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Charting a Course: Batteries in the Maritime Industry

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Low-carbon energy technologies such as ammonia, batteries, e-fuels, biofuels and hydrogen fuel cells are rapidly gaining traction in the maritime industry. Heavy fuel oil will soon no longer be the primary choice for propulsion. Battery technology is an important part of the mix, offering energy efficiency, reduced emissions and improved performance for smaller vessels, with hybrid solutions emerging for longer distances and international shipping. The UK can be at the forefront of these developments but must invest in port and charging infrastructure.

Introduction

The global maritime industry facilitates the movement of goods, people and resources across oceans, seas, lakes, rivers and inland waterways. With over 80% of global trade by volume transported by sea,[1] the maritime industry is a critical component of the global economy. However, the maritime industry is currently heavily reliant on fossil fuels to power ships and is considered a hard-to-abate sector. The industry encompasses navigation, shipping and marine engineering and utilises a wide range of vessels for specific sub-markets.

The maritime industry is currently responsible for approximately 8% and 3% of UK and global carbon emissions respectively. With global trade projected to double by 2050,[2] and maritime transport expected to continue dominating global freight transportation, alternatives to fossil fuels need to be developed. Potential alternatives to oil-based fuels include natural gas, battery-electric propulsion and low-carbon fuels.

The UK's maritime sector is also an important part of the wider UK economy, contributing £19 billion in gross value added and supporting around 227,000 jobs.[3] The International Maritime Organisation aims to reduce carbon emissions in the sector by 50% by 2050 compared to 2008 levels.[4]

This insight explores the alternative technologies for the maritime sector, including hydrogen, natural gas, battery-electric propulsion and other low-carbon fuels, and assesses the size of the battery-powered maritime market. The specific performance characteristics of battery technology for different applications across the maritime sector are outlined, and proposed actions to develop and support the UK maritime industry are also highlighted.

As battery technology continues to advance, full electrification is becoming particularly suited for short routes and vessels such as short-haul ferries, coastal ships, recreational boats and inland waterway craft. For longer distances, hybrid systems are emerging that combine batteries with other fuels to enhance energy efficiency and operational flexibility.

*Image courtesy of Artemis Technologies. The Artemis EF-24 Passenger is a 100% electric foiling passenger ferry.

1 UNCTAD (2018). Review of Maritime Transport 2018.
2 Department for Business and Trade (February 2023). Global trade outlook.
3 CEBR (2022). State of the Maritime Nation 2022.
4 International Maritime Organisation (2022). Update on IMO's work to address GHG emissions from international shipping.

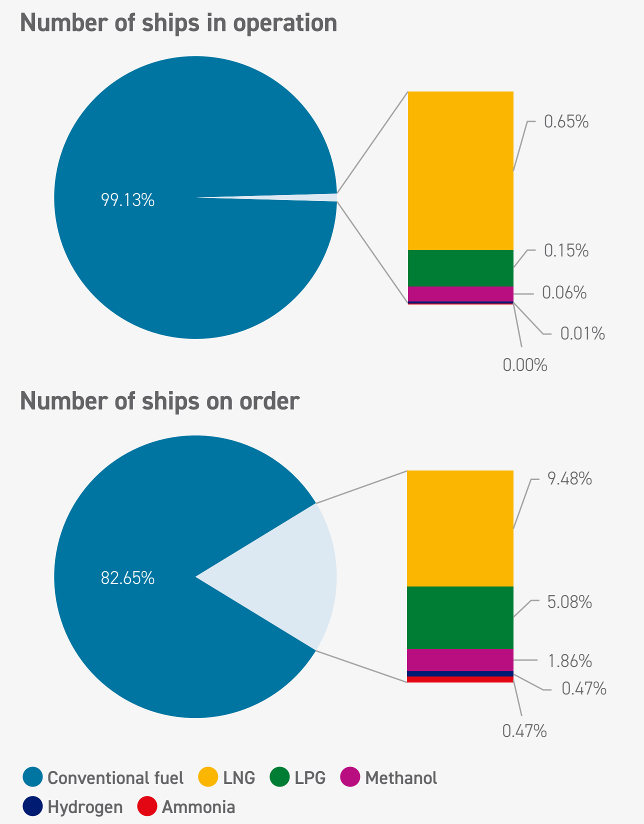
The Maritime Industry

The maritime industry is dynamic and continues to evolve as transport and trade patterns change around the world. It covers a broad range of transportation, commerce and leisure activities. This includes large companies (such as commercial shipping lines, cruise lines and ferry operators), small organisations (such as fishing boats and inland waterways) to individuals using boats and canals for residential and leisure purposes. Examples of the different types of vessels and uses include:

- Shipping: Movement of goods and cargo by sea using bulk carriers, large container vessels and roll-on roll-off (Ro-Ro) ships. The industry transported 11 billion tonnes of goods in 2021, including raw materials, crude oil, oil products, coal, fuels, chemicals and manufactured goods.[5]
- Ferries: Transportation of passengers, vehicles and cargo across fixed timetables and routes. Ferries range from small passenger vessels to large car/passenger ferries (Ro-pax) and as a means of transportation for commuters, tourists and goods.
- Cruise ships: Large passenger vessels focused on leisure and the tourism industry, typically operating on longer routes with multiple destinations in a single trip.
- Offshore vessels: Large and technically sophisticated vessels, typically used in industries such as the offshore oil and gas industry. These ships can be used for the transportation of goods and people, construction/maintenance of offshore infrastructure, exploration and drilling.
- Support vessels: Vessels used to support larger ships when operating in and out of ports including tugboats and refuelling barges.
- Fishing vessels: Boats or ships used for commercial fishing operations, ranging from small boats used for inshore fishing to large trawlers that can process fish at sea.
- Canal boats and barges: Narrow and shallow vessels designed for use on inland waterways, used for leisure travel and residential habitat and transporting bulk goods and materials.
- Recreational boats: Small vessels (ranging from small dinghies to large yachts) that are designed for use on lakes, rivers and other inland waterways and typically used for recreation and transportation.
- Unmanned vehicles: Autonomous marine drones used for specialised underwater or surface operations. Unmanned underwater vehicles rely heavily on batteries for deep-sea endurance, while unmanned surface vehicles need high power for surface activities.

