Technology Roadmap

Competitive, resilient and sustainable ferry sector

Contents

1. Description of the Sector

1.1. Definition and scope

In European transport policy, ferry services form part of the broader short sea shipping (SSS) domain[1]. For the purposes of the Waterborne technology roadmaps, however, ferries are treated as a separate segment from cargo-based SSS, because their operating profile, passenger-safety regime, public-service role, hotel-load requirements and electrification potential differ significantly from those of freight-oriented short sea shipping. As such, a ferry service is understood as a regular transport service linking two or more ports, operating either according to a published timetable or with crossings so frequent and regular that they constitute a systematic service[2]. Ferry services are distinct from cruises, which are transport services operated exclusively for pleasure or recreation, supplemented by accommodation and other facilities, and exceeding two overnight stays on board[3]. In this roadmap, ferries are considered as scheduled transport services whose primary function is mobility and connectivity.

The ferry segment covered by this roadmap includes two main categories. The first is passenger-only ferries, including urban, harbour, inter-island and coastal services. The second is Roll-on/Roll-off Passenger vessels, or RoPax vessels, which combine passenger transport with the carriage of accompanied vehicles and, in some cases, freight units on the same hull[4]. Freight-only Ro-Ro vessels are excluded from this roadmap and are addressed under the Short Sea Shipping roadmap.

The roadmap covers four operational ranges:

1. **Urban and harbour ferries**: very short routes of a few nautical miles, with fixed endpoints, very high call frequency, short crossing times and highly predictable energy profiles. These services are strong candidates for full electrification.
2. **Inter-island and short coastal ferries**: services typically covering approximately 20 to 50 nautical miles, often with daily multi-rotation patterns. These routes are particularly important in archipelagic networks, including in Greece, Italy, Croatia, Denmark and Spain.
3. **Medium-range RoPax services**: services typically covering approximately 50 to 200 nautical miles, combining passenger transport, accompanied vehicles and significant hotel loads. They are important for Baltic, North Sea, Adriatic and Tyrrhenian connections.
4. **Long-distance RoPax services**: services extending up to approximately 500 nautical miles, including overnight crossings. These vessels have the highest hotel-load requirements and are concentrated in Mediterranean and Baltic–North Sea routes.

[1] Regulation (EU) 2024/1679 on Union guidelines for the development of the trans-European transport network
[2] Eurostat/ITF/UNECE, Glossary for Transport Statistics, 5th edition, definition of "maritime ferry service"
[3] Regulation (EU) No 1177/2010, Article 3; definitions of "passenger serevice" and "cruise".
[4] Waterborne Technology Platform, *Strategic Research and Innovation Agenda for the Partnership on Zero-Emission Waterborne Transport* (Brussels: Waterborne TP, 2021), 30.

1.2. Strategic role in the European waterborne ecosystem

Ferries play a distinct role in the European waterborne transport system because they combine passenger mobility, territorial continuity and, in the case of RoPax vessels, vehicle and rolling-cargo transport. They are essential for islands, archipelagos, outermost regions and coastal communities, where regular maritime links often provide the main connection to national and European transport networks. In this respect, ferry services support access to employment, education, health services, tourism, trade and essential goods.

Ferries also complement the trans-European transport network and form part of the European Maritime Space[5]. They connect passenger ports with road and rail networks, urban transport systems, regional logistics chains and, where relevant, inland waterways. Their role is particularly important in the Mediterranean, Baltic, North Sea and Adriatic regions, where ferry services support both domestic and cross-border mobility.

The sector also has a resilience and dual-use dimension. Vehicle decks, passenger accommodation, regular schedules and frequent turnarounds make ferries relevant for evacuation, emergency relief, civil protection and, where appropriate, troop and equipment transport. Ferry modernisation can therefore contribute not only to climate and transport objectives, but also to preparedness, regional resilience and continuity of essential services[6].

Ferries are also industrially relevant for Europe. They require advanced ship design, passenger-safety systems, hotel-load integration, vehicle-deck arrangements, electrical systems, terminal interfaces and specialised shipyard capabilities. Fleet renewal and retrofitting can therefore support European shipyards, equipment manufacturers, ports, digital-service providers and clean-energy suppliers, while strengthening European technological leadership in a segment with strong domestic demand and export potential.

1.3. Operational profile

The operational profile of ferries differs from cargo-based short sea shipping because ferry services combine scheduled passenger mobility, short and frequent port calls, passenger-safety requirements and, in the case of RoPax vessels, vehicle and rolling-cargo handling. Ferry operations are therefore shaped not only by voyage distance and vessel size, but also by timetable reliability, terminal capacity, passenger flows, vehicle loading, hotel loads and the availability of shore-side energy infrastructure.

