCs, the battery system may be OK from a life time perspective, but additional factors contributing to the battery aging should be assessed

# Appendix D: Solstad's Normand Sun crew interview

The crew interview undertaken on the installation of the BESS on Normand Sun was conducted on 27 February 2023. The questions to the captain/chief engineer and their answers are given in Table A 2 and Table A 3.

*Table A 2 - Interview with captain on 497 kWh installation on Normand Sun*

| Questions to captain | Answers |
|---|---|
| Have you commanded a ship equipped with battery capacity? If Yes, What was the biggest battery capacity you experienced? | 1500 kWh |
| What was your confidence level in the battery system use on board the first time you sailed on board the vessel and how is it now (1 to 5)? | First 3, Now 4 |
| How long have you sailed on a ship equipped with a battery capacity? | 6 years |
| What is your confidence level into the battery system use on board now (1 to 5)? | Now 4 |
| What were your expectations about the benefits of the battery system? | Medium |
| Have these expectations been met? | Above expectations |
| Do you monitor the battery state of charge and activity never/once per cruise/every day/several times per day? | Its operational state of charge. Monitor several times per day. |
| In which operating conditions the batteries are the most useful for you? | During all dynamic position operation. The shorepower mode, acts like a UPS if shore power fails. |
| Which operating mode is the most important for you as a captain: Class from the highest to the lowest. | DP -Transit – Manoeuvring |
| Describe your experience with battery system on board: special event, notable use case. | For example, you have immediate available power stored in batteries, if a situation demands fast response on thrusters/main propulsion. This is good for station keeping in DP and manoeuvring vessel. It also protects engines from peaks. In addition, it makes engine loads more even, in bad weather and when handling vessel. |
| Would you recommend to install BESS on other vessels and why? | Yes, it gives vessel extra redundancy in operation.<br>If batteries are used in combination with one M.E instead of running two M.E, this saves fuel and environment. |
| Is the safety of the batteries a concern for you (1 to 5)? | 3 |
| Would you say the batteries complicate the ship's operation, are transparent or help the ship's operations? | Helps ship's operation. |
| Do you feel having received sufficient training? | Today, yes. Not from beginning. Received a web based training last year about handling fire in an ESS system and how system is built and working.<br>This course was very helpful. |
| Open comments or remarks | When using batteries, it's important to have a good understanding of how it works, and of the systems protecting/monitoring batteries. Have knowledge in case of fire in the ESS system. You must understand the limitations when using batteries like capacity and duration. |

*Table A 3 - Interview with chief engineer on 497 kWh installation on Normand Sun*

| Questions to chief engineer | Answers |
|---|---|
| Have you operated a ship equipped with battery capacity? If YES Is the battery system generally working in auto mode (selected through the PMS) or with manual inputs? | In Auto mode through PMS |
| How often do you need to change the battery parameters in the PMS? | Only when vessel change operation mode |
| Do you monitor the battery state of charge and activity never/once per cruise/every day/several times per day? | PMS continues all time monitoring. |
| Do you monitor the battery cell temperature? | Yes |
| What should be the benefits of the battery system according to you? | Straight load line on generators. Save use of one generator. Green operation. |
| What are the benefits of the battery system according to you? | Saving run time on engines, peak shaving load line on generators. Green operation. |
| Which operating mode is the most important for the vessel operation: Class from the highest to the lowest. | There is no straight answer on that. Depends on which mode the vessel is operating in. |
| Have you analysed the consequences of using/not using the batteries in terms of noise, emission, fuel consumption, D/G working hours, etc.? | Yes |
| If yes, in which mode the batteries are the most efficient regarding fuel consumption? | DP mode and Shore mode |
| Are you able to measure the impact of the battery system on the fuel consumption? | Only by calculation. |
| Which kind of battery management tool you would like to be configured for your vessel? (What parameters to be monitored? What actions should be doable?) | To be used with harbour gen and energy generation. |
| What is your confidence level into the battery system use on board (1 to 5)? | 4 |
| What is the level of reliability (damage frequency) of the system (1 to 5). | 4 |
| What is the level of complexity of the system on board your vessel regarding the battery operation management (1 to 5) | 4 |
| Would you say the batteries complicate the ship's operation, are transparent or help the ship's operations? | It helps ship operation.<br>The ship is easier to operate. |
| Are you informed about the battery lifetime expectancy? | Yes |
| Do you feel the current operation is complying to the requirements for maximum battery lifetime or the requirements are too strong and maximum lifetime will not be achieved?<br>What could be done to optimise batteries use (lifetime, overall plant efficiency, minimise fuel consumption, maintenance)? | Tested yearly SOH |
| Do you think that a decision support tool is necessary? Explain your vision of this decision support tool. | Yes we need support from shore.<br>Problems due to take SOH test. |
| Should this tool be automatic or only as advice to be manually selected by the operator? | It should be easier to take the test. |
| Describe your personal experience with battery system on board | Special event, notable use… |
| Do you feel having received sufficient training for battery system operation? | The support can be difficult to reach during operation. |
| Do you feel having received sufficient training for battery system safety management? | Open comments or remarks. It is still a new technology. |

# Appendix E: Ponant BESS decision-making process

Ponant has 13 cruise ships in active service. Its latest vessel is the Le Commandant Charcot, a Polar Exploration Passenger Vessel equipped with a 4.5 MWh BESS which was built in 2021. The decision-making process behind installing a BESS on Le Commandant Charcot is presented in this section. During the BESS concept design phase, there are many questions that should be clearly answered to correctly define the needs and proper dimensioning of the BESS. One set of the original critical questions used in Ponant's decision-making process behind the BESS installation is listed in Table A 4.