The vast majority of ships in operation today use conventional fuels, which include heavy fuel oil (HFO), light fuel oil (LFO) and marine diesel oil (MDO). These fuels are used to power a vessel's main engine and auxiliary on-board power systems. The auxiliary power systems feed into a vessel's electric grid to support processes such as refrigeration, lighting and cargo pumps. However, alternative fuel sources such as liquified natural gas (LNG), liquified petroleum gas (LPG) and methanol are increasing in popularity (Figure 1).

Figure 1: Number of ships in operation and on order by fuel type globally



The number of ships on order using alternative fuel sources is expected to rise, displacing conventional fuel sources.

Source: Alternative Fuels Insight – DNV (Data as of January 2025). The views stated in this Insight are solely those of the Faraday Institution and do not necessarily represent the views of DNV.

The maritime industry is also supported by port infrastructure serving as the intersection between sea transport and land-based logistics. Ports facilitate the docking of ships, the exchange of cargo and refuelling operations. Although extended stays in port may be required during maintenance, the time spent in port is usually short. The average duration of a port call in 2022 was 36.3 hours, with 70% of that time being spent docked.[6]

Transition to Low-Carbon Fuels in the Shipping Industry

Potential for low-carbon fuels

The shipping industry has historically relied on oil-based fuels for propulsion due to their low cost and availability, with

[5] UNCTAD – Handbook of Statistics 2022.
[6] World Bank Group. The Container Port Performance Index 2022.

HFO accounting for 50% of global shipping fuel consumption, 32% from LFO, 12% from MDO and 6% from LNG.[7] Between 2019 and 2020 there was a notable decrease in HFO consumption (which is high in sulfur) towards LFO and LNG due to the International Maritime Organisation (IMO) 2020 regulations that limited the sulfur content of fuel oil on ships.[8] Switching to lower-sulfur marine fuels reduces sulfur dioxide emissions, which helps decrease air pollution and acid rain, while minimising the formation of harmful particulate matter, thereby improving air quality. Additionally, low-sulfur content fuels decrease acidic corrosion in engine components, leading to longer engine life and reduced maintenance.

The shift towards alternative and cleaner fuels is expected to continue as the sector decarbonises, with the following expected to replace traditional fuels:

- Ammonia: This is a carbon-free fuel that can be produced using renewable energy sources, with a growing interest in producing ammonia using hydrogen from renewable sources;
- Batteries: Electric (and hybrid) battery systems are increasingly being used in both smaller and larger vessels, driven by improvements in battery performance and efficiency;
- LNG: A fuel with lower environmental impact than traditional fossil fuels, producing almost no sulfur oxides and less nitrogen oxide, as well as lower carbon emissions particularly when sourced as bio-LNG;
- E-fuels: Synthetic fuels, such as e-methanol, produced using renewable electricity, water and carbon dioxide;
- Biofuels: Fuels made from organic matter, such as crops or waste, which can be used alone or blended with traditional fuels; and
- Hydrogen fuel cells: Production of electricity by combining hydrogen and oxygen.

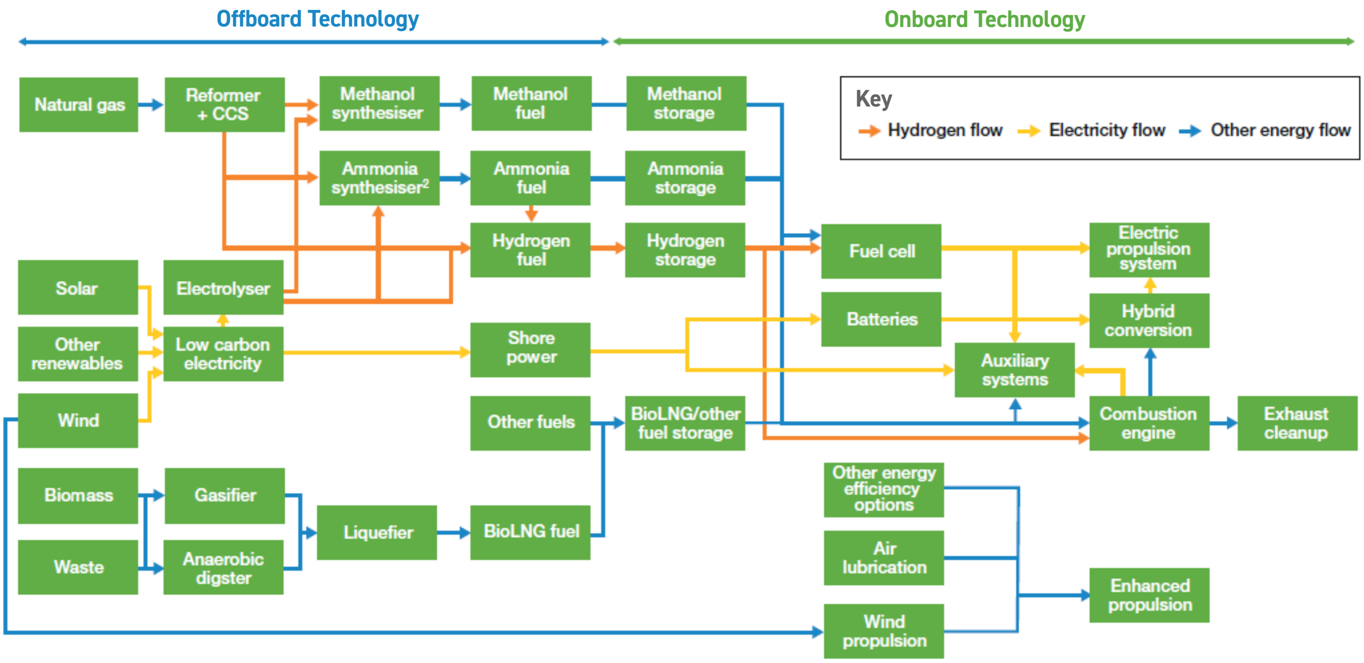
The supply chains for these fuels are outlined in Figure 2, highlighting how hydrogen, electricity and other forms of energy could be produced, stored and converted across different stages to support a zero-emission shipping industry. It also shows the complex interactions between onboard technologies such as propulsion and fuel conversion systems and offboard technologies such as fuel production and storage.