Three operational features structure technology choice:

1. **Route predictability**. Because ferries operate on fixed routes, vessel operators, ports, energy suppliers and public authorities can estimate energy demand, charging windows, shore-power requirements, passenger volumes and turnaround needs with relatively high accuracy. This makes ferries particularly suitable for route-specific deployment packages, where vessel technologies, terminal infrastructure and energy supply are planned together.

[5] Regulation (EU) 2024/1679 on Union guidelines for the development of the trans-European transport network

[6] European Commission, *An EU Industrial Maritime Strategy*, COM(2025), section 4.3

2. **Berth time and turnaround performance**. Many ferry services operate with short port stays and narrow timetable windows. During these periods, passenger embarkation and disembarkation, vehicle loading and unloading, safety checks, shore-power connection, charging, bunkering and provisioning may need to take place in parallel. This creates specific requirements for terminal design, automated or high-efficiency energy interfaces, safe operating procedures and digital coordination between vessel and port.
3. **Continuous hotel-load requirement**. Lighting, heating, ventilation, air-conditioning, galleys, cabins, navigation systems, passenger services and safety systems require reliable power throughout the voyage and while the vessel is at berth. For medium- and long-distance RoPax vessels, hotel loads can be substantial and must be considered together with propulsion demand when assessing electrification, hybridisation, fuel-cell integration, shore power and onboard energy-management systems.

Passenger safety and service reliability are central to ferry operations. Ferry services carry large numbers of passengers, often including commuters, tourists, island residents, people with reduced mobility and accompanied vehicles. Technologies introduced on ferries must therefore support safe embarkation and disembarkation, emergency preparedness, fire safety, crowd management, cybersecurity, accessibility and service continuity.

1.4. Sector baseline and market characteristics

The European ferry sector is large, geographically concentrated and operationally diverse. The statistics in this section draw on different but complementary datasets. Passenger-volume figures refer to passengers embarked and disembarked in EU seaports, excluding cruise passengers. Fleet figures refer to ferries and passenger-only vessels identified within EU short sea traffic and do not capture the entire European ferry stock, especially smaller urban, harbour and national ferry services. Flag-state and alternative-fuel statistics refer to the fleet categories used in the relevant EMSA, DNV and EAFO datasets.

In 2023, EU seaports recorded approximately 395 million passengers embarked and disembarked, recovering to within 6 % of the 2019 pre-pandemic level of 418 million.[7] Intra-national maritime passenger transport accounted for approximately 65% of all passengers embarked and disembarked in EU seaports in 2023, confirming the central role of domestic, regional and island ferry services in European maritime passenger mobility.

Italy, Greece, Denmark, Croatial and Spain together accounted for approximately 68% of EU maritime passenger movements in 2023. This concentration reflects the importance of ferry services in the Mediterranean, the Baltic and the North Sea, as well as the role of islands, archipelagos and short cross-border corridors in shaping European passenger flows. The geographic concentration is set out in Table 1.

[7] European Commission, *Study on Short Sea Shipping's Contribution to the European Transport Network*, 38-39, based on Eurostat dataset mar_mp_aa_cph.

Member State	Passengers embarked/disembarked (million)	Share of EU total
Italy	85	22 %
Greece	75	19 %
Denmark	41	10 %
Croatia	34	9 %
Spain	32	8 %
Top 5 combined	**267**	**68 %**
EU-27 total	≈ 395	100 %

Table 1: *Maritime passenger transport in the EU — leading Member States, 2023*

(Cruise passengers excluded. Source: Eurostat (mar_mp_aa_cph), as reported in European Commission, Study on Short Sea Shipping's Contribution to the European Transport Network, 2025.)[8]

Two main passenger flow patterns can be distinguished. Mediterranean ferry services dominate by total passenger volume, connecting mainlands with large islands and archipelagos (Sicily, Sardinia, the Aegean islands, the Dalmatian coast, the Balearics). The Reggio Calabria-Messina route is the highest-volume passenger route in the EU.[9] Baltic and North Sea services are particularly important for international intra-EU ferry traffic, with dense cross-border corridors such as Helsinki-Tallinn and Helsingborg-Helsingør. Latvia, Lithuania, Finland, Poland, Sweden, Estonia, Denmark and Germany report the highest international intra-EU shares.[10] By fleet registration, concentration is also significant. Approximately 57 % of the European passenger fleet considered in the EMSA baseline is flagged in four countries, namely Norway (19 %), Greece (14 %), Italy (13 %) and Croatia (11 %).[11]

Fleet structure is heterogeneous. Available EU-level data identify 206 ferries or RoPax-equivalent vessels and 853 passenger-only vessels engaged in EU short sea traffic in 2024, distributed across four GT classes (see Table 2). These figures do not capture all urban, harbour and national ferry services, and therefore underestimate the full European ferry stock. They nevertheless provide a useful baseline for understanding the diversity of the sector and the distinction between smaller passenger-only vessels and larger RoPax units.

