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Hybrid Systems

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Contents

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Photo: Selzer

The charge is building – are batteries, hybrids beginning to electrify shipping?

It might just be a sliver of the market today, with only around 200 ships out of the global fleet that have batteries installed, but is electrification on the horizon in shipping?

Photo: Torghatten Trafikkselskap AS

»Hornstind« is a battery-powered hybrid passenger car ferry entering into service between the Tjøtta–Forvik route in Norway. The powertrain includes a 500 kWh battery package, used for peak shaving during harsh sea conditions

All electric ships and hybrid ships with energy stored in large batteries with optimized power control can significantly reduce fuel costs, maintenance and emissions. Additionally, increased ship responsiveness and improved robustness and safety in critical situations are obtained. Power generation units can be smaller or fewer and optimized for a more average (rather than peak) load, and thereby reducing investment costs. Batteries can store energy harvested from waste heat recovery, regenerative braking of cranes and renewable energy. Additionally, they can improve propulsion systems based on LNG and other environmental friendly fuels and improve the performance of emission abatement technologies.

Batteries, chemistry and cost

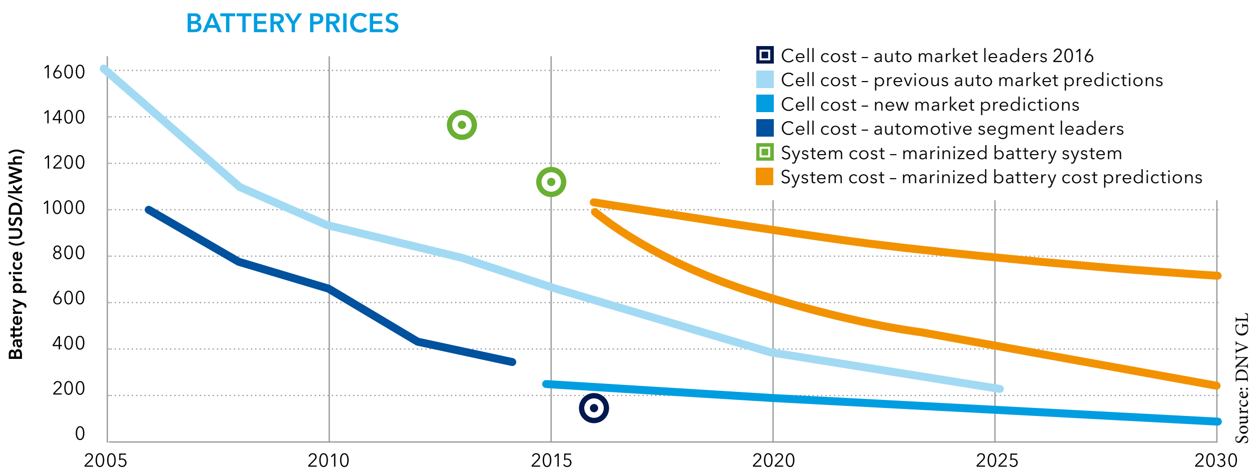
Lithium-ion chemistry (Nickel Cobalt Manganese (NCM) is the clear market leader in the sector at the moment due to its balance of safety, cost, energy density, power, and lifetime. It is likely to remain the key technology in maritime applications over the next few years. NCM battery prices are decreasing rapidly and performance is increasing primarily driven by demand in the automotive and consumer electronics industries. In shipping, however, the additional requirements for safety testing and maritime packaging result in a higher price.

There are other options, however, and for shipping's needs – high performance, greater safety, and reduced degradation – lithium-titanate batteries (LTO) can be an attractive option for many applications. Iron-phosphate (LFP) also presents benefits which can be advantageous. Over the longer term, solid state electrolyte systems could break through into the market, while options such as lithium-air still have significant barriers to overcome, and are not likely to become commercially viable in the next ten years.

The prices of lithium-ion battery cells have dropped and continue to drop markedly, falling by 50 % in 2016 alone. Carmakers have set a price goal of 100 $/kWh for lithium-ion cells by 2020, which seems to be a realistic goal. If this target is reached maritime systems could certainly benefit, although many of the additional costs of marinization will still apply. The wide range in maritime system prices is likely to remain, with different types of solutions available for the different applications.

Total battery system prices for shipping installations include both the lithium-ion battery cells themselves as well as the cost of system integration; including module construction, battery control hardware and software, power conversion electronics, thermal management, and testing. The figure below indicates trends in battery cell pricing as well as potential trajectories for full maritime systems (AC, including power electronics).

In some senses hybrid or electric systems do not face some of the challenges of new fuel types when it comes to infrastructure, as a battery system is essentially a device that stores DC electricity and interfaces to the electrical distribution system with standardized power electronics hardware. As such, the infrastructure required for battery systems on board ships mainly consists in provid-



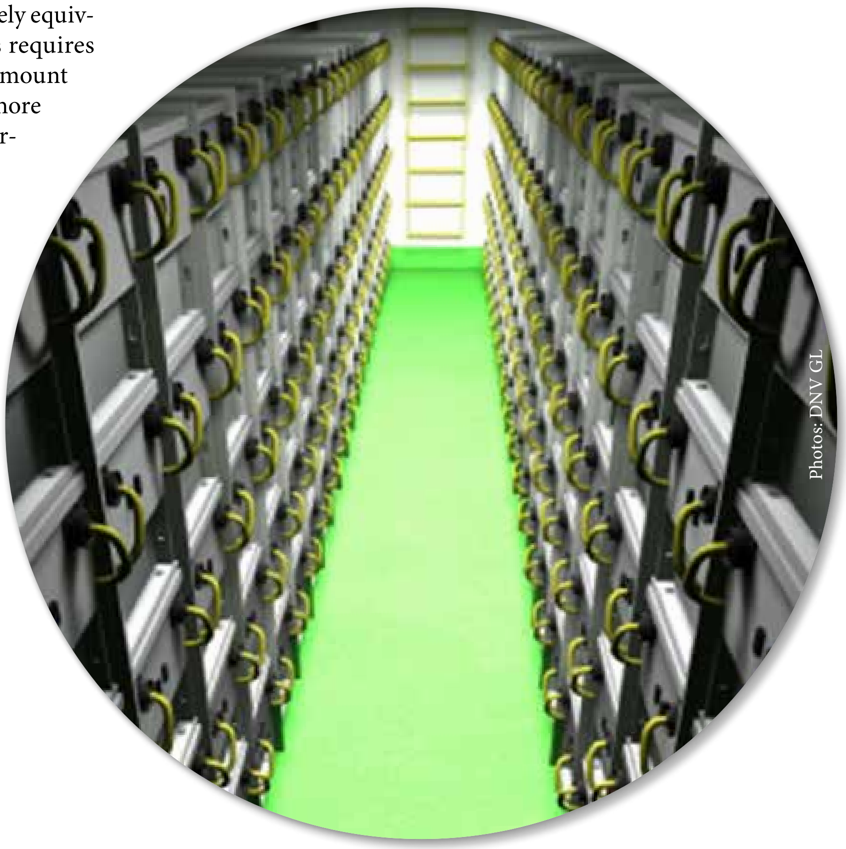
The batteries onboard the »Vision of the Fjords«

Regulations

Regulations for batteries in shipping have been focused on the safety of the batteries and installations, primarily through the classification societies. DNV GL has rules that cover the use of batteries as part of a vessel's propulsion energy in either hybrid battery or »pure« battery-driven vessels for several years now. The rules cover all aspects of their use including such safety requirements as the vessel's arrangement and environmental controls, including temperature and ventilation, and the required location of the battery systems and associated electrical systems. In addition, the batteries on a classed vessel must be certified to the requirements in the Battery Power class rules, for which DNV GL offers a type-approval service.

ing an adequate charging grid. However, when we look at the charging itself the challenge becomes apparent. For instance, charging 1,000 kWh (approximately equivalent to 100 l of oil-based fuel) in 30 minutes requires 2,000 kW of power; while charging the same amount of energy in 10 minutes requires 6,000 kW of shore power. Such demand can represent a considerable load on the local electrical network and therefore may require additional resources. And in the case of hybrid vessels, there is no absolute requirement for a charging network to take advantage of battery systems (plug in hybrids can of course use charging stations).