The global market for alternative fuel production technologies for maritime fuels could be worth £8-11 billion per year by 2050 (Table 1), with potential UK economic benefits from sales and exports of £360-510 million per annum.[9]

Projected global demand for low-carbon fuels

By 2050, ammonia is expected to be the largest energy source with a 35% share in the shipping industry, with e-fuels (including e-methanol) reaching 14% (Figure 3).[10] Ammonia and e-methanol have a lower energy density than traditional maritime fuels, but have superior energy density to compressed or liquid hydrogen, making them most likely to serve the global shipping market. Energy demand is forecast to decline slightly as a result of increased efficiency and technological performance although the size of the maritime industry is expected to remain fairly steady to 2050.

Figure 2: Technologies and fuels on a pathway to zero-emission shipping



Source: Department for Transport (2019). Clean Maritime Plan.

[7] Statista (September 2021). Annual fuel consumption by ships worldwide from 2019 to 2020, by fuel type.
[8] IMO 2020. Cutting sulphur oxide emissions.
[9] Frontier Economics, E4tech and UMAS (2019). Reducing the Maritime Sector's Contribution to Climate Change and Air Pollution. Economic Opportunities from Low and Zero Emission Shipping.
[10] DNV (2023). The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050.

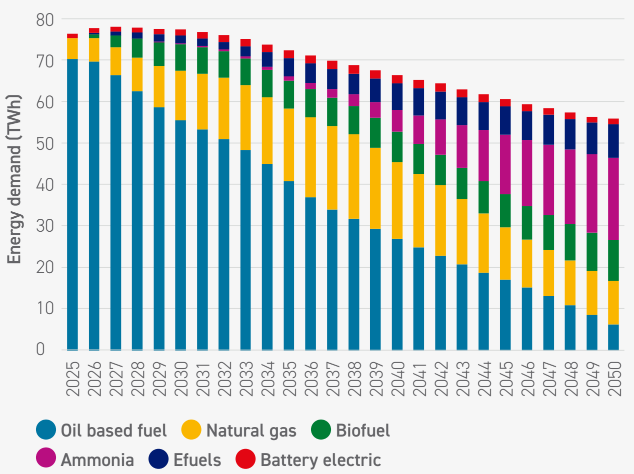
Table 1: Global market for maritime fuels in 2050

Technology	Number of vessels (thousands)	% of global fleet	Annual global market size 2050 ($m)	Annual UK market potential in 2050 ($m)
Ammonia, methanol, hydrogen and bio-LNG[11]	49-60	55-68%	11,000-15,000	490-690
Low-carbon shore-power technologies	43-47	50-55%	<1,000	<10
Onboard hydrogen technology	-	-	-	-
Onboard batteries	3-9	5-10%	<1,000	<10
Electric propulsion	2-6	0-5%	<1,000	0-20
Air lubrication	13-16	15-20%	3,000-4,000	70-90
Wind propulsion	37-40	40-45%	2,000-3,000	70-80

Source: Frontier Economics and E4tech (2019). Economic Opportunities from Low and Zero Emission Shipping.

Battery technology has the highest overall efficiency and is cost-effective, with low noise and vibration powertrains, making it ideal for domestic and short distance shipping such as on rivers, lakes and ferry routes. For longer distance and international shipping, hybrid propulsion systems combining batteries with alternative fuels such as ammonia, methanol or hydrogen, are likely to play an increasing role. These systems could enhance energy efficiency and reduce the amount of alternative fuels required.[12]

Figure 3: UK total maritime energy demand by technology (2025-2050)



Overall energy demand in the UK marine industry is expected to decrease as more energy efficient hybrid and full electric vessels are commissioned.

Source: DNV (2023) - The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050. Numerical data for figures.

While demand continues to increase at a steady pace, the amount of batteries required for the maritime industry remains modest compared to other market sectors, with around 1 GWh per annum being required in the UK to 2040.[10]

The lifetime of ships is typically 25 years or greater. This means the take-up of new fuels will be slower than for passenger cars. Apart from LNG, medium- to long-term propulsion options, such as ammonia, e-fuels, biofuels and hydrogen, will require further development in terms of storage, handling, energy density, cost-efficiency and safety. In contrast, LNG is a well-established technology that is likely to be the first lower-carbon alternative to take market share away from oil-based fuel.[13]

Over 90% of the energy used in the UK maritime industry currently relies on oil-based fuels, but by 2050 this share is projected to decline to 12%. Ammonia is expected to become the leading energy source at 35%, with e-fuels such as e-methanol contributing 14%, alongside natural gas and battery-electric propulsion.

Impact of low-carbon fuel adoption on electricity demand

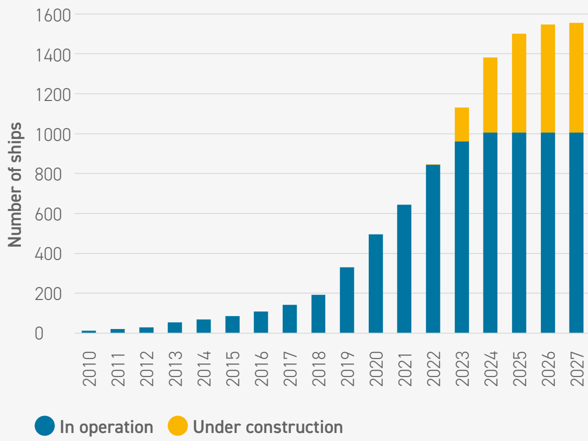
A future technology mix that includes all of batteries, ammonia and e-fuels is likely for marine and consideration needs to be given to the impact of their production on energy demand. Hydrogen-based fuels such as ammonia and e-methanol have multiple production steps, resulting in lower efficiency than battery powered propulsion. Converting hydrogen to ammonia is more efficient than converting it to renewable methanol, but both require significant additional electricity capacity.[14]

[11] Bio-LNG (liquefied natural gas) is produced from biomass or waste using either gasification or anaerobic digestion, followed by liquefaction.
[12] MAN Energy Solutions - Batteries on board ocean-going vessels.
[13] Royal Academy (July 2013). Future Ship Powering Options. Exploring alternative methods of ship propulsion.
[14] DNV (2022). Ammonia as a marine fuel.