[8] Ibid., 39, based on Eurostat dataset mar_mp_aa_cph; cruise passengers excluded
[9] Ibid.,39.
[10] Ibid
[11] European Maritime Safety Agency, *The 2025 European Maritime Safety Report*, Chapter 2 “Flag state”, section 2.3.1, 75.

Vessel type	< 500 GT	500-25,000 GT	25,000-60,000 GT	> 60,000 GT	Total
Ferries (RoPax and equivalent)	9	63	102	32	206
Passenger-only vessels	554	256	34	9	853
Combined	**563**	**319**	**136**	**41**	**1,059**

Table 2: Ferries and passenger-only vessels engaged in EU short sea traffic by size class, 2024 (Source: European Commission, Study on Short Sea Shipping's Contribution to the European Transport Network, 2025, based on Vessel Finder, ferry operators and consortium estimation.[12])

A major structural issue is fleet age. EU Member State-flagged passenger ships have one of the highest average ages among ship categories, reaching approximately 29 years in 2023. RoPax vessels also show a relatively old age profile, with an average age of around 28 years, while high-speed craft are younger, averaging around 15 years.[13] Of the passenger ships that entered EU Member State flags between 2019 and 2023, more than one third were already over 25 years old.[14] Given typical vessel lifetimes of around 25 to 30 years, ferry newbuilds ordered and delivered in the next decade are likely to remain in service close to, or beyond, 2050. This makes early adoption of zero- and near-zero emission designs, retrofit-ready architectures and fuel-flexible systems essential for keeping the sector aligned with the climate-neutrality trajectory.[15]

The current fuel and propulsion baseline remains predominantly fossil-based, but ferries are among the most advanced waterborne segments for battery-electric and hybrid deployment. According to the DNV Alternative Fuels Insight platform, the EU Member State-flagged fleet included 320 battery-equipped ships in 2023, representing approximately 2.5 % of the fleet, of which 14 % were pure-electric, 58 % hybrid and 25 % plug-in hybrid. Passenger ships accounted for 48 % of all battery vessels, making them the largest ship category within the battery-equipped fleet. Most battery-equipped vessels are hybrid or plug-in hybrid, indicating that electrification is progressing but remains uneven across routes and vessel types. Passenger ships also represent a notable share of LNG-ready EU-flagged vessels, accounting for approximately 23% of that category. This confirms that parts of the ferry sector have already adopted alternative-fuel-ready propulsion, although LNG and bio-LNG should be treated as transitional options subject to methane-slip control and lifecycle emission performance.

European experience demonstrates that battery-electric and hybrid ferry operations are already feasible on suitable routes. Norway, although outside the EU, is the leading European reference market,

[12] Ibid., 87, Table 6.3, based on Vessel Finder data and consortium estimation
[13] European Maritime Safety Agency, *The 2025 European Maritime Safety Report (EMSAFE)* (Lisbon: EMSA, 2025), Chapter 2 "Flag state", Tables 21 and 23, [Publications - EMSAFE Report 2025 - EMSA - European Maritime Safety Agency](), 84-85.
[14] European Maritime Safety Agency, *The 2025 European Maritime Safety Report*, Chapter 2 "Flag state", 77 and 85.
[15] European Maritime Safety Agency, *The 2025 European Maritime Safety Report*, Chapter 2 "Flag state", section 2.3.4, 84.

with more than 80 electric ferries in operation[16]. Reference examples include the Bastø Electric on the Oslo Fjord and the Danish e-ferry *Ellen* (4.3 MWh battery, 22 nautical miles per charge).[17]

1.5. Ferries as a technology-leadership opportunity

Ferries represent one of the most promising early deployment markets for European waterborne technology leadership. Their operational regularity, close connection with terminals and high visibility to passengers make them a practical environment for demonstrating zero- and near-zero-emission propulsion, shore-side electricity, high-power charging, digital vessel–port coordination and passenger-centred service innovation. Existing European ferry deployments have already generated transferable experience in vessel design, energy-system integration, safety procedures, charging infrastructure and operational planning, which can support wider deployment across the waterborne sector.