On the other hand, once the electrical system has been established for a given installation, it is nominally a straightforward process to replace the batteries with a new, updated or replacement technology. This means the electrical infrastructure for battery systems can be relatively easily reused enabling a high degree of interchangeability.



Photos: DNV GL

The testing ground and the next generation

In Norway, a combination of government incentives, emissions regulations, and fortuitous timing – with many vessels serving on local and commuter routes due for renewal – have created ideal conditions for electrification. This means that over the next few years, some 50 vessels could be hitting the water with battery-electric or even hydrogen fueled systems.

Over the next several years, batteries will step up to the next weight class, with the construction and launch of much larger vessels in the passenger sector. In February this year, the first of two 140 m hybrid cruise vessels ordered by Hurtigruten at Kleven Verft hit the water. It's hybrid systems feature battery power to supplement auxiliary engines for peak shaving, whereby the battery responds dynamically to cover spikes in demand. This measure alone is predicted to cut fuel consumption by 20 %. And the second vessel will have batteries capable of sustaining fully electric operation for 15 minutes – possibly more.

Last year as well another milestone was reached with the order of »Color Hybrid«. With a length of 160 m, and a 2,000 passenger, 500 vehicles capacity, »Color Hybrid« will be the largest plug-in hybrid ferry after its planned delivery in 2019. Under construction at Norwegian shipyard Ulstein Verft the vessel will operate between Norway and Sweden. As a plug-in hybrid, »Color Hybrid's« batteries will be recharged either by means of a power cable with green electricity from shore, or by the ship's onboard generators and its bank of 4 MWh to 5 MWh batteries will deliver sufficient power to sail, silently and with zero CO_2, NO_x and SOx emissions for 30 minutes on full electric power.

The state of play in 2018

Batteries are still not a mainstream option for shipping – but the arguments for using electric or hybrid technologies are growing stronger every day. The typical use case for a hybrid or electric vessel is one that is typically operating in limited geographical areas on relatively short routes with frequent port calls. But over the next few years we expect hybrid technology, using batteries alongside traditional engines, to quickly grow and to encompass the majority of new vessels; particularly as more companies are gaining experience and new benefits and opportunities are being uncovered. And as the technology advances and stricter emissions regulations loom on the horizon, battery and hybrid solutions will become an increasingly interesting option for even larger vessels.

Author: **Benjamin Gully**
DNV GL

The »Vision of the Fjords«

Photos: Fjord1

Charging up for batteries

Battery technology has been installed on a variety of ship types so far, but for container shipping the use of batteries is at a nascent stage. Market leader Mærsk Line has been assessing the potential

Shipping moves 80 % of global trade and is the most energy efficient way of transporting goods. As such shipping plays a crucial role in creating growth, jobs and opportunities across the global economy. That said, and with the recent agreement made by the UN International Maritime Organisation (IMO) to reduce CO_2 emissions from shipping by at least 50 % in 2050, low carbon technologies are needed to ensure shipping can continue to fuel the global economy in a future low carbon world.Battery technology has been installed on a variety of ship types so far, but for container shipping the use of batteries is at a nascent stage. Batteries are of interest to the industry from both a technical and environmental perspective. Technically, batteries provide both flexibility and balance which, when utilized together, could be key to unlocking the potential of new methods of electri-

cal propulsion. Batteries can also decrease unnecessary fuel consumption and therefore reduce emissions. The opportunity to enhance power management, increasing efficiency and reducing emissions is intriguing.

Maersk has been assessing the potential for battery technology on container ships. Using granular data collected during the voyages of our vessels, maritime technology experts have been able to pinpoint and simulate how and when a battery could potentially be utilised. Af-ter reviewing the data, the team developed a simulation of the battery's operational profile, and evaluated the potential efficiency gains that could be expected. Analysis showed that batteries could be used in a variety of scenarios during a voyage, and that this would ultimately save fuel by allowing engines to operate at higher and more efficient loads. Batteries may also play a role in mitigating unnecessary emissions and potentially enhancing safety on vessels through the provision of an instantaneous source of backup power.

Although clearly a promising technology, the application of batteries in maritime transport is limited presently due to both price and capacity. Additionally, battery technology must be treated with considerable care in a vessel due to the extreme environment in which they would operate and the necessity of the technology to meet rigorous class approval safety standards. Subsequently, it may be a considerable period before we see batteries propelling Triple-E container sized ships across the oceans, but potential step changes in the technology, such the development of solid state batteries, could lead to wider applicability of batteries for a variety of new purposes from a maritime perspective.

With prices dropping and the technology improving exponentially battery technology could have a more significant role to play in meeting the ambitious targets set to cut CO_2 emissions. As with all new and promising technologies, Maersk is looking to cooperate with the wider maritime industry to realize and explore the potential of batteries and get charged up for batteries together.

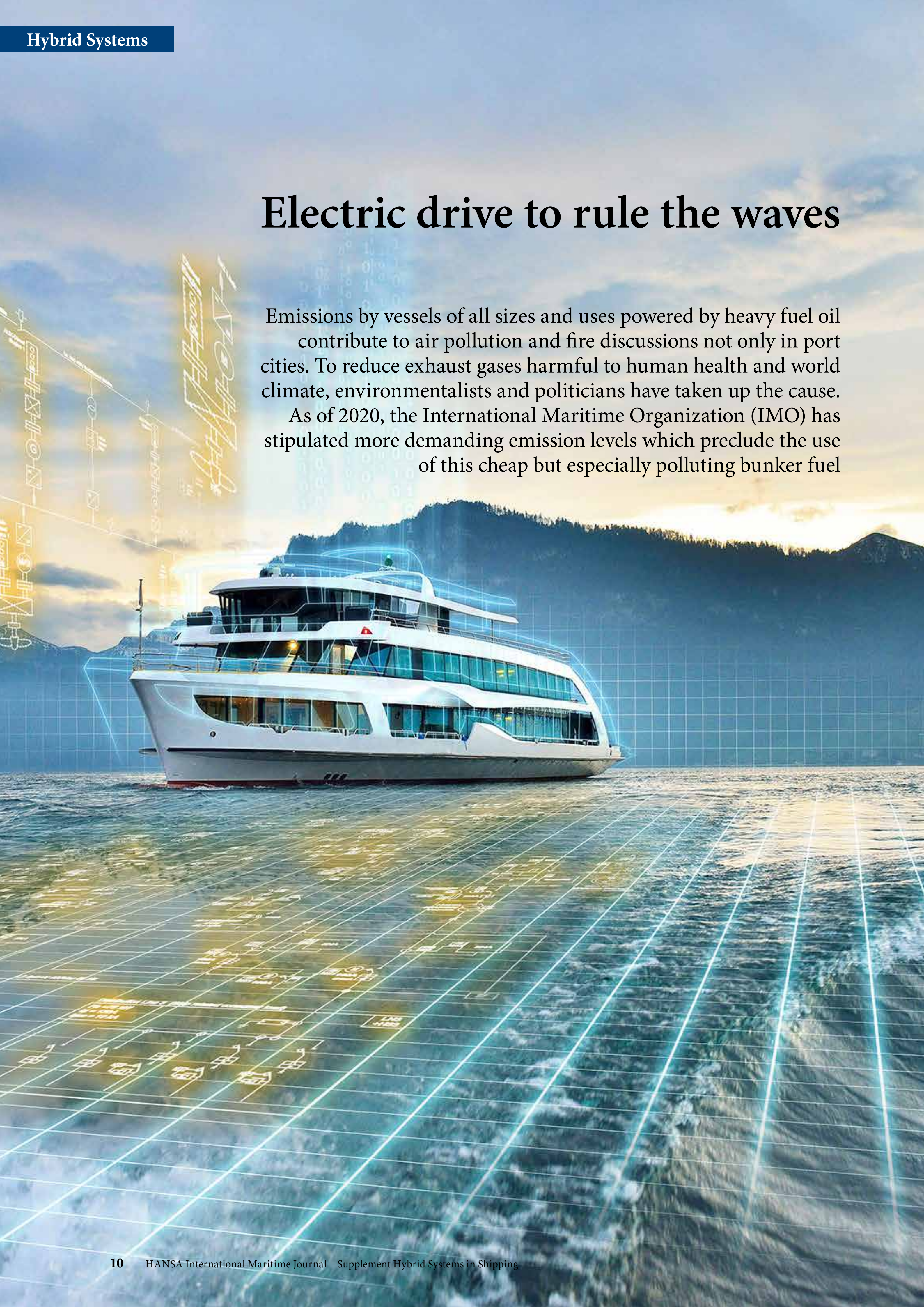
Author: **Andrew Mcintosh**
Senior Technical Innovation Project Manager
Maersk Line

