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Battery-Electric Ships: Economics, Limits and Prospects

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Abstract

Battery-electric propulsion is already the least-cost zero-emission option on short, high-utilisation routes, and is displacing incumbents among ferries, harbour craft and inland vessels. This chapter argues that its economics turn less on energy density than on the opportunity cost of stored energy: batteries must be cycled frequently to pay, so the binding constraint on longer routes is the inability to recharge at sea. Because shipping is a technology taker that inherits cheaper, safer, longer-lived cells from far larger road-transport and grid-storage markets, the economically electrifiable boundary moves outward with global cell production, largely independent of maritime demand—whereas synthetic marine fuels must finance their own scale-up. Comparing shipping with road freight isolates six differences: fuel price, energy efficiency and safety disadvantage maritime electrification, while lower sensitivity to battery weight and large electrical auxiliary loads on cruise and container ships favour it. We trace how powertrain architecture—from mechanical drive with power take-in to fuel-electric and pure-electric—and onboard DC distribution shape adoption, and add an often-overlooked energy-security dividend: electrification converts a disruptible fuel import into a one-off equipment purchase followed by domestic energy. Electrification advances along a predictable ladder, from harbour ferries through inland and short-sea vessels to port-anchored coastal routes, with deep-sea trades reachable only through infrastructure-mediated configurations, if at all. Low-regret policy levers include port electricity infrastructure, harmonised standards and broad emissions pricing.

Keywords

battery-electric vessels, maritime decarbonization, economics of electrification, shore charging, short-sea shipping

JEL Classification

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Battery-electric ships: economics, limits and prospects

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1 Introduction

Battery-electric propulsion is a zero-emission, energy-efficient option available to shipping. It converts stored energy to propulsion with far lower losses than any fuel-synthesis route, eliminates local air pollutants, reduces noise, and is already the displacing technology on a growing set of short routes. Its applicability is set not by the propulsion technology, which is mature, but by where and how electricity can be delivered. Further, batteries can power auxiliary and hotel electricity demands, displacing more fuel per kilowatt-hour than the same electricity used to drive the propeller.

Electricity is projected to decarbonise in advance of other parts of the energy system, with the global electricity system reaching net-zero emissions by 2040 in the IEA's Net Zero scenario (IEA, 2024b). Any transport mode that can use electricity directly inherits this decarbonisation, while modes that must convert electricity into a synthetic fuel pay a large energy penalty for the conversion and storage chain. For shipping, direct electrification therefore sets an efficiency benchmark against which every alternative fuel can be measured (Kanchiralla et al., 2022; Kersey et al., 2022).

The addressable market will widen as battery prices fall and shoreside power grows. This chapter evaluates the technology and its limits (Section 2), the segments where electrification is already commercial and the sequence in which they fall, including the deep-sea frontier (Section 3), charging infrastructure and its economics (Section 4), and policy and regulation (Section 5), before concluding (Section 6).

2 The technology and its limits

2.1 Battery energy storage fundamentals

Modern marine battery systems are overwhelmingly based on lithium-ion chemistries. Lithium iron phosphate (LFP) cells now dominate new installations because of their safety, long cycle life and low cost; nickel-manganese-cobalt (NMC) cells retain a role where space or mass is most constrained. The picture is an evolving menu rather than a single technology. Sodium-ion cells, whose energy density is now close to early LFP and which use no lithium, nickel or cobalt, have moved from laboratory to gigawatt-hour-scale manufacturing in the mid-2020s; lithium-sulphur and solid-state cells remain pre-commercial but are progressing through demonstration. Battery R&D is funded at a scale shipping cannot match and is unlikely to stall, with pack prices continuing to fall steeply (BloombergNEF, 2024).