The opportunity is strongest where vessel technologies, terminal infrastructure and energy supply can be planned together. Urban, harbour and short-distance routes are well suited to early electrification, while inter-island, short coastal and longer RoPax services will require a broader mix of battery-electric, hybrid, fuel-flexible, fuel-cell, shore-power and energy-efficiency solutions.

Ferry modernisation also links climate action with public value and industrial competitiveness. Cleaner and more reliable ferry services can reduce emissions in ports and coastal communities, improve passenger experience, support island and peripheral connectivity, and strengthen the resilience of essential transport links. At the same time, fleet renewal and retrofitting can support European shipyards, equipment suppliers, electrical-system integrators, port-energy providers and digital-service companies.

2. Drivers and Constraints

The transformation of the ferry sector is driven by the interaction of climate regulation, passenger-ship safety policy, port and infrastructure strategy, industrial policy, the dual-use preparedness agenda and territorial cohesion policy for islands. The most important drivers are set out below.

- **Climate, fuel and infrastructure regulation.** The European climate-neutrality trajectory, the extension of emissions pricing to maritime transport, FuelEU Maritime requirements and alternative-fuel infrastructure rules create a clear direction for fleet renewal, emissions reduction, shore-power deployment and the uptake of renewable and low-carbon fuels. For ferries, these instruments are particularly important because many services operate repeatedly between the same ports, making compliance dependent on the alignment of vessel investment, fuel availability, charging capacity and terminal infrastructure.[18]

[16] European Maritime Safety Agency, *The 2025 European Maritime Safety Report*, Chapter 2 “Flag state”, section 2.3.5 and Figure 21, 85, citing the DNV Alternative Fuels Insight platform.
[17] European Commission, *Study on Short Sea Shipping’s Contribution to the European Transport Network*, 92.
[18] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality (European Climate Law), OJ L 243, 9.7.2021; political agreement of December 2025 between the European Parliament and Member States on a binding 90 % net GHG reduction target for 2040, with up to 5 % met through high-quality international credits; Regulation (EU) 2023/1805 (FuelEU Maritime), OJ L 234, 22.9.2023; Directive (EU) 2023/959 (EU ETS Maritime), OJ L 130, 16.5.2023; Regulation (EU) 2023/1804 (AFIR), OJ L 234, 22.9.2023, Article 9.

- **Port electrification and vessel–terminal integration.** Ferry decarbonisation depends not only on propulsion choices, but also on shore-side electricity, high-power charging, grid reinforcement, berth allocation, terminal design and safe connection procedures. Ports are therefore becoming energy and system-integration nodes for ferry services. This is especially relevant for high-frequency urban, harbour and inter-island routes, where the feasibility of clean propulsion depends on the availability of reliable energy infrastructure at both ends of the route.[19]
- **Territorial cohesion and public-service connectivity.** Ferries are essential for islands, archipelagos, outermost regions and coastal communities, where they often provide lifeline mobility and access to essential goods and services. Public Service Obligation schemes, island connectivity policies and regional development instruments can therefore support the deployment of cleaner and more reliable ferry services, provided that technology costs remain compatible with affordability and continuity of service.[20]
- **Passenger safety, resilience and preparedness.** Ferries carry large numbers of passengers and vehicles, operate in dense port environments and often provide essential transport capacity during emergencies. Modernisation must therefore support fire safety, evacuation, passenger registration, vehicle-deck safety, emergency response, cybersecurity and service continuity.[21] In the wider TEN-T context, resilient ferry links and RoPax capacity may also contribute to crisis response, civil protection and, where relevant, military mobility, particularly on routes connecting islands, peripheral regions and strategic corridors.[22]
- **Technology maturity.** Battery-electric and hybrid propulsion, shore power, onboard energy-management systems, digital twins, route optimisation and condition-based maintenance are already available for suitable routes. Fuel-cell systems, methanol-capable engines, hydrogen solutions and other fuel-flexible architectures are developing for more demanding ferry and RoPax applications, although they require further demonstration, safety validation and infrastructure readiness. The ferry sector can therefore support a staged deployment pathway, from short electrifiable routes to more complex inter-island, coastal and longer-distance RoPax services.[23]

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[19] European Commission, Communication on the EU Ports Strategy (Brussels, 2026), section 3.1 (port electrification, OPS, grid capacity), section 4.2 (climate resilience and the European Integrated Framework for Climate Resilience, 2026), and Annex Summary of Measures, Pillar II; European Sea Ports Organisation, Environmental Report 2025 — EcoPorts inSights 2025, as cited therein.