It may be a considerable period before we see batteries propelling Triple-E container sized ships across the oceans

Photo: Maersk

Electric drive to rule the waves

Emissions by vessels of all sizes and uses powered by heavy fuel oil contribute to air pollution and fire discussions not only in port cities. To reduce exhaust gases harmful to human health and world climate, environmentalists and politicians have taken up the cause. As of 2020, the International Maritime Organization (IMO) has stipulated more demanding emission levels which preclude the use of this cheap but especially polluting bunker fuel



Photos: Siemens

By now, long-term technical alternatives are available that could already significantly improve the exhaust gas situation in ports today. In Hamburg, for example, the latest HADAG ferry »MS Elbphilharmonie« is equipped with a diesel-electric drive which turns the first ship of the new »Type 2020« series into an energy-efficient, low-emission and quiet vessel. This system delivered by Siemens for the electric part provides only as much energy as needed for each drive mode.

For over 10 years, the electric company has been working on environmentally friendly alternatives in shipping. The diesel-electric drive was constantly further developed during this time and has been installed aboard numerous, very different ships. »MS Diamant« of the shipping company of Lake Lucerne (SGV) also utilizes this technology. This vessel accomodates up to 1,000 passengers while the propulsion is based on the innovative parallel hybrid drive concept »SISHIP EcoProp«. This design is defined by two permanently excited synchronous electric motors by Siemens, each with an output of 180kW, operated as generators. Two additional diesel generator sets in the bow of the ship ensure the supply of the electrical system at high loads, e.g. at banquets on board. Thanks to the hybrid drive, the machines always run in the optimum range, thus saving up to 25% fuel during operation.

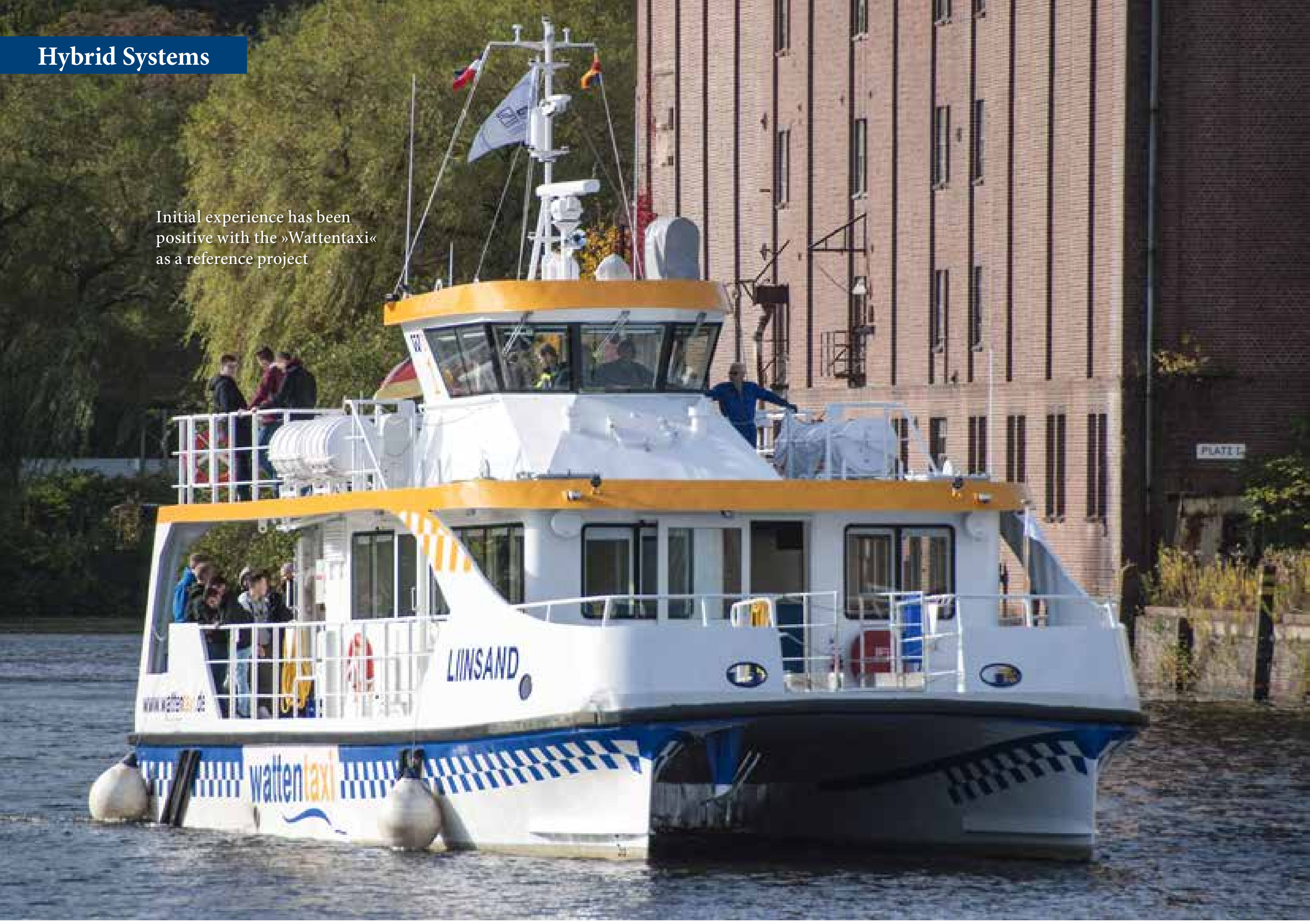
The world's largest hybrid-powered ferries also range among technology pioneers where a combination of diesel engines, electric motors and additional battery storage defines the drive concept. »Berlin« and her sister ship »Copenhagen« commute on the Baltic Sea between Rostock-Warnemünde, Germany and Gedser, Denmark. The Puttgarden-Rødby ferry service is also operated by several vessels which have been retrofitted with hybrid drive systems. These engines save at least 15% of carbon dioxide emissions.