A key difference between battery power and fuels is the opportunity cost of unused stored energy; about three orders of magnitude greater for batteries versus fuel oil (roughly \$100,000/MWh vs \$100/MWh).¹ So while fuel can sit unused in a tank without much opportunity cost, batteries need to be cycled frequently to be economical. This is visible in stationary energy storage, where batteries are used for daily arbitrage but not for seasonal storage.

Another reason batteries cannot sustain long voyages is the relatively low energy density, although this effect is minor in comparison with opportunity cost (Kersey et al., 2022; Wiskich, 2025). Pack-level marine systems deliver on the order of 0.1–0.2 MWh per tonne, against about 11.8 MWh per tonne for marine fuel oil. On a useful-propulsive-energy basis—after allowing for the roughly twofold efficiency advantage of an electric drivetrain over a low-speed diesel—a battery remains about twenty to forty times heavier than the fuel it replaces (Table 1).

Table 1: Indicative energy carriers compared on the parameters that govern vessel electrification. Values are order-of-magnitude and rounded; usable propulsive energy accounts for typical drivetrain efficiency.

Energy carrier	Chemical (MWh/t)	Useful (MWh/t)	Cycle life	Typical maritime role
Marine fuel oil (HFO/VLSFO)	~11.8	~5	n/a	Deep-sea main propulsion
Marine gas oil / diesel	~11.9	~5	n/a	Auxiliary, coastal, workboats
LNG	~13.9	~6	n/a	Deep-sea, lower-carbon transition
Li-ion pack (NMC)	~0.15–0.20	~0.13–0.18	~2,000–4,000	Short-sea, ferries (mass-constrained)
Li-ion pack (LFP)	~0.10–0.15	~0.09–0.13	~6,000–8,000	Ferries, tugs, inland (life/cost)

Note. Battery figures are pack-level, not cell-level. The useful-energy column assumes a propulsion duty cycle, where electric drivetrains convert stored energy roughly twice as efficiently as a low-speed marine diesel; for auxiliary loads the advantage is larger. Cycle life is full equivalent cycles at typical depth-of-discharge. Synthesised from Kersey et al. (2022), Kistner et al. (2024) and Kanchiralla et al. (2022).

2.2 How electrification of shipping differs from road transport

It is useful to compare electrification prospects for shipping with road transport—particularly trucks, where battery propulsion is projected to move from niche to mainstream over the coming decade (IEA, 2024a). We discuss six key differences: the first two shape the *price per useful unit of energy* delivered to the propeller; the third shapes *where* that energy can be loaded; the fourth shapes *what it costs* to install on board safely; and the last two—the *weight* of the battery and the ship’s large *auxiliary loads*—work in shipping’s favour.

Fuel price, taxation and accountability. Ships often pay much less than trucks for fuel per unit energy, for two reasons. First, in *production*: ships often burn residual fuel oil—heavy fuel oil and very-low-sulphur fuel oil (VLSFO)—the cheapest petroleum fuel, drawn from the bottom of the refining barrel, whereas road diesel and marine gas oil (MGO) are at least 20% more costly (Ship & Bunker, 2025). Second, in *taxation*: bunker fuel for international voyages has long been exempt from national fuel duty under customary practice and bilateral arrangements, and shipowners can choose where to bunker, driving the effective rate close to

zero (Keen et al., 2013). Such an exemption extends to carbon for international shipping and aviation emissions (IPCC, 2019); carbon pricing and efficiency mandates have therefore fallen first on *domestic* emissions.

The IMO's mid-term measures, the EU ETS extension to shipping and FuelEU Maritime are the first material erosions of this taxation asymmetry (European Commission, 2025). However, the starting point is stark: marine fuel oil is the cheapest transport hydrocarbon on the market and, for the international fleet, close to untaxed and uncarbon-priced, while electricity prices for charging are broadly similar in either sector. The truck–ship gap therefore narrows for domestic operators but remains wide for the international fleet.