[20] European Commission, Communication: Sustainable and Smart Mobility Strategy — putting European transport on track for the future, COM(2020) 789 final, 9.12.2020, paragraphs 26-27 (Emission Control Areas) and 88-90 (PSOs, islands and outermost regions); OECD, Policy Pathways Beyond the Shoreline (Paris: OECD Publishing, 2026), Chapter 5 (cost of insularity) and Chapter 7 (Croatia, Greece, Sweden case studies).

[21] European Commission, An EU Industrial Maritime Strategy, COM(2026) 111 final, section 3.3 and Annex Summary of Measures, Pillar II; Directive 2009/45/EC, OJ L 163, 25.6.2009; Directive (EU) 2017/2110, OJ L 315, 30.11.2017; Directive 2003/25/EC, OJ L 123, 17.5.2003, as amended by Directive (EU) 2023/946, OJ L, 12.5.2023; Council Directive 98/41/EC, OJ L 188, 2.7.1998; Directive 2014/90/EU, OJ L 257, 28.8.2014; European Maritime Safety Agency, The 2025 European Maritime Safety Report (Lisbon: EMSA, 2025), Chapter 5 “Coastal state”, 44-46 and 185.

[22] European Commission, Proposal for a Regulation on Military Mobility, COM(2025); European Commission and High Representative, Joint Communication on the European Preparedness Union Strategy, JOIN(2025) 130 final, Brussels, 26 March 2025; Joint Communication on Military Mobility, JOIN(2025), referenced in European Commission, An EU Industrial Maritime Strategy, COM(2026) 111 final, section 4.3 “Supporting military mobility and emergency preparedness” and Annex Summary of Measures, Pillar III.

[23] Waterborne Technology Platform, Strategic Research and Innovation Agenda for the Partnership on Zero-Emission Waterborne Transport (Brussels: Waterborne TP, 2021), 30, 47 (solid-state battery horizon) and 67 (alternative-fuel bunkering challenges); IEA, Energy Technology Perspectives 2026, Chapter 3, “Ammonia and methanol propulsion ships”, 129 (TCO gap and bunkering-port readiness).

- **Industrial competitiveness.** Fleet renewal and retrofitting can support European shipyards, repair yards, equipment suppliers, electrical-system integrators, battery and fuel-cell suppliers, port-energy providers and digital-service companies. Because ferries combine vessel design, passenger safety, hotel loads, vehicle decks, electrical systems and terminal interfaces, they offer a strong opportunity for European technology leadership in an integrated maritime segment.[24]

2.2 Constraints

The transition is constrained first by fleet age, diversity and renewal economics. Ferries differ widely in size, route length, frequency, passenger capacity, vehicle-deck configuration and hotel-load requirements. This means that there is no single decarbonisation pathway for the whole sector. Many vessels will remain in service for years, making retrofitability, modularity, fuel flexibility and lifecycle-cost reduction essential. At the same time, newbuild decisions taken in the coming decade will strongly influence the sector's ability to remain aligned with the 2050 climate-neutrality trajectory.[25]

- **A second constraint is the mismatch between vessel needs and port-energy infrastructure.** Full-electric and plug-in hybrid ferries require reliable shore-side electricity, sufficient grid capacity, high-power charging systems, safe connection procedures and adequate berth time. These conditions are not yet evenly available across European ferry networks, and the challenge is sharper for smaller ports, islands and seasonal routes. A single weak link in a ferry route can limit the deployment of clean propulsion, even where the vessel technology itself is mature.[26]
- **Fuel uncertainty remains a major bottleneck for medium- and long-distance RoPax services.** Operators face uncertainty over the availability, price, sustainability credentials and lifecycle-emission performance of biofuels, e-fuels, methanol, hydrogen, ammonia and other future fuels. LNG and bio-LNG may provide transitional options in some cases, but their contribution depends on methane-slip control and credible lifecycle-emission performance. Hydrogen, ammonia and onboard carbon-capture applications on passenger vessels still require further safety qualification, bunkering infrastructure and operational validation.[27]
- **Financing and affordability are particularly important constraints for ferry operators serving islands, archipelagos and peripheral regions.** Zero- and near-zero-emission vessels, charging systems, port upgrades and safety adaptations require high upfront investment. Smaller operators often have limited balance-sheet capacity, while Public Service Obligation routes may operate with short concession periods, regulated tariffs, seasonal demand and limited revenue potential.

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[24] European Commission, An EU Industrial Maritime Strategy, COM(2026) 111 final, "EU maritime manufacturing industrial vision by 2030" and Annex Summary of Measures, Pillar I (public procurement pipeline including ferries) and Pillar V (finance and investment).