*Table A 4 - One set of the original questions used in the Ponant 4.5 MWh BESS decision-making process*

| | |
|---|---|
| **What are the main goals?** | **Safety** |
| | Energy Saving and $CO_2$ |
| | Reduce OPEX |
| | Improve Crew operation |
| **Do we need energy or do we need power or a combination of both?** | |
| **Which quantity of energy?** | |
| **Which power?** | |
| **Which batteries modes are needed:** | Zero emission mode, in which operating conditions? At sea, during manoeuvring, alongside? How many zero emission cycles? |
| | Peak shaving mode, number of cycles? |
| | Spinning reserve and black out prevention? Power and duration? |
| **What is the vessel operating profile?** | |
| **Which lifetime is required? Which maximum SOH is acceptable from on operational point of view?** | |
| **Batteries recycling process at the end of life** | |
| **What about safety on board:** | Thermal runaway risks |
| | Firefighting equipment |
| | Firefighting protecting equipment |
| | Return to normal |
| **Cost, weight, footprint** | |
| **Coolant: Air or liquid?** | |
| **Which batteries chemistry?** | |
| **Location on board** | |
| **Applicable rules** | |
| **PMS integration and interface** | |
| **Maintenance** | |
| **Crew training** | |

# Appendix F: BESS safety plans on Le Commandant Charcot

The safety of BESS installations and operations is always the top priority of all ship owners/operators. Ponant shared its implementation of the 4.5 MWh BESS safety planning and procedures on board Le Commandant Charcot including the energy storage room layout, ventilation, firefighting and emergency plans.

## Energy storage system layout on Le Commandant Charcot

In Figure A 8, the Energy Storage System is located on deck 02 just above the waterline, divided into two compartments and separated from the outer hull by a double hull. In each MVZ 2 and MVZ 3 are the Energy Storage Rooms, connected to ESS converters fed from each HV switchboard.