Drivetrain efficiency. A modern low-speed two-stroke marine diesel operates at around 50% thermal efficiency at its design point, among the highest of any internal-combustion engine, because it runs continuously at near-constant load for days at a time (Geertsma et al., 2017). A long-haul truck achieves roughly 40–45%, with substantial losses from stop-start operation, grades and traffic; a passenger car averages much less. The efficiency gap that electrification can capture on the propulsive side is therefore narrower for ocean shipping than for road transport. Electric road vehicles also recover energy through regenerative braking during the frequent decelerations of stop-start, graded and urban duty; a ship in normal service never brakes but coasts down slowly against water resistance, so no comparable recovery is available at sea.

Charging opportunity. Land has electricity almost everywhere; the ocean does not. A truck can recharge at any depot, service area or factory yard; a ship at sea is hours or days from the nearest connection point. Trip durations compound the difference: road journeys are shorter to begin with and are punctuated by mandatory driver rest breaks every few hours, giving trucks natural charging windows that align with operations; ocean voyages run continuously for days or weeks with no equivalent pause. This is the binding constraint on deep-sea maritime electrification, and it operates through the cycling-economics channel set out in §2.1.

Safety and consequence asymmetry. Marine-rated battery systems have historically traded at a substantial premium over automotive packs, largely due to safety governance. The hazard is thermal runaway, propagating through a pack and venting flammable gases that are hard to extinguish with conventional means (ABS, 2024; MAN Energy Solutions, 2019; Maritime Battery Forum, 2023). The consequences are disproportionately severe at sea: a fire that cannot be extinguished leaves a crew hours or days from shore with no escape, whereas a road vehicle can be abandoned in seconds. The hazard is one of consequence rather than frequency—as in road transport, battery fires appear less likely than fossil-fuel fires, but a marine thermal-runaway event is far harder to contain. Classification societies therefore impose conservative design margins. The premium is easing, however, as lower-risk LFP and sodium-ion chemistries diffuse into the marine supply chain.

Weight. A truck is penalised twice by battery mass: gross vehicle weight is legally capped, so every tonne of battery displaces a tonne of potential payload, and road energy consumption rises directly with mass through rolling resistance, so a heavier truck needs a larger battery to

cover the same distance. A ship is a displacement hull with no legal weight cap, and added mass raises hull resistance less directly—resistance is dominated by wave-making and wetted surface for large, slow vessels. The energy and displacement penalty per tonne carried is far smaller at sea.

Auxiliary and hotel loads. A truck spends almost all its energy on propulsion; its hotel load (cab climate, electronics) is trivial, and even a refrigerated trailer is a small, intermittent share of the whole. In contrast, a large container vessel may carry several megawatts of refrigerated-container (“reefer”) load, and a cruise ship’s hotel demand can rival or exceed its propulsion. These loads are electrical, run continuously, and are today met by burning fuel in auxiliary generators at roughly 40% net efficiency, or about 45% via a shaft generator drawing on the main engine (a power take-off; see §2.3.1). Because the load is already electrical, battery- or shore-supplied power substitutes for this generation directly, with no drivetrain mismatch—displacing, per unit of electricity, roughly 30% more fuel than the same electricity used for propulsion.² Much of it can be met by shore power while the vessel is at berth, without a large onboard battery, making auxiliary and hotel loads among the most accessible and highest-value early targets for electrification—with no equivalent in road freight.

2.3 Powertrain architectures

Vessel powertrains span a four-step progression from pure mechanical to pure electric drive; a vessel’s position on this progression largely determines how cheaply a battery can be added. A separate question—independent of the prime mover and propeller—is whether the electricity moving around the vessel is distributed as alternating or direct current (AC or DC).