First electric car ferry carries up to 120 vehicles

Hybrid drives are an ideal option for inland navigation as well as offshore. Siemens has already supplied such systems to a variety of ship types, including vessels used for offshore tasks. Meanwhile, the pure electrical mode for ships has been realized which is easily implemented on ferries with defined route lengths. Since 2015 car ferry »Ampere«, which travels the Norwegian Sognefjord silently and without emissions, gives proof of this. The world›s first all-electric ferry departs 34 times a day and takes 20 minutes for the route of 6 km. The 80 m ship is powered by two electric motors with 450 kW each which obtain their energy from lithium-ion batteries. The combined capacity of 1,000 kWh lasts for several trips, and the batteries are recharged during every ten-minute stop at port. Since the local power grid at the Sognefjord is relatively weak, two additional batteries in the ports serve as buffers. Because the power is generated entirely from hydropower, the solution is particularly environmentally friendly.

At least 50 more ferry services in Norway alone could be switched to electric mode, by 2050 at the latest, all car ferries in the fjords are scheduled to run on battery power. Given this background, Siemens envisages a great future for hybrid and electrically powered ship types. That is why the company has started the production of battery systems for electric marine propulsion systems in Norway at the Trondheim plant. Testing is already under way. With these developments, the company can go back to its roots – as early as 1886, Werner von Siemens had caused a stir with the »Elektra« accumulator boat on Berlin's river Spree.

Author: **Martin Wünsch**
Siemens



Initial experience has been positive with the »Wattentaxi« as a reference project

Positive experience with Becker Marine Systems' »Cobra«

The market for alternative propulsion systems is experiencing continuous growth. Hamburg-based Becker Marine Systems response to this is a separate product division, in which the »Cobra« battery system is being developed

Becker Marine Systems' new production facilities are located in Winsen an der Luhe. On the outskirts of Hamburg, the expert for high-performance rudders and energy-saving solutions in the field of maneuvering technology has been developing the »Cobra« maritime battery system for a year now. Approximately 15 new jobs for the production of efficient batteries based on lithium-ion cells have been created thus far.

The name »Cobra« is an acronym for »Compact Battery Rack« and can be supplied as a separate system or combined with hybrid drives. »The name says it all, we want to offer a very compact battery system for the maritime market,« says Godehard Gauf, Director of Battery Systems, the up and coming product division at Becker Marine Systems. »Cobra« is not only lighter and more compact than those offered to date by conventional battery suppliers, it is also easy to install on board, he adds.

»We want to produce the smallest system possible on account of the normal lack of available space in machine rooms«, says Gauf. In addition to functionality, weight and size, however, the challenges in developing a new battery system also include issues such as safety, service life and price. The many enquiries coming in confirm that Becker Marine Systems is on the right path and can stand out positively from the rest of the market. Many tests with prototypes under full load have already been conducted at our own facilities. These tests, including FAT acceptance as part of production, can be performed on the specially developed battery test stand.

In principle, the »Compact Battery Rack« can be used on all ships, such as in offshore supply, for harbour and workboats or for passenger ships and car ferries. It may also be of interest for larger cargo ships, particularly for newbuildings over the long term. The focus is on hybrid or all-electric drives as well as on compensation for load fluctuations (»peak shaving«). The market for this is growing strongly – and not just in countries like Norway where all-electric drives are subsidized.

The »Wattentaxi«, in which the »Cobra« battery system is already in use, has also become a successful project for Becker Marine Systems. Gauf talks about the launch of the »Wattentaxi« on the North Sea: »For the first time, locals and visitors to the region are now able to organize travel between twelve ports on their own.

The modern ship operated by Watten Fährlinien impresses with its high level of environmental friendliness.« Asked for the part »Cobra« plays in this, he adds »The Wattentaxi uses a redundant parallel hybrid drive system with two diesel engines and two battery systems. It can be operated both fully electrically or by diesel. Last summer we outfitted the Wattentaxi for this and used the autumn and winter for further development and sea trials. It has been in regular operation on the North Frisian Wadden Sea since spring 2018. Cobra is fully functional and we are getting very good feedback.«

According to Gauf, the goal of more environmentally-friendly ship operation is being achieved by both diesel engines with particulate filters and high-performance batteries for low-emission use. »The prototype for Cobra deployment more than exceeds all current and planned IMO Tier III requirements from the International Maritime Organization,« he explains.

»Cobra« is being produced in Winsen an der Luhe

Photos: Becker Marine Systems

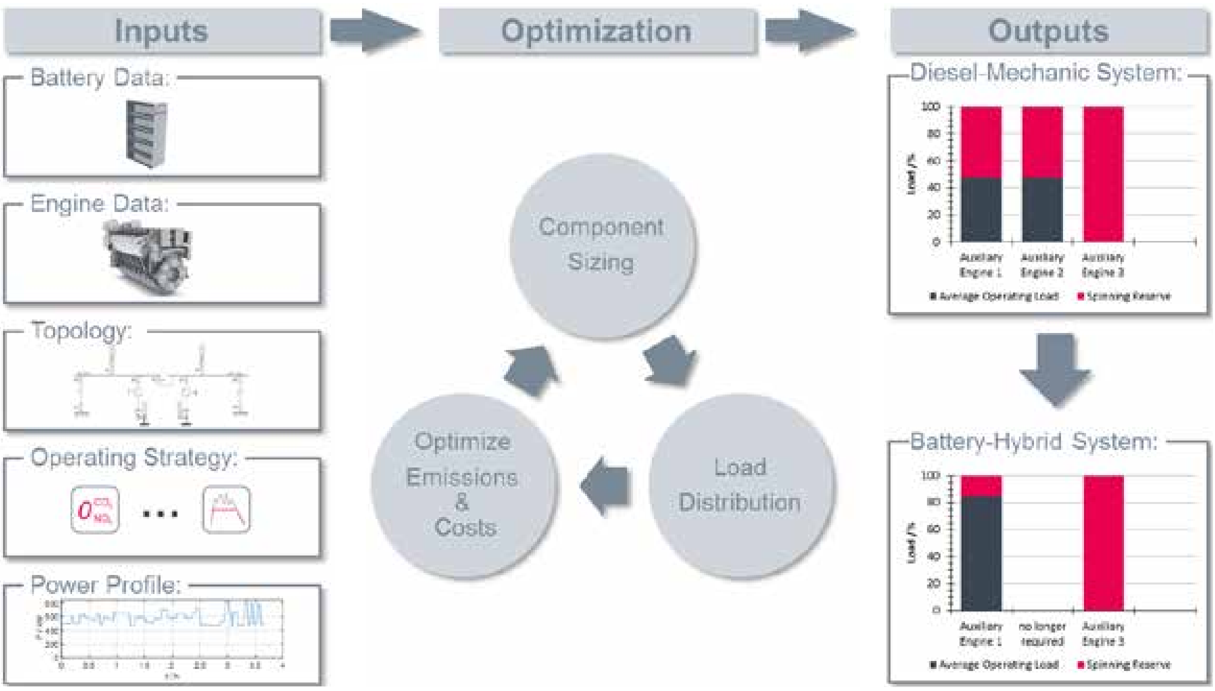
Battery-hybrid vessels: optimized sizing to fit the application

MAN Diesel & Turbo shows its optimization tool for hybrid systems – with a load profile and a comparison of the resulting conventional as well as battery-hybrid. Positive use cases for battery-hybrid systems are given not only for commonly referenced applications such as ferries but many further applications as well

As IMO indicated in its third greenhouse gases study (2014), total shipping accounts for approximately 2.5% of the overall greenhouse gases in 2012. Furthermore, marine-related CO_2 emissions are projected to increase significantly in the future scenarios due to growing sea trade.