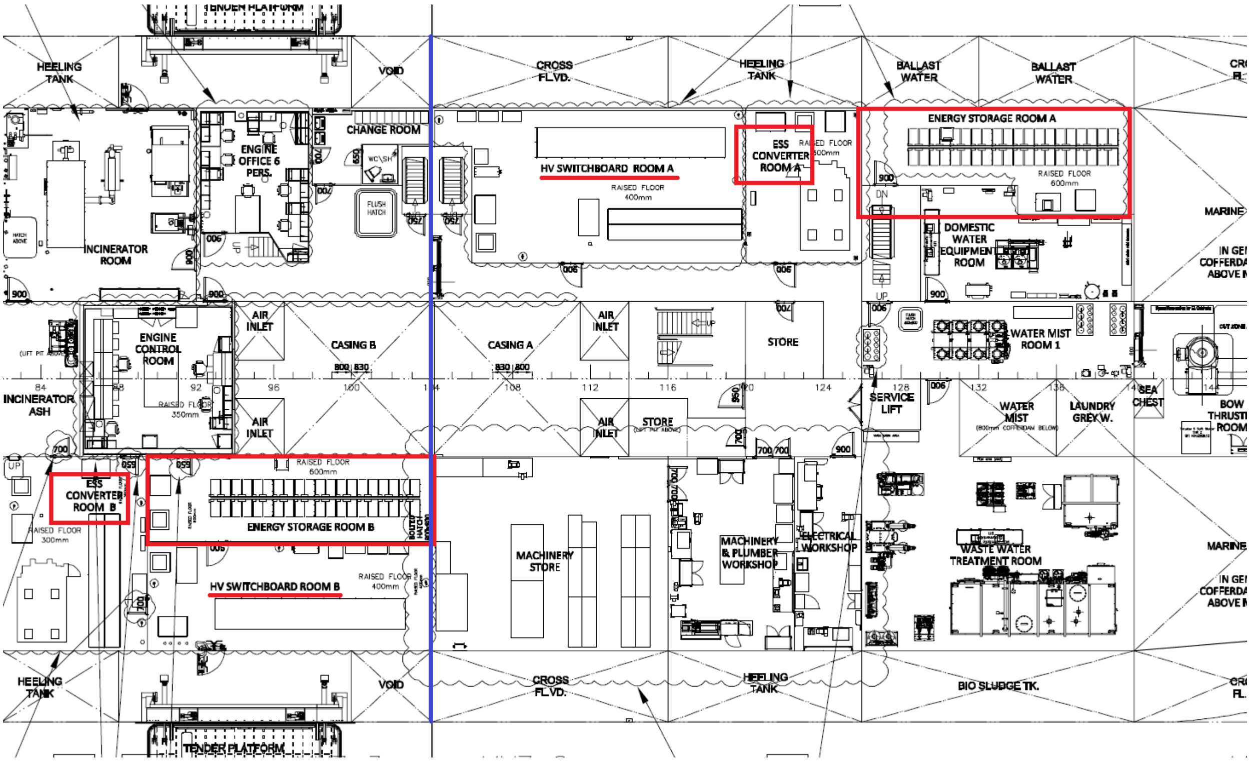



*Figure A 8 - Layout of the 4.5 MWh Energy Storage System located on deck 02*

In the energy storage rooms, the batteries are located at the center, allowing easy movement around and the rooms are also equipped with a CCTV system. For maintenance purposes, within energy storage room B a hatch has been added for easier battery exchange through the machinery store. The energy storage room has a non-hazardous category 10 assigned to it. Indeed, it is considered essential that the battery racks are enclosed within a gas-tight enclosure and that a dedicated exhaust vent is the sole way of venting all potential hazardous gases to the outside. Only this exhaust gas vent ducting is considered to be a hazardous zone 2 in case of thermal runaway and those ducts are routed respectively to the forward mast for battery room A, and to the aft mast for battery room B.

## Ventilation

The optimal working temperature for the battery is within the range of 10-15 °C. The room temperature should be maintained within this range all the time under any condition (external temperature -25°C + 35 °C, battery charging/discharging). An AHU unit is supplying treated, dry, fresh air (six times air change per hour) into the ESS room and the thermal balance is controlled through a fan-coil unit, which has a full back up through a self-contained unit.

A local temperature sensor is present monitoring the ESS room temperature and gives an alarm on IAS should the temperature deviate from the optimal range. In addition, the ventilation of the battery racks is separated from the room ventilation. A forced ventilation system is included within the racks to provide cooling to the battery modules. A dedicated document concerning ventilation approach has been produced and has been reviewed by Class Society. The ventilation system for the battery is fed by an emergency power source to be able to keep the exhaust fan available for operation during any emergency situation that may occur.

As indicated during the risk analysis, in case of a high temperature alarm being detected in the ESS room, the ESS should undergo an immediate emergency stop which upon being activated immediately stops all charging, discharging operations.

ESS room A & B exhaust ventilation are connected to the exhaust ventilation systems of other rooms, this is why exhaust vent lines are equipped with non-return dampers to prevent gas extracted from the ESS rooms being sent to other rooms as opposed to being vented outside.

#### Firefighting systems

In case of fire, redundant fixed firefighting systems have been installed in each ESS room:

- Fixed NOVEC extinguishing system
- Fixed pressure water mist system

The recommendations for all Corvus ESS are as follows.

Early stage detection of any thermal event is the key to mitigate undesired situations for an ESS and Corvus Energy recommends using both temperature and gas/smoke detection in the battery room to identify any potential hazards. The type of gas detection system should be determined by the characteristics of the emitted gases of the specific battery type. If a CCTV-installation is planned or already installed on the vessel, it is advisable to also consider installing CCTV-monitoring inside the battery room, minimising the requirement of entering a battery room during any hazardous situations. It is necessary to take precautionary measures against fire in both battery room and adjacent rooms, reducing the risk of exposing the energy storage system to elevated external temperatures. Submerging any Corvus ESS under water (whether freshwater or seawater) as a means of fire-suppression is not recommended. Please note that the design, dimensioning and installation of fire suppression systems must be in accordance with the rules and regulations of the relevant marine classification society/governing body.

Third-party fire suppression installations which require modifications to any part of Corvus Energy's scope of delivery are not recommended and will void all Corvus Energy warranties, breach the system type approvals and could damage the integrity of the Corvus passive single cell thermal runaway isolation layer.

Any equivalent systems to the systems mentioned in the specific recommendations for each product must be evaluated by a fire expert as Corvus Energy is not able to cover all different variants and suppliers of water mist or inerting systems.

Please note that any battery room ventilation system when using inert-gas firefighting systems (exchange of air inside the battery room with ambient air) shall be normally closed. Water-based firefighting systems should not be used to accelerate the cool-down period during a situation that is under control by inert gas.

This design is also supported by DNV studies given in Figure A 9.

**Table 7-2: Fire suppression systems' capability matrix**

| | Primary objective | | | Secondary objective | | Suppression method properties | |
|---|---|---|---|---|---|---|---|
| | Flame extinction | Long Term Heat Absorption | Short Term Heat Absorption | Reduce Gas Temp in room | Gas Absorption in room | Can be Used with Ventilation | Suppression method |
| Sprinkler | | | | | | YES | Total-flooding |
| Hi-Fog | | | | | | YES | Total-flooding |
| NOVEC 1230 | | | | | | NO | Total-flooding |
| FIFI4Marine | | | | Not evaluated | Not evaluated | YES | Direct injection |
| Direct Water injection *) | | | | Not evaluated | Not evaluated | YES | Direct injection |

*) Not expected or recommended to be used in practice for high voltage applications, due to the risks of short circuit and hydrogen production. The method is presented as a flame extinction and heat absorption capability reference.