2.3.1 The four configurations

Pure mechanical. A long-stroke two-stroke main engine drives a fixed shaft and slow, large-diameter propeller, with auxiliary generators supplying the hotel load. This is the deep-sea cargo incumbent and has the lowest drivetrain losses of any architecture afloat, on the order of 3–5% (Geertsma et al., 2017). Adding a *power take-off* (PTO)—a shaft generator driven by the main engine that feeds the auxiliary bus—is near-standard on cargo newbuilds: because the main engine is the most fuel-efficient prime mover on board, PTO displaces auxiliary running and saves a few per cent of total fuel without changing the architectural category.

Mechanical with electric capability (PTI). The same mechanical drivetrain is retained but an electric motor on the propeller shaft (a *power take-in*, PTI) and a modest battery are added. PTI engages only when preferable to the main engine—slow steaming, peak shaving, take-home redundancy, electric-only manoeuvring in port—so the mechanical drive’s efficiency advantage is preserved during ocean transit. Increasingly specified on LNG carriers, large bulkers and container ships, this is the most plausible route by which deep-sea cargo fleets begin partial electrification without forfeiting two-stroke direct-drive efficiency.

Fuel-electric. Combustion engines or fuel cells drive generators that feed electric motors at the propeller through a common bus. The category is fuel-agnostic, though large fuel-oil-burning low-speed engines rarely appear in it because their efficiency at design point favours direct mechanical drive; medium-speed gensets running on diesel, LNG, biofuel or methanol are typical. Cruise ships, ferries, offshore support vessels and naval combatants have long favoured this configuration because their propulsive load is variable and hotel and dynamic-positioning loads are large: an electric architecture provides redundancy, layout flexibility and substantially lower noise and vibration than a directly-coupled engine. Drivetrain losses run perhaps 8–12% against pure mechanical drive (Geertsma et al., 2017), which is why deep-sea cargo did not historically choose this path. Adding a battery is incremental—it sits on the existing DC or AC bus. Plug-in hybrid ro-pax vessels such as *Color Hybrid* (Table 2) sit at the battery-rich end of this category, running electrically near port and on fuel for longer legs. Hybridisation with energy storage—whether a battery on this fuel-electric bus or the PTI-plus-battery arrangement of the previous category—commonly delivers around 5–15% fuel savings at modest cost and without the infrastructure dependence of full electrification (Geertsma et al., 2017), with the upper end reached on the most variable load profiles.

Pure electric. No combustion prime mover; the vessel recharges entirely from shore. Already the incumbent on the shortest repetitive routes (harbour ferries, harbour tugs, inland barges).

2.3.2 DC versus AC distribution

This subsection concerns how power is carried between sources and motors, not the choice of prime mover. Because batteries, fuel cells and solar are inherently DC, the distribution architecture bears directly on how easily a battery integrates. The long-standing default within electric architectures has been a fixed-frequency AC bus, with generators at synchronous speed and frequency-converters feeding variable-speed motors. Onboard DC distribution—pioneered by ABB’s Onboard DC Grid and now offered by all major suppliers—has gained ground steadily over the past decade. A DC bus lets engines and generators run at their best specific fuel consumption rather than at fixed frequency, removes one conversion stage between battery and motor, simplifies integration of multiple DC sources (batteries, fuel cells, solar), and reduces switchboard mass (Sulligoi et al., 2016; Geertsma et al., 2017). Reported fuel savings against comparable AC vessels span roughly 10–15% across realistic duty cycles, largest where load is most variable. AC remains the incumbent on large cruise and naval platforms where high-power short-circuit protection is more mature, but the direction of travel in distribution architecture for battery-rich vessels is clearly toward DC. Overall, DC architectures both improve fuel efficiency and make batteries cheaper to integrate—a complementarity that strengthens the design-stage case for electrification.