[25] European Maritime Safety Agency, The 2025 European Maritime Safety Report, Chapter 2 "Flag state", Tables 5, 21 and 23, 73, 77 and 84-85; Waterborne Technology Platform, Strategic Research and Innovation Agenda, 14, sections on "Diversity of the sector" and "Age of vessels".

[26] Waterborne Technology Platform, Strategic Research and Innovation Agenda, 14, 47-48 (energy models and shore-side electricity for passenger ships) and 67 (lack of standards for higher-power cold ironing for large passenger vessels); European Commission, Communication on the EU Ports Strategy, section 3.1.

[27] European Community Shipowners' Associations, The Economic Value of European Shipping: 2026 Update, Annex 1; Clarksons Research, World Fleet Register database, 2026; DNV, Maritime Forecast to 2050, 2025; Transport & Environment, E-fuels observatory for shipping, 2024; IEA, Energy Technology Perspectives 2026, Chapter 3.

Without suitable financing models, public support and risk-sharing mechanisms, the cost of decarbonisation could be passed to captive users or delay investment altogether.[28]

- **Safety and regulatory readiness remain critical.** Alternative fuels, large batteries, high-voltage charging, fuel cells, methanol, hydrogen, ammonia, automation and cyber-physical systems introduce new risks in passenger-vessel operations. These risks must be addressed through updated standards, certification procedures, emergency-response protocols, crew training, port preparedness and practical approval pathways. If regulatory processes remain fragmented or case-specific, deployment costs and uncertainty will increase.[29]
- **Digitalisation creates both opportunities and vulnerabilities**. Ferry operations increasingly rely on connected ticketing, passenger information, navigation, propulsion control, energy management, terminal coordination and reporting systems. Poor interoperability between vessel, port, energy and authority systems can limit efficiency gains, while cybersecurity requirements impose additional compliance responsibilities. Smaller operators and ports may need support to meet cybersecurity, data-sharing and digital-readiness requirements.[30]
- **Skills availability is a cross-cutting constraint.** Crews, port personnel, emergency responders, maintenance teams, shipyard workers and shore-side operators will need new competences in battery systems, high-voltage operations, alternative-fuel handling, digital monitoring, cybersecurity, remote support and emergency response. The transition will therefore require not only new technologies, but also training, certification, human-centred design and social dialogue.[31]

3. Target Capabilities

3.1. Current state of play and achieved developments

The ferry sector already has a practical basis for technology transition, but deployment remains uneven across routes, sea basins, vessel types and operators. Battery-electric and hybrid propulsion, shore-side electricity, onboard energy-management systems, port-call optimisation, digital monitoring and condition-based maintenance are already available for suitable ferry services, particularly on short and predictable routes. However, their uptake depends on route length, berth time, grid capacity, terminal readiness, vessel age, operator resources and safety approval.

The state of play differs by operational range. Urban, harbour and short-distance ferries are closest to full electrification. Inter-island and short coastal services can increasingly use battery-electric, plug-in hybrid and modular energy-storage solutions where both ends of the route are prepared. Medium- and long-distance RoPax services require a broader combination of hybrid-electric architectures, shore

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[28]OECD, Policy Pathways Beyond the Shoreline (Paris: OECD Publishing, 2026), Chapter 7 (Greece and Croatia case studies); European Commission, Study on Short Sea Shipping's Contribution to the European Transport Network, 88-89.

[29]European Commission, An EU Industrial Maritime Strategy, COM(2026) 111 final, section 3.3 and Annex Summary of Measures, Pillar II; Waterborne Technology Platform, Strategic Research and Innovation Agenda, 67-68.

[30]Directive (EU) 2022/2555 (NIS2), OJ L 333, 27.12.2022; Regulation (EU) 2024/2847 (Cyber Resilience Act), OJ L, 20.11.2024; European Commission, An EU Industrial Maritime Strategy, COM(2026) 111 final, section 4.3.

[31]European Commission, An EU Industrial Maritime Strategy, COM(2026) 111 final, Pillar VI "Access to skills and quality jobs"; SEA Europe, Setting Sail to Build in Europe 10,000 Sustainable and Digitalised Vessels by 2035 (Brussels: SEA Europe, 2024); Waterborne Technology Platform, Waterborne Technology Leadership (Brussels, 2026).

power, energy-efficiency measures, fuel-flexible engines, sustainable fuels and, in selected cases, fuel cells.

The regulatory framework now provides a clear deployment signal. EU ETS Maritime, FuelEU Maritime and AFIR are pushing the sector towards lower greenhouse-gas intensity, shore-power use, port electrification and renewable or low-carbon fuels. At the same time, passenger-safety, cybersecurity and alternative-fuel requirements make regulatory readiness, certification, emergency response and crew training central to deployment.