Box 1: Growth of battery-powered ships in the maritime industry

The adoption of battery-powered ships has accelerated in recent years, following modest growth in the previous decade. Currently, 944 battery-powered ships are in operation around the world and a further 451 are under construction and will be in operation within the next four years. Europe is the leading region in terms of adoption, accounting for 68% of battery ships. Norway alone accounts for 33% of battery powered-ships globally.

Figure 4: Ships with batteries in operation and on order, 2010-2027



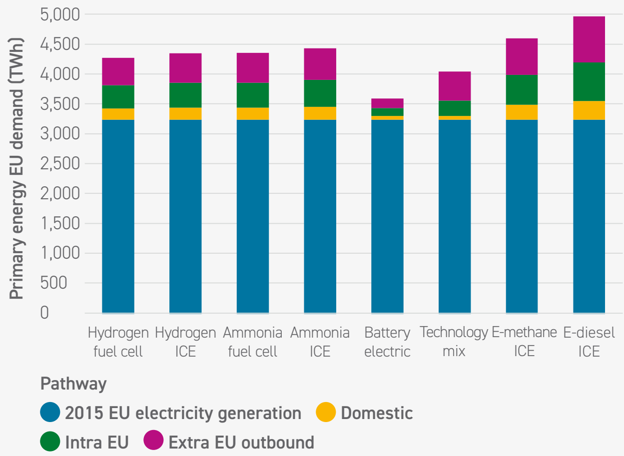
The use of batteries in marine applications is on the rise, as the number of hybrid and full electric vessels in operation and on order continues to increase.

Source: Alternative Fuels Insight – DNV (Data as of January 2025).

Fully electric ships represent 18% of the total, with hybrid and plug-in hybrids accounting for 65% and 17% respectively. Car/passenger ferries are the most common vessels where batteries have been installed, accounting for 353 (35%) of the total number of ships in operation. Other important vessel types with battery installations include offshore supply ships, fishing vessels, cruise ships and tugboats.[15]

The increased efficiency of battery-electric solutions is significant in terms of the overall energy required from a zero-emissions industry. If a fully battery-electric technology pathway could be achieved, only 11% additional primary energy demand would be needed by 2050 across the different segments of EU shipping (domestic, intra-EU and extra-EU) compared to 2015 electricity generation levels. In contrast, other technologies (Figure 5) would require significantly more, with synthetic methane and synthetic diesel needing up to 42% and 53% additional energy respectively.

Figure 5: Shipping's additional electricity demand under different technology pathways in 2050



A battery electric technology pathway results in lower additional energy demand due to the high efficiency of full electric vessels.

Source: Transport & Environment (2018) - Roadmap to decarbonising European shipping. Numerical data for figures.

Potential for Battery Technology in the Maritime Industry

Batteries are an increasingly important technology across a wide range of vessel types. Batteries can serve as the main source of propulsion power in full electric vessels or be installed in hybrid vessels to support propulsion and auxiliary systems. Full electrification is particularly suited to short routes, typically up to one hour, while hybrid systems are more effective for longer routes.[16]

Full electric systems and diesel-electric systems offer many advantages including lower space requirements, vibration and noise, as well as increased payload and manoeuvrability.[17] Electric powertrains also have lower maintenance costs and energy efficiency benefits. Estimates of conversion rates from input energy to propulsive power range from 80-95%[13] to 90%[18] and 98%.[19] This can help lower fuel consumption and emissions. Finally, these systems are more easily adapted to future fuelling solutions.

Full electric propulsion systems

Full electric systems require only the battery energy storage system (BESS) to power the vessel throughout its entire

[15] DNV Alternative Fuels Insight (Data as of January 2025).
[16] Siemens Energy (2022). Decarbonising maritime transport. A study on the electrification of the European Ferry Fleet.
[17] Marine Insight (May 2019). Electric Propulsion System for Ship: Does it have a Future in the Shipping?
[18] Energy Transitions Commission (2019). Mission Possible sectoral focus: shipping.
[19] ABB (2021). Electrifying the maritime and ports sectors.

route, making them ideal for shorter distances but less suited for large-scale or long-haul shipping.

The BESS on electric vessels tends to be larger than necessary for the distance required by a given route, allowing flexibility in power demand. Larger batteries are needed to ensure the vessel has enough power to deal with unforeseen circumstances and to allow the battery to be cycled over a limited depth-of-discharge, helping extend battery life. For example:

- The Ellen ferry in the west Baltic Sea navigates a 41 km journey while transporting up to 200 passengers and 30 cars onboard. The ferry's battery pack possesses a capacity of 4,300 kWh[20] compared to an average of 55 kWh in the passenger car market,[21] cycling on average between 100% and 61% state-of-charge.[22]
- The battery pack of the Aurora ferry, which covers a 4 km journey between Sweden and Denmark, is cycled between 66% and 40% state-of-charge, leaving almost three quarters of the battery capacity unused on most trips. In this case, although the majority of the capacity is not used, cycling over a limited capacity range helps extend the lifetime of the battery.

DFDS – the world's leading ferry operator – is investing €1 billion in six battery-electric vessels for the UK-France cross-channel ferry routes, with two expected to launch by 2030.[23] The company is focusing on ensuring vessel design meets stringent safety and performance standards. It is working with authorities, infrastructure partners and energy suppliers to ensure the required energy and port infrastructure for electric ships is available in time.

Hybrid electric propulsion systems

Hybrid solutions are expected to become more widespread as the distance travelled by electric vessels increases. Three main hybrid solutions exist for ocean-going vessels:[12]

- Semi-hybrid systems have a diesel-mechanical main engine and batteries installed alongside the auxiliary engines to give a hybrid electric grid on board. This grid is used to power key ship systems such as navigational equipment and lighting.
- Full-hybrid systems have a diesel-mechanical main engine that is connected to the vessel's hybrid electric grid via a power take on (PTO) / power take off (PTI) system. The PTO/PTI allows the BESS to provide power to and be charged from the main engine during operation, allowing for emission free port stays.
- Full-hybrid diesel-electric systems, where diesel generators alongside BESS are used to provide electricity to electric motors. The biggest advantage of using full-hybrid systems is that they can be retrofitted to new fuels much easier, as only the generators need to be replaced rather than the whole propulsion system.[24] These systems are attractive for ships being commissioned now, as they will be able to take advantage of low-carbon fuels when they become more widely available.