2.4 Comparison with alternative fuels

2.4.1 Cost trajectory and spillovers

The trajectory of maritime batteries is best read against the much larger markets that drive cell development. Lithium-ion pack prices fell from above US\$1,000 per kWh in 2010 to roughly US\$115 per kWh by the mid-2020s—a sustained learning rate of about 19% per doubling of cumulative production, overwhelmingly financed by road transport and stationary storage (BloombergNEF, 2024). Electric cars passed one in five new vehicles sold globally, electric buses became the default choice for new urban fleets in several countries, and grid-scale storage scaled from negligible to tens of gigawatt-hours per year. Shipping is therefore a *technology taker*: it inherits cheaper, safer, longer-lived cells—LFP chemistry, in particular, migrated into marine use precisely because volume manufacturing made it cheap and durable. The same pattern that moved road transport up the size and range ladder, from scooters and cars to delivery vans and now long-haul trucks, is the most reliable indicator of where the economically electrifiable boundary in shipping will sit a decade hence: it moves outward with increases in global cell production, largely independent of maritime demand.

In contrast, shipping’s zero-carbon synthetic fuel options do not benefit as much from sectoral spillovers. Markets for ammonia (mostly fertiliser) and methanol (mostly formaldehyde and plastics) are substantial, but the high costs of zero-carbon production imply uncertain growth from a small base, and existing production methods in these mature feedstock markets do not drive the learning-rate decline that road-EV and grid-storage volumes have given batteries. In short, ship batteries inherit progress and scale while ship synthetic fuels must finance it.

2.4.2 Energy cost and operational profile

While alternative zero-emission fuels can retain some of the operational flexibility of fuel oil, they are typically several times more expensive per joule, less volumetrically dense, and impose more demanding handling and safety systems (Korberg et al., 2021). Their operational gains over heavy fuel oil are climate benefits and reductions in sulphur, particulates and (for ammonia and hydrogen) carbon-bearing pollutants. In contrast, the variable cost of propulsion energy using batteries is already *below* that of fuel oil where electricity is cheap, while also eliminating local pollutants and underwater noise.

2.4.3 Energy security and independence

A further driver, distinct from cost and climate, is energy security. Marine fuel oil is a globally traded petroleum product whose price is exposed to OPEC decisions, geopolitical shocks and maritime chokepoints; for the many states that import it, bunkering is a continuous claim on foreign exchange and a standing supply vulnerability. Direct electrification changes this de-

pendence: a battery-electric vessel runs on electricity that can be generated domestically, and is insulated from fuel-price volatility. In contrast, e-fuels will most likely be produced where renewable energy is cheapest and then traded internationally, reproducing import dependence under a new set of exporters. The qualification is that battery manufacturing is itself geographically concentrated; but electrification converts a continuous, disruptible fuel import into a one-off equipment purchase followed by domestic energy—a structurally more secure position. The argument is strongest for domestic and short-sea fleets drawing on the national grid.

3 Where battery-electric ships already work

Battery propulsion is no longer speculative; in several segments it is the incumbent-displacing technology. Table 2 traces its trajectory through milestone newbuilds: pack size has grown rapidly and the addressable segment has expanded from short fjord crossings to autonomous container feeders, inland swap barges and fast ro-pax vessels on international routes—each entry sitting one rung higher on the ladder.

Table 2: Selected milestone battery-electric vessels, illustrating the expansion of pack size and addressable segment over the decade to 2026. Pack sizes are from builder and operator announcements and are indicative.

Year	Vessel	Route / country	Type	Pack (MWh)
2015	<i>Ampere</i>	Sognefjord, Norway	Car/pax ferry	1.0
2019	<i>Ellen</i>	Søby–Fynshav, Denmark	Car/pax ferry	4.3
2019	<i>Color Hybrid</i>	Sandefjord–Strömstad	Plug-in hybrid ro-pax	5.0
2021	<i>Bastø Electric</i>	Moss–Horten, Norway	Car/pax ferry	4.3
2022	<i>Yara Birkeland</i>	Brevik, Norway	Autonomous container feeder	7.0
2024	<i>Greenwater 01</i>	Yangtze, China	Inland container, swap packs	~50
2025	<i>China Zorrilla</i>	Buquebus, Río de la Plata	Fast battery ro-pax	~40
2026	<i>Zen</i> (2 ordered)	Hamburg–Oslo corridor	Short-sea container	>100

Note. Selected, not exhaustive. The 2026 entry is on order, with delivery expected from 2028.