Battery-hybrid systems are a promising new technological approach to mitigate the emissions increase in the marine sector and ultimately contribute to the vision of a CO_2-neutreal world. The energy storage system acts as spinning reserve and peak shaving entity to optimize the engine operating point. It can furthermore improve emissions during transient engine behavior at high load steps or during start-up. Moreover, especially local emissions in emission control areas can be tremendously reduced by battery only mode and cold ironing at harbors enabling emissions free operation.

As shore connections to recharge battery systems are still rare, batteries are mainly recharged by the onboard engines. This results in the need for an optimized sizing



of engines and batteries based on load profiles in order to achieve an economically and environmentally beneficial hybrid system. In that, the overall system architecture as well as the parameters defining the individual components such as efficiency curves and aging behavior have to be taken into account. Considerations can either be focused individually on the propulsion power or the hotel load, or on optimizing the overall energy supply system.

Figure 1 shows the structure of MAN Diesel & Turbo's optimization tool. Next to component data such as battery aging or the engine efficiency profile as well as the system topology (diesel-mechanic/electric, ac-grid/dc-grid, …) are handed over as input parameter. Moreover, the operating strategy is defined depending on the particular power profile. Based on an initial component sizing, the load is ideally distributed among engines and battery on a given route in order to minimize emissions and costs. In that, operation and maintenance as well as battery aging are taken into account. The overall optimized system configuration is derived by adapting the system configuration with regard to e.g. amount of cylinders, battery size or battery operating window in the loop.

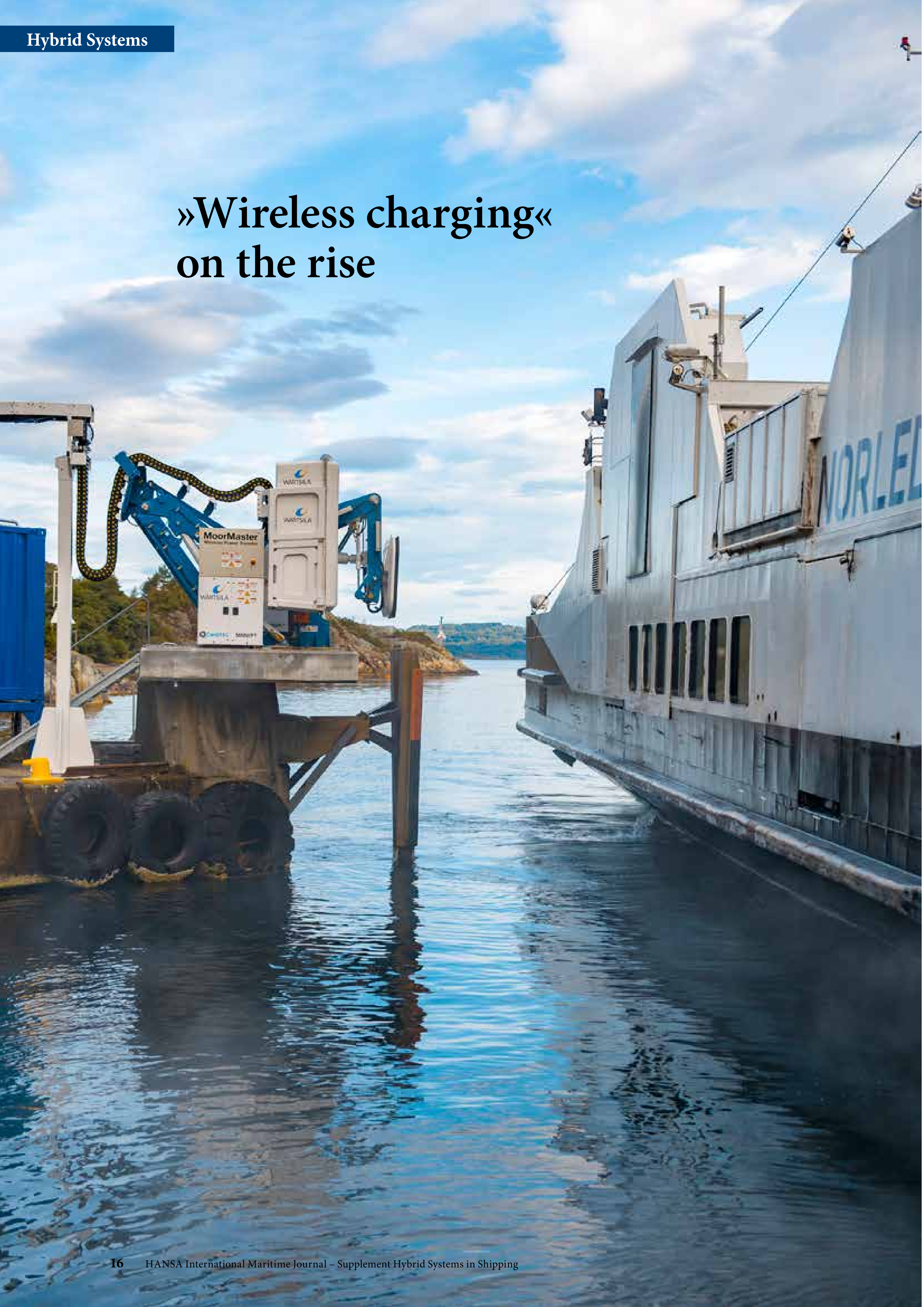
The hotel load of a bulker during harbor operation is investigated to highlight the achievable saving potential of a hybrid system. A corresponding load profile and a comparison of the resulting conventional as well as battery-hybrid system are shown in figure 2. The conventional diesel-mechanic system consists of three 5L23/30H auxiliary engines, each delivering 710 kW in an n+1 configuration. Thus, two engines are running on average at a part load of only 43 %. Maintaining an n+1 configuration also for the battery-hybrid system, the average load of the running engines increases to 85 % with the battery system acting as spinning reserve and peak shaving entity. The state-of-charge of the 0.38 MWh battery system only varies in the range of 73 to 86 % during peak shaving and thus a sufficient spinning reserve can be guaranteed at all times. This further allows running on one engine only. Reducing the number of the required engines by one with regard to initial installation and maintenance, results in a commercially and from the emissions point of view beneficial system configuration.

The given example shows that positive use cases for battery-hybrid systems are given not only for commonly referenced applications such as ferries but many further applications as well. A detailed investigation of the overall energy demand can result in reduced emissions and positive business cases in all areas of shipping and is the base for a successful transition of the sector.

Authors:
Susanne Lehner, Carina Dormann, Alexander Knafl
MAN Diesel & Turbo

Source: MAN Diesel & Turbo

»Wireless charging« on the rise



The world is moving towards a future that is more and more connected and this is already apparent in the shipping industry. The opportunities offered through smart technology are fostering a new era of collaboration and knowledge sharing with customers, suppliers and partners

The system was successfully tested with the ferry »Folgefonn«

Finnish technology group Wärtsilä emphasizes to be fully engaged in developing »intelligent« vessels since such technologies are considered vital to maintaining a profitable future for ship owners and operators. Wärtsilä's »Smart Marine Ecosystem« vision foresees a future wherein smart vessels will be sailing between smart ports at optimal speeds over optimal routes and with minimal loss of delays through ship traffic congestion.

New technologies that were considered completely unachievable just a few years ago are rapidly being introduced, creating new levels of efficiency and cost savings that are influencing the future of shipping. Nowhere are these developments more apparent than on the »Folgefonn«, an 83 m ferry owned by leading Norwegian operator Norled. The ferry was built in 1998 and fitted with conventional diesel power. In 2014, it was retrofitted into being a plug-in hybrid vessel combining diesel engines with batteries and charging from shore. By converting the energy system into a hybrid system, significant overall energy efficiency gains were achieved since the engines could be run at optimal load. Wärtsilä's contribution to the project has been the concept development, including the inverter systems, the hybrid control, the battery package and systems, the power transfer and land-based energy storage system, as well as the integration of the onboard systems.