In hybrid propulsion systems, the BESS can help reduce fuel consumption and increase engine efficiency by allowing the engines (both main and auxiliary engines) to operate at a constant power output, with the battery providing peak shaving capabilities. Some systems can also be run solely off the BESS, allowing for zero emission running for a short period of time, for example, when entering a port to reduce pollution close to shore. While full hybrid systems do have the ability to run purely off battery power, the battery in these systems are not sized to power the vessel for the full length of their trip. The inclusion of BESS in the ship's electric grid also reduces the need to run auxiliary engines, minimising mechanical wear and giving the option to more easily carry out engine maintenance. In all cases, the BESS installed on the ship will be charged using the on-board engines. While the ability to charge the engines using shore power is theoretically possible, this would need to be included in the ship's design from the start or be retrofitted onto the vessel. However, the current lack of shore charging capabilities means that this capability is only used in certain cases.

While batteries are common in smaller vessels and coastal shipping, their use for deep-sea vessels remains limited.[25] Currently, only a few ocean-going cargo ships use small battery packs, primarily within hybrid setups to support auxiliary power and improve efficiency. Fully battery-powered long-distance operations face significant challenges, particularly related to energy density and space. Despite these limitations, these initial deployments are providing valuable insights into performance and reliability.

Some examples of typical characteristics of full and hybrid electric vessels in operation are provided in Table 2, with examples of specific vessels provided in Box 2.

Charging infrastructure for full and hybrid electric vessels

The key challenge for plug-in battery solutions in the shipping industry is delivering sufficient energy to the vessel within a limited timeframe. High-power shore-to-ship charging infrastructure, capable of rapid energy transfer, is therefore essential to meet the short docking times of many full electric vessels and ensure batteries are fully charged for operational efficiency on departure. This often requires grid reinforcements or onshore stationary batteries.

Having adequate charging infrastructure in place is particularly critical for full electric vessels, but one that can be difficult to implement as grid upgrades may be required to handle the additional electricity demand. To help improve efficiency and cost-effectiveness, automated charging operations can be installed as part of the docking procedure.

For hybrid electric vessels, providing shore power for vessels is not such a strict requirement, as the batteries

[20] BBC News (January 2020). Plug-in and sail.
[21] Global EV Outlook 2021. Trends and developments in electric vehicle markets.
[22] E-Ferry Project (May 2020). Final validation and evaluation report.
[23] DFDS (May 2024). DFDS to invest €1 billion in battery electric ships for the Channel.
[24] Wartsila - Marine electric propulsion systems.
[25] Maritime Battery Forum and CIMAC (2024). Environment for the use of batteries in deep-sea shipping.

Table 2: Comparison of hybrid and fully electric ferries

	Ampere	Bastø Electric	Colour Hybrid	Elektra
Propulsion type	Fully electric	Fully electric	Hybrid (diesel electric + battery)	Hybrid (diesel electric + battery)
Length of route	20 min 6 km	30 min 10 km	2h 30 min 68 km	15 min 1.6 km
Type of crossing	Fjord crossing	Fjord crossing	Sea crossing	Sea crossing
Trips per day	34	20-24	4 (2 round trips)	25
Propulsion power	Two electric motors of 450 kW	4 x 1,100 kW electric generators (+4x backup diesel generators)	2 x 6L (3.6 MW) and 2 x 8L (4.8 MW)	2 x 900 kW (+ 3x diesel generators)
Battery capacity	1,040 kWh	4,300 kWh	4,700 kWh	1,000 kWh
Charging power	1,200 kW	Up to 9,000 kW	7,000 kW	N/A (vessel charges directly from the grid)
Charging time	10 min + overnight	Within minutes	25 min at lunch stop + overnight	5.5 min + overnight

Source: Siemens Energy (2022) - Decarbonizing maritime transport, A study on the electrification of the European Ferry Fleet.

Box 2: Examples of full and hybrid electric ships

The Aurora (Passenger/car ferry, full electric propulsion): In 2017 the Aurora was retrofitted to be a fully electric vessel powered by a 4.2 MWh battery.[26] The ship operates on a short ferry route between Sweden and Denmark, using a robot to help facilitate the charging of the vessel while docked between trips. The typical charging time is between 5 and 10 minutes, with the ship making 46 crossings every 24 hours.

Saint-Malo (Passenger/car-ferry, hybrid electric propulsion): The Saint-Malo, set to launch in February 2025, will become the largest hybrid vessel in operation.[27] The ship will transport vehicles and passengers between France and the UK, powered by a hybrid-LNG system, combining the use of LNG fuel and an on-board battery pack of 11.3 MWh.[28] The ship will also be shore-power capable, which allows the BESS to be charged and removes the need for auxiliary engines while in port, helping reduce the environmental impact of the vessel.

Viking Queen (Offshore support vessel, hybrid electric propulsion): In 2015 the Viking Queen, an offshore support vessel for Eidesvik, was retrofitted with a 1.6 MW / 0.65 MWh BESS. The high-power system is used to create a more optimal load on the vessel's engines. The BESS can also allow for one of the ship's engines to be shut down, to reduce maintenance on the machinery. The use of this system is estimated to provide a fuel saving of approximately 18%.[29]

P&O Pioneer (Passenger/car ferry, hybrid electric propulsion): The P&O Pioneer began operations in 2023 between Dover and Calais. The vessel is fitted with four diesel engines supported by a single 8.8 MWh battery pack and is estimated to use 40% less fuel compared to the existing fleet. The vessel operates under battery power only while manoeuvring in port and has been designed to be converted to all-battery electric once charging infrastructure is installed at the two ports.[30]

can be recharged using the on-board engines. However, shore power will further improve fuel efficiency and reduce emissions by removing the need to run the auxiliary engines while docked and charging the batteries before setting off again.[31]

The UK Chamber of Shipping has recommended setting a target of 2030 for UK ports to provide shore-power services. This will influence the operational standards for ships, making it essential for vessels to have the capability to connect to shore power. Portsmouth International Port is on