3.1 The electrification sequence

These segments fall on a predictable ladder ordered by voyage length and battery capacity. The sequence begins with the shortest, most repetitive duty cycles, where the energy-density penalty is smallest and a single berth serves every sailing: harbour ferries and river crossings, then tugs and workboats. It advances to inland barges and short-sea coasters, which travel further but call frequently near grid connections, often using battery swapping. It then reaches longer coastal and regional routes that remain *anchored to ports*—fixed end-points where high-power charging or swap infrastructure can be concentrated. Finally come the open-ocean trades where electrification, if it occurs at all, would likely be mediated by infrastructure.

Each rung is unlocked by the same two levers: cheaper packs and more available charging power at fixed points. Long merchant-ship asset lives (25–30 years) expose owners to battery-

cost and technology risk, yet total-cost-of-ownership studies already find battery propulsion competitive on high-utilisation short routes, with the viable-route threshold falling each year as cell prices decline (BloombergNEF, 2024; Mackenbach et al., 2026; Moon et al., 2024; Perčić et al., 2020). Policy affecting capital investment should follow the ladder, concentrating scarce charging capital where vessels are tethered to known locations.

The *value* of electrification can vary along the ladder. While greenhouse- gas abatement scales with the carbon intensity of the supplied electricity, the local air-quality and underwater-noise gains accrue wherever combustion is displaced and are largest where vessels operate close to people; further reasons why urban ferries and harbour craft electrify earliest.

3.2 Ferries

Short-route ferries are the flagship application. Norway has led deployment, catalysed by the all-electric *Ampere* (Sognefjord, 2015) and by grant funding and procurement that together made zero-emission operation a tender condition; scores of electric and plug-in hybrid ferries now operate on Norwegian fjord crossings, with comparable projects in Denmark (*Ellen*), Sweden, Canada and China (Anwar et al., 2020). Fixed routes, predictable schedules, frequent dockings and public-sector ownership make ferries the ideal early market: charging is designed into the berth, the duty cycle is known in advance, and the cycling-economics argument of §2.1 is at its most favourable.

3.3 Harbour tugs and workboats

Harbour and escort tugs spend much of their duty cycle idling or in transit and deliver short bursts of high bollard pull. Battery and hybrid tugs exploit this profile: Crowley’s *eWolf* (San Diego, 6.2 MWh, 2024) was the first fully electric harbour tug to enter regular US service, and equivalent vessels are operating in Auckland, Singapore and Istanbul. Pilot boats, patrol craft and other workboats follow similar logic on smaller scale.

3.4 Inland and short-sea vessels

Inland barges and short-sea coasters operate over modest distances with regular port calls and near grid connections. Containerised swappable battery concepts have been demonstrated commercially on the Dutch and Belgian inland network through the Zero Emission Services (ZES) consortium, and the Chinese inland container vessel *Greenwater 01* entered service on the Yangtze in 2024 with a similar architecture (Table 2), both decoupling charging from vessel turnaround. The 100–400 km short-sea band is the contested frontier where viability turns on charging power, electricity price and battery cost.

3.5 Coastal and regional routes

Voyage energy on these routes rises steeply with speed and distance, demanding large pack size and charging power. Ro-pax services lead deployment: the 2025 *China Zorrilla* (Buquebus, ~40 MWh, Table 2) crosses the Río de la Plata fully electrically, and plug-in hybrid ro-pax such as *Color Hybrid* operate longer Scandinavian crossings on a mix of battery and fuel. Such hybridisation—sizing the battery for most at-sea energy while retaining engines for the longest legs—is emerging as the pivotal configuration here: a pre-feasibility study of deep-sea container ships finds a viable case when batteries supply around 80% of at-sea energy, the balance from methanol gensets (Seidl-Zelenka & Normann de Boer, 2024). Coastal feeder containerships and offshore supply vessels are plausible next adopters as cell prices fall, though few are yet in service: in 2026 the Norwegian group Zen ordered two 900-TEU container ships carrying over 100 MWh of batteries for a 500–600 nautical-mile range, intended for a Hamburg–Gothenburg–Oslo corridor (The Maritime Executive, 2026).