High capability — Low capability — Medium capability — No or very low capability

*Figure A 9 - DNV-GL technical reference for battery explosion risk and fire suppression*

## Emergency plan

**The following important warnings were given to the crew in case of fire including:**

- In case of internal battery cells fire, the combustion will last a few seconds and the gas will be evacuated through the internal gas duct without any fire propagation to adjacent cells. The ventilation of the room should be kept running in order to evacuate potential gas leakages from the racks.
- In case of fire outside of the battery pack, the NOVEC system may have been released and ventilation stopped.
- Theoretical NOVES efficiency: 15 minutes
- In case of Ultrafog activation:
  - ESS rooms are equipped with 6 spray nozzles K0.73.
  - Average flow rate: 3m$^3$/h.
  - Water mist freshwater tank: 38 and 41 m$^3$.
  - Spraying autonomy: 12 hours per water mist module before to switch to sea water
  - Containment capacity of the ESS room A: 17 m$^3$. Spray duration 5.5 hours.
  - Containment capacity of ESS room B: 20 m$^3$. Spray duration 6.5 hours

**After a thermal event, the assessment and response plan should be implemented as follows.**

1. If a gas release or thermal runaway situation is suspected, do not power down the battery equipment within the battery room. Doing so will remove the ability to monitor important system parameters (voltages, temperatures) that are needed to fully assess the situation.
2. The thermal runaway event will automatically disconnect the affected pack from the DC bus. Depending on the situation and the way the battery equipment is used, it should be safe to continue operating other pack(s) of battery equipment in the battery room.
3. Through the control system, note the number and location of the module, pack, and array that are affected.
4. If possible, verify if a gas release was witnessed at the open-air TR vent pipe.
5. Also note the following parameters at/before the time of incident: pack SOC, module voltage, pack current, module temperatures (for affected module and surrounding modules). Identify whether the extracted values are of good quality and can be trusted to draw conclusions. For example, cell temperature values should not be erratic or moving rapidly.
6. Investigate and understand the failure mode and the sequence of events that led to the thermal runaway event. This will aid in understanding the state of the battery modules and the potential latent safety hazards present during disconnection, handling and removal of the equipment. There is a risk that some battery cells have been damaged and further handling could cause them to vent their electrolyte. Even if a cell has no remaining electrical energy, the cell electrolyte has stored chemical energy and the vented gases are toxic.
7. If any windows or cameras exist into the battery room, perform an initial assessment of the state of the battery modules, pack controllers in the battery room through the window(s). Also note the state of the air and environment inside the battery room, and whether there is smoke or evidence of gas leakage, and whether the room’s fire suppression system has deployed. Be sure to wear appropriate PPE for a potential fire risk.
8. Perform a risk assessment of potential latent safety hazards surrounding the battery modules, and customise the response procedure as needed to ensure the safety of personnel and the minimising of hazard and any remaining risk before entering the battery room.
9. Contact Corvus Energy to discuss the specifics of the event and to receive further instructions in fully diagnosing the scope of the event. Also to be discussed is the safe disconnection of the battery equipment and/or to arrange for on-site assistance from Corvus technical personnel.
10. When safe to do so, stop current flow to all packs within the battery room of interest. Allow the entire battery system to cool down to ambient temperature.
11. Monitor all available temperatures within the system to judge any change in risk.

**Procedure for entering the battery room**

1. Operate the room ventilation system on maximum for several hours before entry of personnel, and leave it operating at all times while personnel are inside.
2. All personnel who enter the room should be equipped with breathing protection consisting of either self-contained breathing apparatus or a mask with nose and mouth coverage and filtration cartridges designed to protect against organic vapours. Other PPE should include safety glasses, high-voltage gloves, electrically insulated safety shoes, and fire-retardant coveralls.

3. Perform an initial assessment of the battery room space:
    a. Confirm that the thermal event is centered at or contained at the expected location (based on voltage and temperature feedback gathered through the control system).
    b. Use a thermal camera to look for any hot-spots in the affected equipment

**Procedure for removing the equipment**

1. Involve Corvus Energy in defining a removal procedure that is specific to the situation.
2. The removal procedure should include a plan to remove the affected module(s) all the way to an open air or other location. (Note that the modules are safest when they are installed in the rack, as they have the protection of the TR duct. When they are damaged and out of the rack, they are at a relatively increased risk of additional venting due to a latent defect).
3. Turn off (power down) the pack(s) of interest.
4. Instruct the team in the safe handling, removal, and storage of the battery equipment at the storage location.
5. Perform an initial assessment of each battery module to determine its functional state, its level of hazard, and whether there is any risk of further thermal runaway or cell venting.
6. After taking any necessary precautions, unfasten the equipment from the rack and move it to the storage location. After the initial movement of each battery module from the rack, monitor it with thermal camera to gauge any change in its condition.
7. All other modules in the same column as the TR module should be removed and inspected. However, they should be replaced in order to retain the safety provided by the TR duct.