[26] Shift Clean Energy - Aurora Electric Ferry.
[27] Britanny Ferries - Introducing Saint-Malo.
[28] Offshore Energy (January 2023). Stena Line, Brittany Ferries order Leclanché battery systems for next-gen hybrid ferries.
[29] Green Car Congress (May 2015). Eidesvik Viking Queen retrofitted.
[30] Electric & Hybrid Marine Technology International (March 2023). P&O Ferries delivery of latest battery hybrid ferry.
[31] Wartsila (April 2023). How is a hybrid power-up boosting Brittany Ferries' drive to decarbonise?

track to be the first port in the UK to be shore-power capable, which will help accommodate the new hybrid ships being launched by Brittany Ferries, one of its major customers.[32]

Port infrastructure

Ports are major hotspots for environmental impacts in the maritime sector, particularly air pollution from ships and water contamination from industrial activities.[33] These impacts arise from shore-based infrastructure such as cranes and drayage trucks, as well as vessels on-board auxiliary engines. These are used to power a vessel's electric grid while docked. As ports are often located within population hubs, efforts are underway to minimise the impacts of pollution. The electrification of port operations (as well as marine vessels) has the potential to reduce marine oil consumption and air pollution (Box 3).

Future Innovations and Research Directions

Battery requirements across marine applications

Battery technology is currently limited to smaller vessels with lower power and energy demands. Nonetheless, there are still viable use cases for fully electric and particularly hybrid systems. The electric operation of deep-sea vessels, however, remains limited due to the size and weight of the batteries required.

Table 3 outlines the feasibility of battery applications across various shipping sectors and their typical performance requirements, which vary considerably. Currently, lithium nickel manganese cobalt (NMC) batteries have become the preferred battery technology in marine applications, due to high energy and power densities. However, as battery requirements can vary considerably depending

Box 3: Electrification of ports and port infrastructure

The electrification of onshore port infrastructure as well as the electrification of auxiliary power systems on-board vessels arriving at port will play a role in reducing pollution and emissions from ports.

Onshore infrastructure includes cargo handling equipment such as cranes, forklifts and drayage trucks, as well as vessels such as tugs and dredging boats. Electrified and hybrid alternatives exist for many of these support vehicles, where battery packs are used to power electric motors.[34] Electrifying these types of vehicles would require the installation of charging infrastructure around the port, using technology that is already widely deployed for electric vehicles. Examples of ports that have adopted substantive electrification measures include the Ports of Genoa, Livorno, Los Angeles, San Francisco, Juneau, Gothenburg and Lübeck.[35]

Ships docked in port typically use fossil-fuelled auxiliary power systems that provide power for support processes such as refrigeration, lighting, cargo pumps etc. However, several options exist for electrification, including shore-to-ship power and hybrid electric vessels.

Shore-to-ship power, also known as cold ironing,[36] is where the vessel is connected directly to the port's electricity supply while docked. This allows the vessel to power off its engines and connect to a land-based electricity supply. Alternatively, having a BESS installed on hybrid vessels can allow ships to partially or completely run their auxiliary power systems using batteries, reducing emissions while in port.[12] Ships that use batteries as part of a fully electric or hybrid system can also recharge using the port charging infrastructure.[37] Charging infrastructure must be designed to withstand harsh environmental conditions, such as water immersion, salt corrosion and exposure to sand.

The electrification of ports will enable a reduction of emissions both from port operations and docked vessels. Full electrification of ocean-going vessels, harbour craft and drayage trucks could reduce up to 75% of port emissions in Seattle and 69% in New York.[38]

Despite these technologies being readily available today, several barriers to widespread electrification of port infrastructure exist, including high capital costs, expensive electricity and a lack of consistent demand.[39] Once these barriers are overcome, the economic impact could be significant. Economic activity supported by electrified ports could more than double between 2020 and 2050 compared to diesel-powered operations.[40] Grid connections to ports will also require updating. The UK Chamber of Shipping emphasised that "strengthening energy connectivity to and around ports is essential to enabling shore power and broader electrification".[41]

[32] Portsmouth Port - Portsmouth ahead of UK schedule to provide shore power facilities.
[33] EMSA (2021). Facts and figures: the EMTER report.
[34] PNNL (2024). Port Electrification Handbook: A Reference to Aid U.S. Port Energy Transitions.
[35] Climate Chance (2019). New initiatives in international maritime transport.
[36] Marine Insight (March 2023). What is Alternate Marine Power (AMP) or Cold Ironing?
[37] International Transport Forum (November 2020). Navigating Towards Cleaner Maritime Shipping.
[38] International Council on Clean Transport (2022). Electrifying ports to reduce diesel pollution from ships and trucks and benefit public health.
[39] British Ports Association (May 2020). Reducing emissions from shipping in ports: Examining the barriers to shore power.
[40] University of Delaware (2020). Macroeconomic & Environmental Impacts of Port Electrification: Four Port Case Studies.
[41] Written evidence submitted by the UK Chamber of Shipping (FTF0057).

on the specific application, multiple battery chemistries could be deployed across the same market sector. Other battery technologies, such as lithium iron phosphate (LFP) and lithium titanium oxide (LTO), which are already well established in other markets, are starting to find new applications in the maritime industry.[42] LFP cells are widely used in the automotive industry and are less costly to manufacture than NMC cells, although they offer lower power and energy densities. LTO cells provide very high power densities, with some compromise on energy density that may suit some maritime applications.[43] In addition, LTO based systems may require less over-capacity than other systems, as the batteries can be operated across a wider state-of-charge, effectively increasing cycle life.[44] In applications where energy density is not as much of a concern, new lower cost battery chemistries such as sodium-ion cells could start to compete with LFP,[45] although such systems are not currently under development for maritime applications.