3.6 The deep-sea frontier

The hardest and largest-emitting segment is the ocean-going container ship, bulk carrier or tanker, where no zero-emission pathway is yet established. For batteries, cycling economics suggests mediating infrastructure would be required. Fixed offshore charging stations positioned along busy corridors, at which vessels pause to recharge mid-voyage, are one option (Li et al., 2025). Another is to use a fleet of dedicated battery vessels that can rendezvous with and power ships under way for a limited time; these fleets would best operate on busy, calmer routes close to land and with access to cheap electricity (Wiskich, 2025). Both approaches would involve hybrid host ships as fuel would still be needed for long route sections where mediating infrastructure is not viable, and to provide operational flexibility. So electrification would be partial at best, reducing the need for fuel.

4 Charging and shore infrastructure

Electrification shifts the energy-system burden from vessel to port. Charging a large vessel during a short turnaround requires megawatt to tens-of-megawatts power, which can exceed local distribution capacity and attract severe demand-charge costs.

These pressures are eased by decoupling the power delivered to the vessel from the power drawn from the grid. At the berth the delivery method is either a high-power conductive or automated plug-in connector or battery swapping, where discharged container-format packs are exchanged for charged ones. Swapping decouples grid draw intrinsically, as the spare packs charge slowly ashore, whereas a connector transfers the full charge in a single high-power burst unless a shoreside buffer battery—drawing steady grid power and discharging rapidly through the connector—is placed behind it to cap the grid draw. The buffer concept extends offshore: the

ABB–SeaFjord Energy “e-bunker” vessel, a mobile battery ship delivering up to ~50 MW and able to recharge other vessels in ports, fjords or offshore from a shore or wind-farm connection, is an industry realisation of charge-delivery decoupled from a fixed berth (ABB, 2024). Fixed offshore charging is likewise moving from concept to service: charging buoys now let crew-transfer and service vessels at some offshore wind farms recharge at sea rather than returning to port.

These responses build on existing infrastructure: shore-power (cold-ironing) connections, mandated in a growing number of jurisdictions for at-berth emissions, provide part of the electrical backbone that vessel charging can build upon. Connector geometries, automated plug-in mechanisms and swap-pack physical dimensions are still vendor-specific; the OCIMF (2023) tanker shore-power recommendation is one of the first cross-industry technical specifications.³

The cost of upgrading a berth or grid connection is lumpy and route-specific, so the first operator on a route bears a fixed cost that later entrants share—a first-mover disadvantage that slows the very deployment that would spread the cost. Demand charges can likewise dominate operating cost if charging is left unmanaged, making load scheduling and shoreside buffering (above) central to a viable charging business case.

Managed charging is moreover an asset, not merely a cost to be contained. Unlike a fixed industrial load, a vessel or shoreside battery is flexible in *when* it draws power, so charging can be shifted into periods of cheap, abundant or low-carbon electricity and absorb renewable surplus that would otherwise be curtailed (Mimica et al., 2022). Where the connection is bidirectional, the same battery can discharge back to the grid—ship-to-grid operation—providing balancing and arbitrage services that earn revenue and improve the charging business case (Frković et al., 2025). Port and vessel batteries thus couple maritime electrification to grid flexibility, turning a charging demand into a dispatchable resource.