**Emergency procedures**

According to HAZID recommendations, specific crew emergency procedures must be developed:

- Manual Emergency stop of the ESS in case of fire in the ESS room or in the vicinity of ESS room.
- Manual Emergency stop of the ESS in case of fire in the HV main switchboards
- Manual Emergency Stop of the ESS in case of ventilation shut down in the ESS room

Manual emergency stop push button have been placed in three locations:

- Bridge safety center
- Engine Control room
- At the exit of the ESS room

The external emergency stop circuits are monitored and the BESS controller will issue an alarm should any of the emergency stop signal cables experience a signal failure. The emergency stop circuit is hardwired to safety relays in all converter cabinets and towards the battery BMS. All converters will trip immediately, and emergency stops should be activated, while the safety relay for the BMS includes a delay function. This is to guarantee that the BMS contactor do not attempt to trip before load has been removed from the batteries. Once the battery contactors have opened, the batteries are isolated from the rest of the power system and considered to be in a safe state. Note that if a battery module trips, the rest of that array will be immediately disconnected.

# Appendix G : Crew interview report and feedback

A questionnaire was sent to the Ponant fleet of 13 ships to the captains (group 1), staff captains (group 2), chief engineers and chief electricians (group 3). In addition, the "doublure" of Chief Engineers and Chief Electrician of Le Commandant Charcot were also sent the questionnaire as they have several months of experience of sailing on a ship with batteries.

We received the replies from 6 captains, 5 staff captains, 6 Chief engineers and Chief Electricians, out of 54 so around 32% of replies. Out of the 17 replies, 10 replied having sailed on ships with batteries installed. However, the study of the replies to the questions regarding battery capacity and usage, shows that 5 replies mentioned batteries of the Uninterrupted Power System (UPS). Indeed, it was not explicit in the questionnaire that the current project is focusing on Energy Storage Systems (ESS). The UPS batteries are installed onboard all ships to comply with the SOLAS regulation and supply uninterrupted power to sensitive navigation systems in case of black out.

Therefore, in the rest of the current document, we will specify when replies concern UPS batteries or ESS batteries. Non depending on UPS or ESS batteries, a majority of the participants are confident to very confident (12/17) about the use of batteries. One participant was not confident due to safety reason "At the moment there is no effective system to extinguish the lithium battery fire.". It is also to note that in this pool of participants, there is no obvious relation between the confidence level and the experience with ESS.

## Risk and reliability level

Despite the high confidence levels, all the participants in group 2 which had experience with batteries, in this case only UPS batteries, deem the batteries of high risk (level 4 on 5). On the other hand, almost all the participants of group 3 consider high reliability of the battery (UPS and ESS) systems.

Only one participant considers a reliability of 1 on 5 and mentions "[reliability] very low for the moment, only 2 years old" which can be explained by the high level of unavailability of the ESS system onboard Le Commandant Charcot during the first year of operation.

In addition, the participants of group 3 informed their opinion on the level of complexity of the system with a majority of 3/5 (ESS) and one 1/5 (UPS).

From the 10 participants having sailed on ships equipped with battery systems (UPS and ESS), half considers having received sufficient training and half considers not having received sufficient training regarding the operation or safety management of the batteries with the following remarks:

- "Yes, because I was part of the New building team."
- "No, I feel that we discovered a lot by ourselves."
- "Could be improved."
- "We don't have enough training concerning this class of fire or the management of such equipment and their risk."
- "No contingency plan available on board. No training document support"

## General knowledge status and expectations about the batteries

In this chapter are analyzed the expectations of the participants towards batteries and for those having experience with ESS, if these expectations are met.

The main expectations before any experience with battery systems are:

- Redundancy, black-out prevention x7
- Fuel Economy x5
- Sustainability, CO2 emission reduction, noise x4
- Zero emission at port or anchor or when necessary x4
- Decrease the running hours of the Diesel Generators x1
- Energy storage x1
- Peak shaving x1
- Punctual Additional power in order not to start another DG x1
- Avoid DG underload or use of the Diesel Generator at optimum load x 2

These expectations can be grouped into four main focuses:

- Increase the safety of the systems x7
- Optimize the use of Diesel Generators x6
- Reduce environmental footprint, locally or globally x8
- Direct fuel consumption reduction x5

Noting that the two last points are linked but it is interesting to pinpoint that participant expectations were either environmental or economical. On the other hand, one participant mentioned that a lifecycle analysis of the batteries shall be done in order to prove CO2 emission reduction.

For participants experiencing sailing with batteries, the follow expectations have been met:

- Zero emission mode x4
- Back-up power, prevention of black out x4
- Energy Storage x1
- Reduce environmental impacts x1
- Reducing the costs of the fuel x1
- Less noise around the ship x2
- Peak shaving x2
- Use of DG at better load x1
- Smoothing power consumption especially during navigation in strong ice condition x1
- Punctual additional power in order not to start another DG x1

It shows that in general the participants feel that their expectations of the batteries are met. In particular, we can underline that the batteries perform well for the zero emission mode, but less in the expectation of fuel economy or environmental impact. In addition, it has been noticed that the capacity of swift reaction of the batteries to load variations, especially in ice conditions is beneficial and was not foreseen.