Additionally, while unmanned underwater vehicles (UUVs) and unmanned surface vehicles (USVs) both commonly use lithium-based chemistries, they differ in their specific choices based on power and energy needs. UUVs typically use lithium-ion cells for their high energy density and capability

Table 3: Feasibility and technology requirements of batteries by different vessels and applications

Type of ship	Fuel savings potential (%)	Payback time (years)	Main battery function considered	Factors that can maximise benefit	Power requirements	Cycling demands
Ferry	Up to 100%	Less than 5	Full electric where feasible	Low electricity costs, high port time, short crossing distance	Very high	Very high
High speed ferry	Up to 100%	3 – 6	Full electric or hybrid	Detailed duty cycle analysis	High	High
Cruise	< 5%	Highly variable	Hybrid system	Ability to operate in full electric mode for extended period	Low	Likely high
Short sea shipping	Highly variable	Highly variable	Full electric or hybrid uses	Vessel and duty cycle dependent	Highly variable	Highly variable
Deep sea vessels	0% – 14%	Highly variable	Hybrid systems with PTI/PTO	Highly variable, detailed duty cycle analysis	Highly variable	Highly variable
Bulk vessels with cranes	0% – 30%	0 – 3	Crane system hybridisation	Integration with genset sizing	High	High
Offshore supply vessel	5% – 20%	2 – 5	Dynamic positioning for vessel / providing support to auxiliary systems	Low power and energy needs for backup	Very high	Very low
Offshore drilling unit	10% – 15%	1 - 3	Spinning reserve and peak shaving	Large battery size	Very high	Variable
Shuttle tanker	5% – 20%	2 - 5	Dynamic positioning for vessel - spinning reserve	Low power and energy needs for backup	Very high	Very low
Fishing vessel	3% – 30%+	3 - 7	Hybrid load levelling and spinning reserve	Diesel sizing relative to loads	Nominal	Nominal
Tugboats	5% – 15% (100% if full electric)	2 – 8	Full electric or many hybrid uses	Detailed duty cycle analysis	Highly variable	Highly variable
Yachts	5% – 10%	Highly variable	Silent operation, spinning reserve	Detailed duty cycle analysis	Low	Low

Source: DNV (May 2020) - Study on Electrical Energy Storage for Ships: Battery Systems for Maritime Applications – Technology, Sustainability and Safety.

[42] Wartsila (August 2023). Seven fascinating hybrid ship trends that everyone needs to know about.
[43] For more information on different battery chemistries, see Faraday Insights - Developments in Lithium-Ion Battery Cathodes (September 2023).
[44] Echandia - Marine battery systems explained (December 2021).
[45] For more information on sodium ion, see Faraday Insight - Sodium-ion Batteries: Inexpensive and Sustainable Energy Storage (May 2021).

to operate at depth, with nickel-metal hydride and silver-zinc batteries used to a lesser extent. In contrast, USVs use lithium-ion, lithium-ion polymer and lead-acid batteries, selected according to the range and speed requirements for surface operations.

Innovations in batteries for maritime applications

Current battery requirements for marine applications are already being met by commercially available technologies. However, batteries could be applied to a wider range of marine applications with further innovations in safety, energy density, cost and cycle life. Innovative new applications include the development of full electric foiling vessels, which foil above the surface of the water (Box 4).

Box 4: Examples of electrification in foiling vessels

Foiling vessels are vessels where the use of a hydrofoil allows the hull to be lifted out of the water, reducing drag and allowing higher speeds to be reached with greater energy efficiency. This concept was first developed in the early 20th century in an attempt to break speed records and has since been applied to a wide range of wind powered sailing craft. However, the concept is increasingly being applied to full electric vessels with applications ranging from short-haul ferries to pilot boats.

The main advantage that foiling vessels provide is an improvement in power consumption by reducing the drag on the vessel. This also allows vessels to travel at much higher speeds. Recent technological advancements have allowed this concept to be applied to a wider range of vessel craft. The high-performance sailing vessels in the America's Cup have led to improvements in foil design and control software improving the understanding of foiling vessels,[46] while the widespread deployment of electrification in road transport has enabled cost reductions in key components such as batteries and electric motors.

A number of companies today are developing foiling electric vessels. Artemis Technologies is a UK company based in Belfast developing a wide range of electric foiling vessels, including an electric ferry capable of carrying 150 passengers over a range of up to 70 nautical miles.[47]

Battery safety issues in the maritime industry are similar to those of land transport sectors, but the consequences of any safety incident are much more severe due to the distance ships often are from assistance. While lithium-ion batteries are already safe, and accidents are very rare, care must be taken in choosing where to install the BESS on board. In certain cases, the BESS has been placed on the deck of the ship, where the consequences of the battery being affected by fire or a vessel collision could be minimised. Increased standardisation of BESS systems could help increase the speed of installation and improve the safety of BESS installed on new or retrofitted ships.[48]

In 2023, the European Maritime Safety Agency (EMSA) highlighted the importance of ensuring safety and reliability in the use of lithium-ion batteries on board ships, given the risks related to thermal runaway and fire. EMSA outline how these risks can be mitigated through uniform safety standards, comprehensive risk assessments (e.g. ISO 31000) and fire safety measures such as early detection, containment and extinguishing systems. Battery installations on ships should also ensure redundancy and resilience under adverse weather conditions for operational safety.[49] The energy density of commercially available lithium-ion batteries are sufficient for hybrid vessels. However, energy density can be a limiting factor when considering a full electric propulsion system. While weight will always be critical for any vessel, this is especially true for full electric vessels where the presence of heavy battery packs directly impacts a vessel's efficiency and range. For example, the E-ferry project in Denmark had to implement several weight saving measures to ensure the vessel design would be successful. These measures included innovative designs for the drivetrain and charging system and the use of aluminium for various parts of the ship.[22] New battery chemistries such as solid-state batteries, which promise higher energy densities and good power capabilities, could help increase the breadth of applications batteries can service in the marine sector.

Reducing a ship's energy consumption, such as by reducing speed, could also increase the range of a vessel, potentially enabling new routes for fully electric vessels. While this may affect the economic viability of a route, it demonstrates the potential for full electric propulsion to increase in popularity as energy density improves.