The main capability gap therefore, lies in the limited availability of integrated route-based deployment packages that combine vessels, terminals, charging or bunkering infrastructure, digital systems, safety procedures, financing models and workforce capabilities. The target capabilities below are therefore organised around progressive deployment phases for 2035, 2040 and 2050.

3.2. 2035: Early deployment phase

By 2035, the European ferry sector should have entered an accelerated transition phase, leveraging its structural suitability as the most electrifiable maritime segment.[32] Operational capability targets by range class are as follows.

Short-distance and harbour ferries (under 50 nautical miles). Full battery-electric propulsion will be mainstream on new and retrofitted units, with standardised high-power charging interfaces deployed in pairing ports. Zero-emission operation is the operational norm, not the exception.[33]

Inter-island ferries (50-150 nautical miles). Battery-electric and plug-in hybrid configurations are operationally proven on representative routes in the Aegean, Adriatic, Baltic and Scandinavian archipelagos. Modular battery and energy-storage systems support route flexibility and progressive capacity upgrades.[34]

Medium-range RoPax (150-200 nautical miles). Hybrid-electric architectures with fuel-flexible internal combustion engines are standard for newbuilds, designed for methanol, bio-LNG or bio-methane with methane-slip control as transitional fuels. Fuel-cell modules are deployed selectively on units with significant hotel loads.[35]

Long-distance RoPax (over 200 nautical miles). Internal combustion engines running on sustainable alternative fuels, complemented by energy-efficiency packages (hull optimisation, waste-heat recovery, digital voyage optimisation), will be the dominant solution. Hybrid configurations with battery buffers enable zero-emission approach, harbour stay and departure.[36]

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[32] Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, 30 (ferries are "the most suitable application to become fully electric with completely zero emissions"

[33] Ibid., 30; Waterborne Technology Platform, *Waterborne Technology Leadership*, section 3.2.4 "Development trajectories by 2035".

[34] Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, 30 and 34 (high-capacity batteries as single energy source up to 150-200 nautical miles); European Commission, *Study on Short Sea Shipping's Contribution to the European Transport Network*, 39 (Mediterranean, Baltic and Scandinavian ferry passenger volumes)

[35] Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, 30 (fuel cells as candidates for ferries with significant hotel loads); IEA, *Energy Technology Perspectives 2026*, Chapter 3, "Ammonia and methanol propulsion ships"

[36] Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, 30 (ICEs with alternative fuels for long-distance ferries supported by energy efficiency and smart port-side power buffer)

Operationally, all ferries calling at TEN-T core ports are able to connect to shore power or charging infrastructure, meet FuelEU Maritime GHG-intensity thresholds and EU ETS surrender obligations, and integrate digital tools for voyage optimisation, port-call planning, passenger flow management, emissions monitoring and condition-based maintenance. Safety protocols for batteries, charging, OPS and alternative fuels are harmonised across leading ferry corridors. Cyber-resilience baselines are in place under NIS2 and the Cyber Resilience Act, practical for smaller island-serving operators while protecting passenger-safety-critical systems. Dual-use design features compatible with the proposed dual-use ferry construction support mechanism are available for newbuilds intended for strategically important routes.[37]

3.3. 2040: Scale-up and system integration phase

By 2040, the ferry sector moves from first-mover routes to system integration across European sea basins.

The fleet is predominantly zero-emission for short and inter-island ranges, and substantially hybrid-electric or alternative-fuel for medium and long-distance RoPax. Solid-state battery technology, commercially available from the late 2020s, has expanded the viable range of full-electric operation beyond 150 nautical miles for selected services. Ammonia or ammonia-derived fuels are deployed selectively on longer RoPax services where safety, bunkering and aftertreatment integration justify their use; hydrogen-derived fuels are available for selected medium-range services. Newbuilds adopt modular, software-driven, fuel-flexible and hybrid-electric architectures, designed for retrofit upgrades over the vessel lifecycle.[38]

Major ferry hubs provide mature multi-fuel and electric infrastructure: high-voltage OPS for large RoPax (up to 20 MW and beyond), high-power charging stations sized for fast turnaround, standardised bunkering of methanol and bio-LNG, and grid capacity matched to peak passenger-port demand. Renewable power procurement, energy storage and demand management are standard practice. The European network of green shipping lanes and hubs, launched from 2027, covers the principal Mediterranean, Baltic-North Sea and Atlantic ferry corridors.[39]

Digital integration supports real-time coordination between ferries, ports, energy systems and hinterland transport. Just-in-time arrival, berth allocation, simultaneous bunkering and charging, passenger and vehicle flow synchronisation and energy scheduling is standard at major hubs. Partial autonomy expands from navigation support to engine-room and machinery functions with safe fallback. Predictive safety and dynamic risk modelling are embedded in ferry corridor operations, with

[37] Directive (EU) 2022/2555 (NIS2), OJ L 333, 27.12.2022; Regulation (EU) 2024/2847 (Cyber Resilience Act), OJ L, 20.11.2024; European Commission, *An EU Industrial Maritime Strategy*, COM(2026) 111 final, section 4.3 and Annex Summary of Measures, Pillar III (dual-use ferry construction support mechanism, 2027).