However, a few limitations arise from the study:

- Zero emission mode: limited in time x1. Indeed, the zero emission mode lasts only 1-2 hours on Le Commandant Charcot.
- Prevent underload of Diesel generator: limited x1. Indeed, the operational profile of Le Commandant Charcot allows it to go at speeds in correlation with optimum Diesel Generator load.
- Increase global efficiency of electrical network by using the Diesel generator in their optimal range (for the moment not demonstrated) x1. Indeed, the calculation and generalization of fuel savings linked to battery use has not been done at this stage.

### How the batteries are used on board

The majority of participants of group 3 use the ESS batteries in auto mode. Only one participant uses it only with manual inputs and one participant uses manual inputs from time to time.

Based on the quiz study, manual inputs are necessary for the following cases:

- Preparation to use Zero Emission Mode,
- Special short operations: harbor maneuvers, strong ice conditions,
- "More or less each time we change type of navigation. From several time a day to several time a week"

When used with automatic settings, here are the most used ESS modes, listed by order of priority:

1. Hybrid mode (Charge ON, Peak shaving ON with adjustable limits)
2. Zero Emission Operation (ZEO) shallow usage (SOC between 25% and 50%)
3. Spinning reserve
4. Ice Mode
5. Custom settings mode
6. ZEO deep usage (SOC between 17 % to 90 %)

In addition, it is remarkable that even being a novel technology onboard ships, the current design is either seen as transparent (for group 1 user) or help the ship's operation (group 3 users). The group 3 users are all informed about the battery lifetime expectancy and confirm are able to monitor it and keep the number of cycles under the limit to keep the maximum lifetime expectancy.

However, some drawbacks arise listed by number of mention in the quiz replies:

1. Safety, fire, risk of thermal runaway
2. Efficiency: electrical losses in the ESS.
3. Price and low ROI
4. Size and Weight

**Monitoring**. All ESS users confirm monitoring the state of charge of the batteries several times per day and do not rely on alarms to check for low charge level or high charge level. Constant monitoring seem to be necessary when in ZEO.

**Efficiency.** While the fuel economy and CO2 emissions reduction were ones of the highest expectations, the participants are not confident on the possibility to measure the ESS impact on fuel consumption. It is not straightforward as one of the participant mentioned: "For the moment by use of an excel file by taking some data from different systems IAS, Green Pilot (data acquisition software), PEMS (Power management system) and putting all together we can have an approximately visual on the fuel economy."

Only 2 users were able to qualify the consequences of using the ESS which are listed below:

- Noise and emission reduction during ZEO mode
- Fuel consumption – low reduction (not very exact at this moment)
- D/G working hours – for every ZEO mode cycle there is 1 hour less for 1 DG. But one additional start/stop equivalent to 50 running hours.
- Without batteries, stability of the network is reduced a lot during strong demand periods on propulsion (strong ice condition)

However, to quantify the fuel economy does not seem easy when the question is asking which mode is the most efficient:

- "I think that we can see a small reduction of the fuel consumption in ZEO mode."
- "Zero emission mode"
- "Should be "Charging from low load limit ", in order to prevent D/G to be underloaded ( Not efficient in our system due to the excessive power of our gensets)"

## Technical issued encountered

The issues which were encountered and related by the participants are:

- Batteries water ingress due to water leak on the ceiling above batteries pack (bad installation design to have this risk right above the pack). Consequence of this water ingress, a whole section of the batteries pack was unavailable.
- Leakage on the internal cooling system of the Drive – due to vibrations
- Communication lost with the battery packs – due to vibrations
- Wrong indication of the PDM Contactor in the PEMS (MODBUS signal)
- Pre charging resistors of the DC BUS on the SU of the Drive burned due to wrong cabling from delivery
- Overvoltage trip when used in ICE mode (sometimes)
- Battery pack overload with or without pack trip (result from bad change of parameters by the operators, or real demand overload)
- Reactive power delivery from the battery inverter and not from Diesel Generator: high losses.

## Crew proposals on design

The following proposals on the design were issued:

- Very good ventilation of the battery room is important and has to be well positioned to distribute the cool air uniformly. Ventilation supply must not face the battery packs. System automatically reduces power charging or discharging when battery cells are too cold.
- During Zero emission mode, we observed a slowly increase of the heat inside the battery packs. If ventilation is not good enough, temperature inside the battery packs and inside the room is rising very quickly.
- No heat exchanger or water pipe to be installed above the battery packs, because of a risk of water leak.

- We have to be trained to face any issues that could occur. Like manually isolate a battery pack because of any trouble, not only automatic actions.
- We have to keep the control of the system at any time.
- Adjust Reactive droop of the ESS converters.
- Submit improvement in collecting and analysing data

### Improvements on the ESS

Here are the remarks on the possibility of improvements that were mentioned in the survey.