Wärtsilä, with support from Norled and part funding from Innovation Norway, a Norwegian funding institution, then in 2017 successfully tested its automatic wireless induction charging system on the »Folgefonn«. The ferry thus became the first commercial ferry in the world operating with high power wireless charging capability for its batteries.

Wireless charging eliminates the cable connection between the vessel and shore, thereby securing and facilitating safe connections and disconnections. It also reduces maintenance since the usual wear and tear to physical connection lines is eliminated. The integrated Wärtsilä system is based on inductive power transfer and is capable of transferring more than a MW of electrical energy.

The system is designed to maintain efficient power transfer at distances up to 50 cm between the two charging plates built into the side of the vessel and the quay. No other wireless charging system is as powerful, or capable of maintaining the transfer of energy at such a distance.

In cooperation with engineering group Cavotec, Wärtsilä has combined its inductive charging technology with Cavotec's vacuum mooring system to enable automatic mooring, and this too has been successfully tested on the »Folgefonn«. The mooring system allows the ferry to maintain a steady position, while the main propeller can be stopped during docking to reduce energy consumption.

The latest in this series of innovations introduced for this ferry is Wärtsilä's autodocking technology – again a world first. The technology is said to deliver notable benefits since there is less likelihood of human error, less wear and tear because the thrusters are optimally utilised, and greater efficiency in docking which allows more time at berth. *RD*

The 2 x 68 kWh Li-Ion EST-Floattech Battery system with battery management system

Photo: Danfoss

»Vacon DCGuard« protects DC grids

On board hybrid ships, DC grids help reducing system losses compared to AC grids. But they are more difficult to design for safe short circuit protection and to limit the short circuit energy requires more sophisticated protection devices

There is no doubt today, that hybrid propulsion and power generation systems help make a vessel extremely energy efficient compared to classic pure diesel-mechanical driven systems. But integrating electrical systems on board is also demanding and it calls for the right Know-how to master the perfect and hassle-free interaction of the systems: DC grids can be much more energy efficient regarding system losses. But a short circuit current in a AC system will pass through zero Amps twice each period (100 times @50Hz). Basically, what's happening inside an AC circuit breaker is that the short circuit is being cut off when it passes through zero Amps. A short circuit in a DC system will never pass through zero Amps. It will in very short time become very high, and stay high as long as there is energy available to feed the short circuit. If a traditional (slow) circuit breaker is used to cut off a DC short circuit current the result may be an arc inside the circuit breaker which can damage the whole system and protection selectivity can be difficult to achieve.

Fast cut-off in microseconds

In addition, there is a common requirement in marine that a failure in one part of the system shall not affect the whole system. To solve that requirements, a fast DC-current tie-breaker is needed to isolate the healthy part from the faulty part. Today such a product is not available as a standard component on the market. For that purpose, the Vacon DCGuard is a semiconductor protection device that can detect and cut off any DC faulty currents and isolate the faulty part of the system in microseconds. In case of a short circuit, the DCGuard will disconnect the faulty DC bus from the healthy DC bus so the remaining grid will maintain fully operational. During the fault the feeding DC grid will see only a small dip in DC voltage. The DCGuard is already marine type approved by DNV GL and covers the whole range from 3A to 4140A. The type approval is useful when asking for system approval as there is as of today no relevant standard for such application as DCGuard.

Technology already proves its reliability

On the IJ River GVB´s (public transportation company of Amsterdam) hybrid ferries powered by VACON drives enjoy 24/7 uptime, smaller generator size and therefore help improve air quality, produce less noise and deliver easy maneuverability. GVB has a policy of reducing the emissions and environmental impact from its ferries, trams, buses and cars to an absolute minimum. So, when GVB ordered two new ferries from Holland Shipyard they decided to use battery hybrid technology to improve fuel efficiency and reduce pollution.

Peak shaving reduces generator size

The ferries operate 24 hours 365 days per year. It takes about four minutes to cross the IJ River and the ferries are docked for only about 2 minutes before departing on the next trip. A 100 % battery-powered electric ferry was not possible as the time spent docked in port was too short to charge the batteries from a shore power connection. Instead, GVB decided to use electric propulsion with diesel-powered generators and Lithium-Ion batteries to shave the power peaks. This allowed them to downsize the generators, as these batteries enable the generators to run very efficiently with an almost constant load. To reduce the remaining air pollution the diesel engines are fitted with efficient exhaust gas cleaning systems, also known as SCR (selective catalytic reactor), which remove toxic gases and particles.

To help improve performance by making better use of energy, hybridization combined with energy storage is increasingly being introduced into marine systems. DC/DC converters can be used to connect sources such as batteries, super capacitors, fuel cells and solar panels. To protect the DC grid, an extremely fast circuit breaker is indispensable.