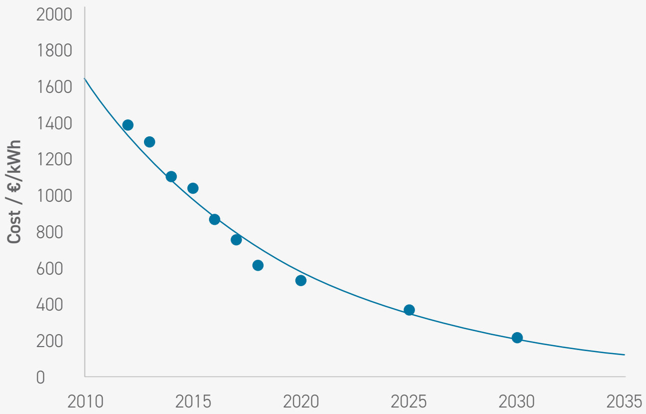
The cost of battery-powered vessels has been a significant barrier to their use in the past. However, with advancements in battery technology and scale, battery prices are decreasing rapidly. Over the past decade, the cost of lithium-ion battery cells has significantly decreased – a trend that is expected to continue. In addition, improved designs of marine battery packs have helped reduce prices (Figure 6), with marine battery pack prices forecasted to reach 211 €/kWh by 2030, down from over 1,000 €/kWh in 2015.

Future research priorities

Research focused on improving cell performance and safety of lithium-ion batteries is already underway in certain sectors such as automotive and energy storage. These improvements will be beneficial to the maritime industry, helping enable the widespread uptake of electrification across a range of marine applications. Achieving a reduction in the degradation of lithium-ion batteries would help improve the useable cycle

[46] America's Cup - The boats.
[47] Artemis Technologies - EF-24 Passenger.
[48] Journal of Energy Storage (2024). Wei He et al., Lessons learned from the commercial exploitation of marine battery energy storage systems.
[49] European Maritime Safety Agency (November 2023). Guidance on the Safety of BESS on board ships.

Figure 6: Past and future battery pack costs for maritime applications



The cost of battery packs for marine applications is expected to fall, in line with the cost decreases seen in the automotive and energy storage sectors.

Source: European Commission Horizon 2020: E-Ferry Project Evaluation report of the E-Ferry. Numerical data for figures.

life of cells and allow a wider range of state-of-charge to be consistently used during operation. The development of new cell chemistries such as solid-state batteries could also lead to improvements in energy density, opening up new applications for electrification in the marine sector.

Research and development in the systems engineering of full and hybrid electric vessels is an area that would help improve the uptake of batteries in the marine sector. Safety improvements in battery technologies will have an impact on the design and positioning of the BESS system within the vessel. The development of vessel safety standards for high voltage components is also required. Additionally, developments in electric powertrain design are needed to improve the performance, reliability and feasibility of BESS in full electric vessels.[50] Research should also be focused on use-cases where full or hybrid vessels could be cost-competitive with existing vessel types.[51]

To facilitate this research, there are multiple efforts underway in the UK. A national centre for maritime innovation and technology (MarRI-UK) has been established by a consortium of British companies, academia and the government. The centre is a membership organisation based at the University of Strathclyde and focused on addressing the innovation and technology challenges in mid-technology readiness levels.[52] Innovate UK has also funded a number of demonstration projects in the maritime sector, including establishing the potential of electrification of the existing fleet of hire cruisers on the Norfolk Broads.[53]

Conclusion

Battery technology offers numerous benefits in the maritime industry, including energy efficiency, reduced emissions and improved performance. Battery technology has significant potential for smaller vessels and short-distance ferry services, with full electrification being most suitable for routes up to one hour. To decarbonise long-haul maritime transport, however, hybrid systems that combine batteries with low-carbon fuel ready system designs will be the more practical option. This is largely due to higher costs, significant space needs and lower energy density of batteries.

The feasibility and technology requirements for battery applications vary across and within each shipping sector, depending on the energy, cycles and power needed. Ferries have the highest potential for fuel savings when they operate in all-electric mode and hybrid systems that use batteries alongside diesel or dual fuel engines can significantly reduce emissions. The existing battery chemistry of choice in maritime applications is NMC, but different chemistries such as LTO or LFP may prove to be a good fit for many maritime applications despite their lower energy density.

To support the transition to battery-powered maritime applications, the following strategic actions are recommended:

- Promote the development and deployment of hybrid systems for larger vessels by providing targeted subsidies, research funding and industry incentives to optimise fuel efficiency and emission reductions by using batteries alongside low-carbon fuels.
- Support research into battery chemistries such as LTO and LFP, by funding targeted R&D programmes and facilitating industry-academia partnerships to develop enhanced suitability for specific maritime applications.
- Strengthen UK national and regional centres for innovation in battery and maritime technology, by investing in centres such as MarRI-UK, to drive advancements and commercial readiness.
- Enhance the safety and standardisation of battery systems on vessels through collaboration between organisations such as the UK Maritime and Coastguard Agency, Maritime Battery Forum, IMO, European Maritime Safety Agency and global battery safety bodies.
- Expand battery technology in hybrid propulsion systems onboard vessels by supporting retrofitting initiatives and offering incentives to lower fuel consumption for auxiliary power, particularly through shore-to-ship power or battery storage options when ships are docked near populated areas.
- Ensure investment in port electrification infrastructure by private port operators, UK Government and local

[50] International Chamber of Shipping and Ricardo (November 2021). A zero emission blueprint for shipping.
[51] Hee Seung Moon et al., Exploring the cost and emissions impacts, feasibility and scalability of battery electric ships, Nature Energy (2024).
[52] Maritime Research & Innovation UK (MarRI-UK).
[53] UKRI, Innovate UK (2022). Clean Maritime Demonstration Competition.

authorities in order to provide charging stations, refuelling points and robust power connections, enabling berthed vessels to access reliable shore power and reduce operational costs.

The maritime industry is transitioning to low-carbon technology such as ammonia, batteries, e-fuels, biofuels and hydrogen fuel cells. The UK's established strength in global shipping, alongside advancements in battery technology and the creation of national centres for innovation, positions it well to benefit from the shift to new energy fuels and technologies. Realising the full benefits of this transition will require coordinated investments in both vessel technology and port infrastructure to enable wide-scale adoption of clean energy solutions.

About the Faraday Institution and Faraday Insights

The Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis, and early-stage commercialisation. We bring together academics and industry partners in a way that is fundamentally changing how basic research is carried out at scale to address industry-defined goals.

Our 'Faraday Insights' provide an evidence-based assessment of the market, economics, technology and capabilities for energy storage technologies and the transition to a fully electric UK. The insights are concise briefings that aim to help bridge knowledge gaps across industry, academia and government. If you would like to discuss any issues raised by this "Faraday Insight" or suggest a subject for a future Insight, please contact Stephen Gifford.

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