Regarding Battery management tool, parameters to monitor and possible actions:

- For each Battery Pack: cell temperature, cell voltage, pack voltage, pack current, pack SOC, pack SOH, status for: Connected/Not Connected, Maintenance mode active/not active, Cell balancing active/not active, Derating active/not active, Power save mode active/not active
- For each ESM (group of 5 battery packs) x 4 Batteries: Actual charge power, Actual charge current, Max charge current, Max discharge current, Max charge power, Max discharge power, Alarms
- For each ESCS: DC link voltage, DC link Current, Active power, Reactive power, AC Grid voltage, AC grid frequency, Line Current, SOH, SOC, connected/not connected
- For each ESS transformer: windings temperatures
- For each Drive: LCU – cooling pumps status, inlet/outlet pressures, temperature, alarms. Status of the SU breakers opened/closed, status of AC/DC output modulating/not modulating
- Breaker supply line HV SWBD to ESS transformer – status opened/closed
- Preset modes should be configured same as the ones on Le Commandant Charcot (Hybrid, Charge, Discharge, ZEO deep usage, ZEO shallow usage, Ice mode, Custom mode – operator choice of parameters), Control mode – auto power reference, manual done by the PCU or operator
- Actions – connect/disconnect complete ESCS, manually connect/disconnect individual ESCS(A1,A2,A3,A4) in case of failure, usually this operation is done automatically ESM system.
- What is missing it's the instant flow meter for each D/G in the PEMS, that will permit to have a clear image on the fuel consumption, by creating an algorithm that can give the quantity of fuel that we have economies during a complete cycle discharge/charge.

Regarding efficiency improvements (lifetime, overall plant efficiency, minimize fuel consumption, maintenance):

- Lifetime – operate them in a controlled cooled space and respect the maximum cycles/year.
- Overall plant efficiency – losses in stand-by mode due to the reactive power flowing back and forth.
- between the grid and the inverter of the ESCS A and ESCS B, delivered by the batteries, can be reduced if the reactive power is delivered only by the D/G and the reactive droop of the ESCS A and ESCS B Converters is adjusted.
- Minimize fuel consumption – alternative source of charge like gas turbine generator, bigger capacity of batteries.

Regarding the need of a decision support tool, out of 5 replies, 2 consider it necessary (to optimize battery use), 2 consider it unnecessary (but operators shall be properly trained), the last participant haven't replied to the question (UPS user).

In addition, the participants inform in majority that this tool should be an advice and not have control over the system. However, two participants note that the tool should have the possibility to control the system if needed.

### List of open comments or remarks.

- Special skills for firefighting would be required.
- More training technical for engine team
- We got video trainings showing what is a thermal runaway or a fire of battery and what could be the issues but we have not received any training to fight battery fire or action to be done after a thermal runaway.
- Special care should be made of fire extinguishing system for the room where the batteries are installed.
- During training with Marseille firemen, they explained us the way they are extinguishing fire on batteries (electric cars for example) by flooding totally the device in fire into water, only possibility to stop the fire because of the quantity of energy dissipated.
- On a ship, having the batteries installed in the room that can become totally watertight to air and water, and that can be totally flooded with water as last chance of extinguishing would be an important safety to me.
- The capacity of the batteries should be bigger in order to permit a bigger autonomy in ZEO mode, like 12 hours at least on ZEO mode. In this moment, with the installed battery capacity we can have only 1 hours in ZEO mode but with limited cycles/year
- If we take all the stages of the life of the batteries from production and after-life treatment, I'm not sure that this system is more ecological than without using it on board.
- We need to continue to developing the super-condensator that is the future without contains chemicals or rare earths.
- The use of batteries is MDO or LNG less consumption means less exhaust gas in the atmosphere.
- As you understand, my main concern, is the safety. Which mean, the battery room on board should be built, in order to be totally isolated (almost waterproof) and close to any other vital area, in case of fire / explosion.
- Principle matter is about fire risk assessment, we have only limited knowledge. Firefighting equipment, location of batteries on board. Training on battery/power management for bridge OOW and masters.
- After several exchanges with professional fireman, the safety issue of the battery is a real problem as there is no perfect solution in case of fire/explosion.

# Appendix H: ELKON's recommendations for BESS integration

As a marine electrical system integrator of BESS, Elkon has made 3 different approaches for BESS integration planning as follows.

- BESS integration introduction to an existing vessel as a retrofit
- Battery addition to an existing BESS application on board
- New built vessel electrical design with commercial and future development on energy storage systems.

Firstly, as an experienced marine electrical system integrator, the basic requirement that is demanded from marine battery suppliers is to get pure power quality without any EMC problems. This is because in hybrid electric ships, BESS can behave as both a power supplier (discharge) and a power consumer (charge). Batteries and their BMS should be compatible with PMS modes and drive units on board. For example, there should be a dedicated DC/DC converter for each battery on board if they have specific duties like high energy or high power in order to build a safe DC voltage level. If the existing drives would not be changed as part of the work, PMS modes can be updated accordingly. Communication between drives and BMS should be arranged as well through either MODBUS or CANBUS or any other future protocols.