Author: **Helge Vandel Jensen**
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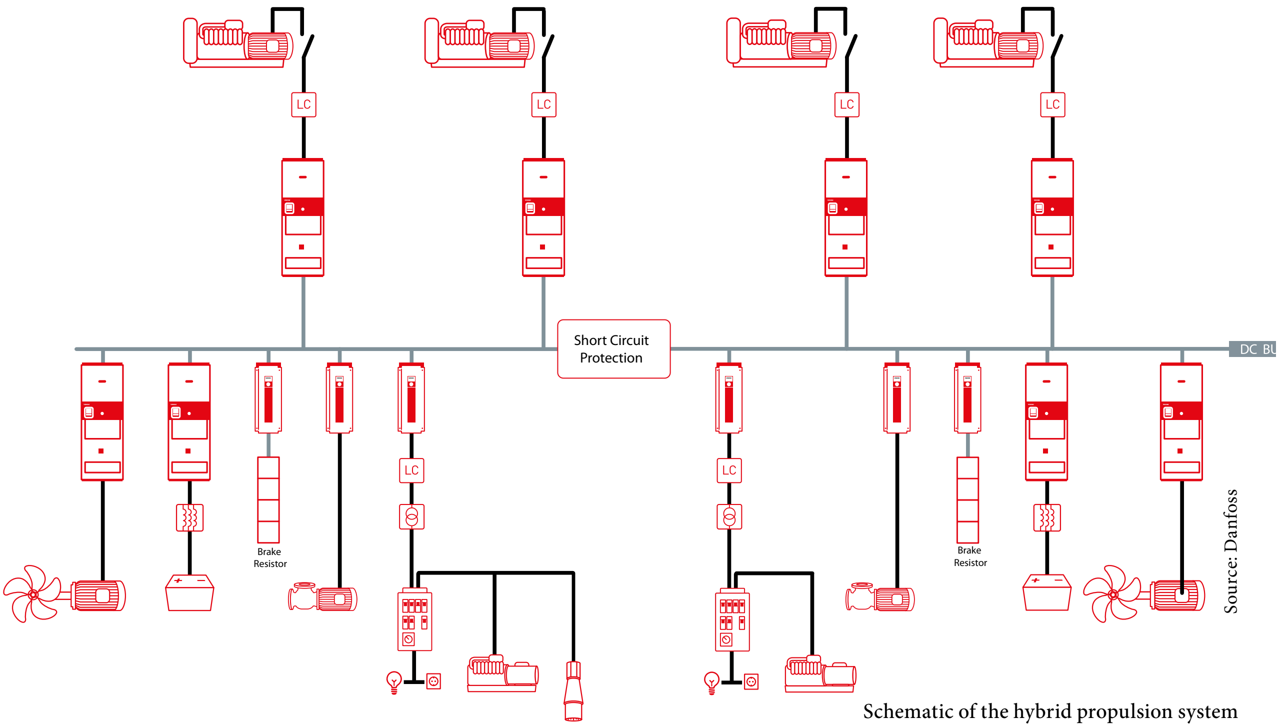
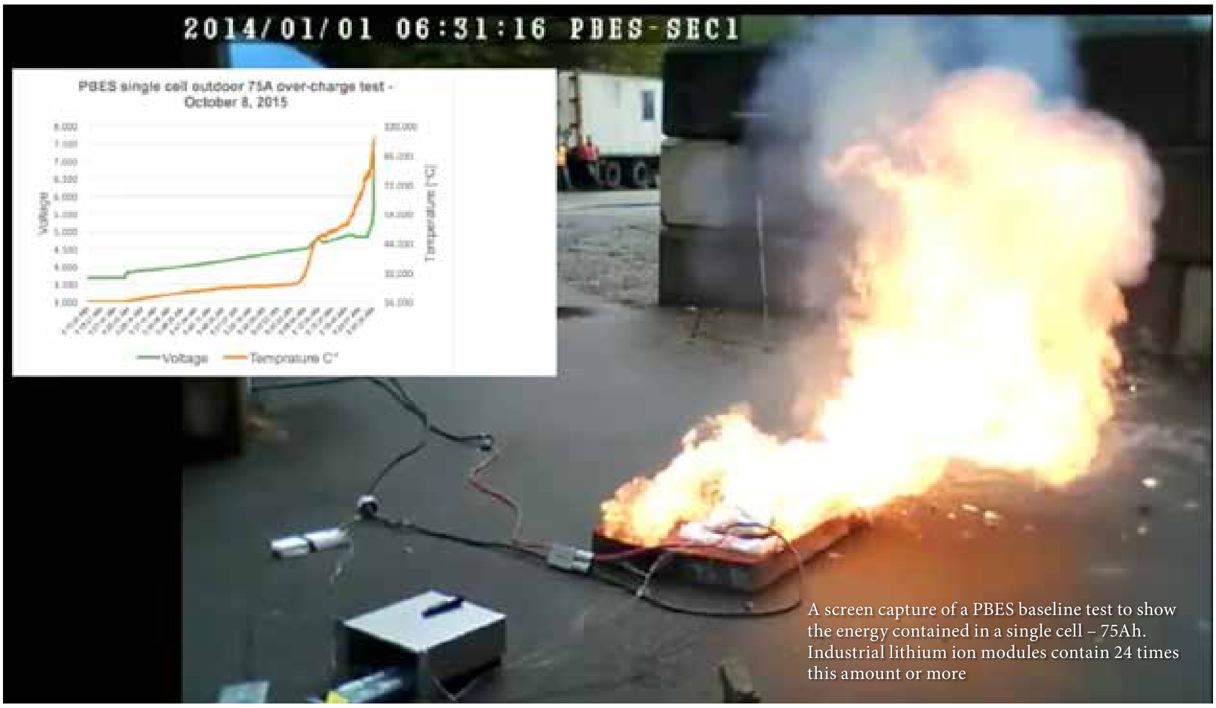


Source: Danfoss

Schematic of the hybrid propulsion system



A screen capture of a PBES baseline test to show the energy contained in a single cell – 75Ah. Industrial lithium ion modules contain 24 times this amount or more

Safety concerns for hybrid & electric ships – is the industry doing enough?

Each year there are more hybrid or fully electric ships navigating waters worldwide. These ships increasingly rely on lithium energy storage as their power source, with modern designs containing over 1,000 individual modules (batteries). The technology has proven itself reliable and powerful, however safety concerns still linger.

As a member of the first team that brought energy storage to large marine projects, here is what is lacking in the industry and how we will improve safety.

Current Testing & Certification Failings

One of the biggest risks for batteries is thermal runaway. Thermal runaway occurs if the lithium-ion cells used in marine batteries are subjected to mechanical abuse, suffer from internal manufacturing defects, or operate over or under the correct voltage or temperature, heat is generated within the lithium-ion cells and causes a reaction. This can result in the cells' temperature increasing until the cell vents toxic and flammable gases are emitted. If ignition occurs, these gases can create an unpredictable fire, which can be very difficult to extinguish.

The minimum requirement by the Norwegian Maritime Authority for batteries used in commercial vessels in Norway is the Propagation Test Type 1. This test simply means that if a cell in a single module enters thermal runaway and ignites, fire will consume the module but will not ignite the other modules, and thus the larger system remains safe. Approval is granted when a single module in a battery pack is tested in a lab situation by putting it into thermal runaway and the adjacent modules in the pack do not ignite. However, the likelihood that only one cell or module in the pack be affected by itself is extremely unlikely.

It is much more probable that a) the entire system was damaged or b) any number of individual modules were damaged. In a multi module event, it is my assertion that NMA Propagation Test Type 1 may not prevent propagation from module to module. In my opinion, this renders Propagation Test Type 1 an ineffective method to ensure the safety of the vessel.

Currently there are many battery solutions on the market that use an air cooling system in an attempt to try to maintain safe internal temperatures. The effectiveness is questionable and the reliance on a thin-layer fire-resistant separator between cells only reduces the fire risk from thermal runaway – it does not prevent it. Almost all of these manufacturers claim this »inherent« and »passive« system prevents propagation from one module to the next. This is the minimum requirement by the Norwegian Maritime Authority Propagation Test Type 1 for batteries used in commercial vessels in Norway.

I assert that adherence to this standard alone endangers the vessel, crew, passengers, cargo and environment.

The Solution – Prevent Thermal Runaway

Liquid cooling is the only safety system currently tested and proven to prevent thermal runaway. It prevents batteries from entering thermal runaway by simply extracting more heat than the cells can produce. PBES has developed a proprietary cooling system, CellCool that takes the idea one step further and circulates coolant through the alloy core of the battery, around each individual cell in every battery. Testing shows that the PBES system is so effective that is works even if the coolant pump is disabled, meaning that in the event of catastrophic damage to the vessel, the system will still protect the batteries. Due to its patented design, CellCool also eliminates hot spots on the cells and maintains optimal cell temperature thus increasing lifespan.

In comparison, forced air cooling only cools the external surfaces of the module. An air-cooled battery requires around 3500 times more air flow volume than water flow volume to achieve the same heat removal. To try to compensate, the battery room for an air-cooled system requires a robust HVAC system, a misleading extra cost.

Thermal Barriers and Venting

Effective internal thermal barriers are an essential part of lithium battery safety systems. PBES Thermal-Stop is a metal barrier integral to the structure of the battery that works similar to a firewall. It prevents an overheated, overcharged or damaged cell from propagating to the adjacent cell. The event is therefore isolated to one cell and does not affect the others. Ignition will not jump to adjacent cells because of the metallic barrier between them.

Cooling System Disabled:

Screen capture of a PBES thermal runaway test with the cooling system disabled. Graph shows the voltage and temperature as it increases to cell failure, and subsequent cooling. No thermal runaway event occurs.

E-Vent is a PBES patented system to vent flammable gases from a damaged module safely away from the battery area. It reduces risk of a secondary explosion and allows the crew to re-enter the vicinity of the battery system sooner to make repairs and restore power. The image above shows the prototype vent tube of the PBES E-Vent system in testing. In all of PBES' testing to date (observed by independent third parties) no measureable amount of gas could be captured. Using the PBES CellCool system, the cells simply do not combust.

Will it happen on your watch?