5 Policy and regulation

In addition to a lack of shore charging and of broad carbon and fuel taxes, international harmonisation of connector, swap-pack and communication *standards* is incomplete, fragmenting the market and weakening the network effect that would attract later entrants; the Maritime Battery Forum (2023) containerised-system guideline is the most visible response. *Safety governance*—thermal-runaway risk, gas detection, fire suppression, deflagration venting and crew competence—is similarly mid-maturity: class rules are converging but still diverge between societies, complicating flag-state administration approvals and resale.

Action is nonetheless accelerating. Classification societies have issued battery rules and type-approval frameworks; the IMO’s revised greenhouse- gas strategy (International Maritime Organization, 2023) and its energy-efficiency and carbon-intensity instruments strengthen the commercial case for zero-emission technologies; regional measures such as the EU ETS extension to shipping and FuelEU Maritime (European Union, 2023) add direct price signals;

and port authorities are investing in shore power and high-power charging. Local externalities add a bottom-up driver: port cities facing air-quality, health and noise pressure increasingly mandate shore-to-ship power for vessels at berth, as in the EU's shore-power requirements for major ports. Industry-led action complements regulation: government–industry green shipping corridors target zero-emission routes that often suit batteries, cargo-owner buyer coalitions are creating demand-side pull, and consortia such as Zero Emission Services coordinate the swap and standards ecosystems.

A low-regret path is to help establish the enabling infrastructure — port electricity, swap standards — that has value across multiple decarbonisation pathways, such as electrification of stevedoring, and is a prerequisite for the battery pathway. Electricity pricing matters alongside hardware: time-varying tariffs and access to wholesale and balancing markets let operators capture the value of flexible charging and ship-to-grid discharge (§4), rewarding the flexibility that also lowers system-wide costs.

A standing risk to battery adoption is policy dilution. Public support and shipowner attention are spread across a broad slate of candidate decarbonisation technologies, each with its own advocates. Spreading scarce capital thinly across many options can delay the infrastructure rollouts and standards work that batteries depend on for their next decade of growth. Regular review of policy settings against the latest cost, safety and deployment data will help ensure support tracks the changing cost and safety landscape rather than yesterday's expectations.

6 Conclusion

Battery-electric propulsion is a highly efficient zero-emission option in shipping and is already the displacing technology for ferries, harbour craft and inland vessels; the 100–400 km short-sea band is the contested frontier where the boundary is currently moving. Its reach is bounded by cycling economics and the capital demands of batteries and charging infrastructure. Where electricity is cheap, batteries already undercut fuel oil per useful joule, particularly for auxiliary loads, and run on domestic rather than imported energy.

The realistic trajectory is incremental: the electrifiable niche widens as pack prices fall and charging networks mature, hybrid and PTO/PTI configurations capture efficiency gains across a far larger fleet in the interim, and deep-sea decarbonisation, if it occurs via batteries, proceeds through partial, infrastructure-mediated concepts rather than wholesale fuel substitution. Low-regret policy paths include port electricity infrastructure, harmonised standards and broad emissions pricing.

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Endnotes

¹These figures are rounded to single round numbers to convey order of magnitude only. The battery value is pack capital of about US\$100 per kWh ($\approx$ \$100,000 per MWh of usable storage; cf. the \$115/kWh of §2.4.1), whereas the fuel value is the commodity cost of the stored energy itself—marine fuel oil at roughly \$500 per tonne and $\sim$ 5 MWh per tonne of useful propulsive energy (Table 1) is of order \$100 per MWh.

²The gain compounds two effects: the auxiliary generator's lower efficiency ($\sim$ 40%, against the main engine's $\sim$ 50%) and the absence of the $\sim$ 10% electric-drive/train conversion loss incurred when electricity drives the propeller. Electricity is thus about 2.4 times as effective as fuel for auxiliary loads, against about 1.8 times for propulsion.

³Standardisation efforts include IEC and ISO work on high-power shore connection and charging interfaces.

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