**Recommendations for BESS integration**

According to Elkon's experience in PMS engineering and BESS integration, it would be beneficial to make a ship initial design for its electrical and mechanical installations in a way that would enable easy integration of future BESS developments. Initial design must be a kind of "DAY-1" design, which is made by considering the load analysis and BESS load profiles as per designed operational needs. Mechanical and electrical design must then be done by considering possible "DAY-2", "DAY-3", "DAY-X" installations. Those installations can be done for the following reasons:

- By keeping rated power constant, DAY-2, DAY-3 and DAY-X installations can provide greater DoD
- DAY-2, DAY-3 and DAY-X installations may include new technologies that increases efficiency and safety
- DAY-1, DAY-2, DAY-3 and DAY-X approach can be financially more applicable for ship owners and encourage them to invest more in BESS technologies
- Modular and plug & play solutions will be pre-engineered and be more readily applicable.

Spaces assigned for possible DAY-2, DAY-3 and DAY-X installations can be used for other purposes (for cargo etc.) during the usage of the DAY-1 design.

# Appendix I: Siemens BESS experience learnt from the automotive sector

**Introduction**

New technologies and changing consumer demands are pushing the automotive industry to a continuous evolution where the main automotive trends include electrification, autonomy, connectivity and shared mobility. Automotive companies and government continue to declare their electrification plans. The added complexities of the vehicles create new opportunities for the automotive OEMs as well for the battery companies.

Electrification, the most advanced key trends, is being driven by policy and consumer demand at this point. Economic policies to reduce GHG emissions are increasing, so the automotive OEMs need to meet these targets. Autonomy includes everything from blind spot visualizers to autopilot modes where self-driving cars supposed to improve safety on the roads and reduce the time and energy required for driving.

**Automotive battery technologies**

The batteries used in automotive domain are typically lithium-ion (Li-ion) batteries due to their high energy density, low self-discharge rate, and low maintenance requirements. There are also other battery chemistries used, such as lead-acid, nickel-cadmium, and sodium-ion batteries.

The main challenge of automotive BESS is managing the battery life, controlling risk of fire and system efficiency. The thermal characteristics control of the batteries through battery cooling systems is also a key factor of a BESS.

The experience gained from the use of BESS in the automotive follows the following four criteria.

**Battery management system (BMS)**

For battery protection and optimisation, in vehicles the monitoring of the voltage, temperature, current, battery state of charge (SoC) and cell balancing of batteries are done through the battery management systems (BMS). The process of engineering BMS control software is a complex activity that must produce a balance between immediate battery power performance and long duration safe operation. Robust algorithms are required to accurately predict battery degradation and adjust the system operation to maximise the life of the batteries. A challenge is to ensure a safe and permanent BMS communication with other BESS components as the power electronics and charging infrastructure.

**Charging infrastructure**

Charging equipment for EVs is classified by the rate at which the batteries are charged including three different categories: charging level, charger power output, and electrical service specifications. The growing number of EVs requires a robust network of charging stations, so the BESS charging infrastructure is critical to the success of the technology. This requires significant investment in infrastructure development and coordination between stakeholders.

**Integration with power grid**

BESS systems can provide a range of benefits and grid services such as frequency regulation, ancillary services/grid stability, voltage support/stabilization which add a significant benefit to the grid by improving his stability. Communication protocols between the BESS and the grid is one of the main challenges in BESS-grid integration.

**Environmental impact**

The environmental impact of BESS production is a critical consideration and the metrics to assess the BESS impact power system is provided by LCA (Life Cycle Assessment) tool where the LCA methodology is used to assess the BESS system across its entire life cycle to its end-of-life. LCA studies have shown that the environmental impact of BESS is highly dependent on the battery chemistry and the energy source used to produce the electricity for charging the BESS. Recycling contributed to reduce the overall life cycle environmental impacts across all categories – most notably are on mineral resource scarcity and toxicity related categories.

**Future of BESS**

The growing EV's demand has a huge impact on the BESS market, which is expected to achieve a considerable increase in the next decade. The future of BESS is expected to include a range of emerging technologies and applications. In order to increase safety and obtain higher energy density and faster charging times one trend can be the development of new batteries technologies. Other emerging trend can be second-life battery usage, range extensions of grid services and future development of Vehicle-to-Grid (V2G) Technologies.

**Conclusions**

The increased vehicle complexity comes with new challenges and propose a new transportation revolution where the car of the future will be self-driven and electric. Due in part to the introduction of high voltages, electrification are needing significant changes to electrical and electronic architectures within vehicles. The impact of the new trends starts from the design and engineering processes of new parts and components to the integration of those into the vehicle. Also, the manufacturing process and all the way through to the servicing of these vehicles after they are on the road should be reconsidered. The new challenges in automotive industry will force the companies to lower development steps, production and operating costs, to create new business models where sustainability will be a strategic issue.