Given the rapid uptake of the use of large format lithium-ion batteries in commercial marine vessels, I believe that energy storage system safety is lacking. Current standards leave significant potential for hazardous situations to arise. Unfortunately, the majority of the industry has responded to price pressure from owners and operators by reducing costs and subsequently, safety systems to meet the bare minimum of requirements. In the interest of hastening the adoption of energy storage in industry, PBES has always been willing to licence its safety systems. This will help those who wish to go beyond the minimum requirements and help move the clean marine industry forward. For now, the industry may have to suffer the consequences of inaction.

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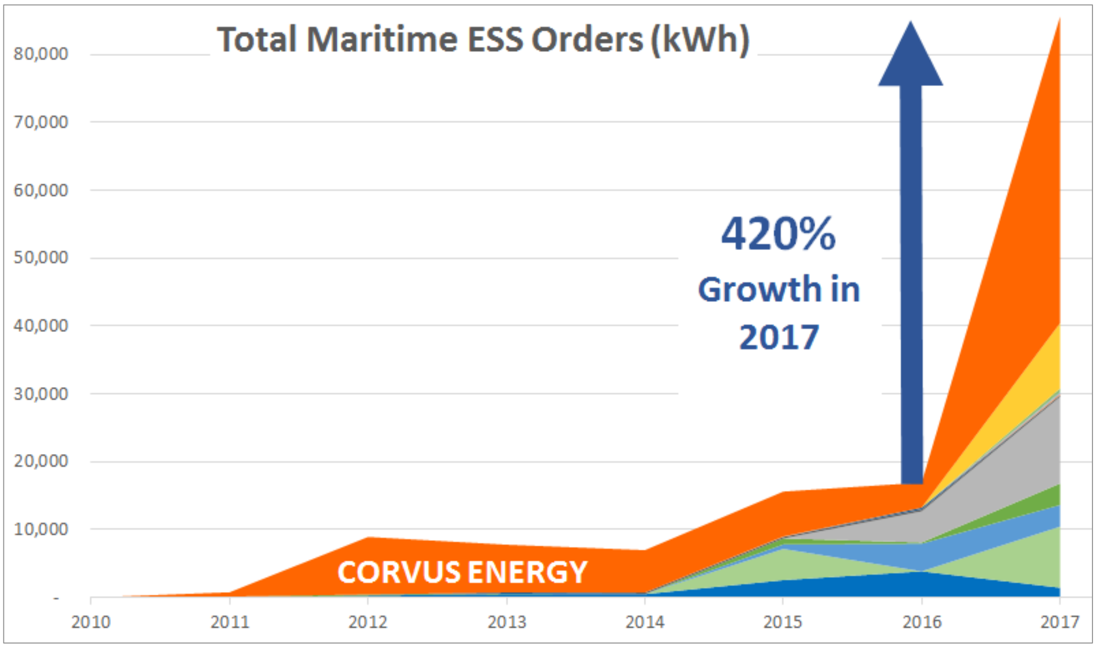
Proven technology, economic viability

Conditions are ripe for rapid growth in electric and hybrid marine technology. The world market for maritime ESSs grew 420 % last year

For the past five years, ship owners, charterers, maritime authorities, coastal governments and marine technology suppliers have strategically invested R&D dollars into clean technologies and operational trials aboard both newbuilt and retrofitted vessels. We now understand the capabilities of these technologies to reduce fuel consumption, emissions and noise.

Battery-based Energy Storage Systems (ESS) have been at the heart of electric and hybrid energy sources for propulsion, backup power and house loads. We will look back on 2017 as a breakout year for the electric and hybrid marine technology industry. The world market for maritime ESSs grew an astounding 420 % in terms of energy capacity. Corvus will supply over half of ESS capacity ordered – a total of over 45 MW.



Some examples for Corvus' projects are:

- »North Sea Giant«, the first hybrid DP3 vessel –expected fuel savings is two million litres yearly
- »Viking Princess«, the first PSV to remove a generator and replace it with an ESS
- Seacor Marine PSVs, which will be the first hybrid PSVs to operate in the Gulf of Mexico
- Wärtsilä-designed hybrid fish farm processing and transport vessel, an industry first
- »Stena Jutlandica«, which will be the first Swedish ferry to operate emissions-free in harbour
- »Ampere«, the first all-electric ferry in the Norwegian fleet – one million litres of fuel not consumed yearly

Understandably, the industry proceeded cautiously for almost a decade, testing various technologies, collaborating with suppliers and maritime authorities to minimize risk and maximize performance. Hybrid and all-electric applications were tested one vessel at a time, systematically verifying performance, safety, and economic benefit.Now we're seeing the results – and they're good. Emissions reductions are as promised. Crew acceptance is better than expected. Fuel and maintenance savings are accumulating year after year, leading to quick investment payback in many applications. In conjunction with significant cost reductions in lithium-ion battery cells, the economics are now quite attractive. We'll see ship owners make decisions about the rest of their fleets in 2018-2020, and there's hardly a newbuild that will not have an ESS. The 100+ Corvus ESSs in the marine industry now total over 75 MWh and 1.5 mill. operating hours.

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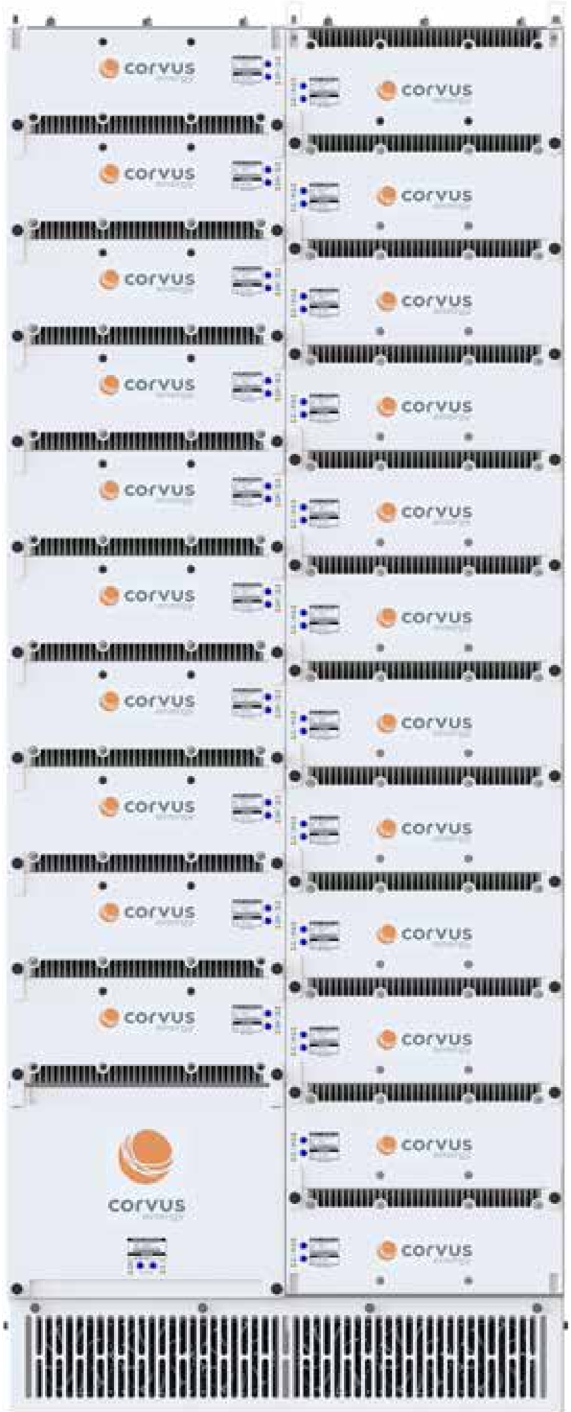

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