[38] Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, 47 (solid-state battery horizon) and 56-58 (modular and retrofit-ready design); Waterborne Technology Platform, *Waterborne Technology Leadership*, section 3.2.4

[39] Regulation (EU) 2023/1804 (AFIR), Article 9; European Commission, *Communication on the EU Ports Strategy*, section 3.1 (port electrification and grid capacity); European Commission, *An EU Industrial Maritime Strategy*, COM(2026) 111 final, Annex Summary of Measures, Pillar II (European network of green shipping lanes and hubs, 2027).

winterisation and extreme-weather resilience integrated into design for Baltic, North Sea and Atlantic routes.[40]

The Passenger Ship Safety Directive and the Marine Equipment Directive, revised in 2026-2028, provide a stable safety framework for alternative fuels, battery integration, automation and digitalisation on passenger vessels. Cybersecurity certification under the Cyber Resilience Act and IMO cybersecurity rules are operational across the EU fleet. Dual-use ferry standards developed jointly by the European Commission, EDA, EMSA and EU Military Staff are applied to vessels deployable on strategic routes.[41]

3.4 2050: Full transformation phase

By 2050, the European ferry sector operates as a climate-neutral, digitally integrated and resilient component of the European transport system and the European Maritime Space.

The fleet eliminates harmful GHG emissions across the operating lifecycle, substantially eliminates air pollutants (SOx, NOx, particulate matter), eliminates water pollution and reduces underwater noise. Short-distance and inter-island services are fully battery-electric; medium-range RoPax operate on hybrid-electric architectures with sustainable alternative fuels and fuel-cell modules; long-distance RoPax run on sustainable alternative fuels with wind-assisted propulsion and waste-heat recovery as standard. Modular ship architectures support continuous retrofit and technology upgrade over the vessel lifecycle.[42]

Ferry terminals and passenger ports function as clean-energy, logistics and industrial hubs, providing renewable electricity, zero- and near-zero-emission fuels, climate-resilient infrastructure and seamless multimodal links with rail, road and inland waterways. The European Maritime Space embeds ferries as the backbone of EU passenger mobility and a critical dual-use asset for military mobility, evacuation and emergency relief, fully consistent with the European Preparedness Union Strategy. Ferries support island and outermost-region connectivity at affordable cost, contributing measurably to closing the cost-of-insularity gap quantified by the OECD.[43]

Operations are supported by continuous safety and cyber assurance, AI-assisted navigation and energy management, predictive maintenance and mature human-automation teaming. Workforce competences cover sustainable alternative fuels handling, high-voltage systems, battery safety,

[40] Waterborne Technology Platform, *Waterborne Technology Leadership*, sections 3.2 and 3.3 (development trajectories by 2040); Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, 47-48 (energy models and digital integration.

[41] European Commission, *An EU Industrial Maritime Strategy*, COM(2026) 111 final, Annex Summary of Measures, Pillar II (Passenger Ship Safety Directive and Marine Equipment Directive review, 2026-2028; extension of EU passenger ship safety requirements to all intra-EU routes, 2027-2028) and Pillar III (dual-use ferry standards); Directive 2009/45/EC; Directive 2014/90/EU

[42] Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, 30 and Part 3 "Expected Impacts"; Waterborne Technology Platform, *Waterborne Technology Leadership*, section 3.2.1 "Vision".

[43] European Commission and High Representative, *Joint Communication on the European Preparedness Union Strategy*, JOIN(2025) 130 final, Brussels, 26 March 2025; European Commission, *An EU Industrial Maritime Strategy*, COM(2026) 111 final, section 4.3; OECD, *Policy Pathways Beyond the Shoreline*, Chapter 5; Regulation (EU) 2024/1679 on the trans-European transport network, OJ L, 28.6.2024

cybersecurity and remote support, with crews and shore operators trained under harmonised EU frameworks.[44]

3.5 Cross-cutting capability implications

The 2035-2050 capability pathway implies a shift from individual vessel optimisation to route, hub and sea-basin optimisation. In the first phase, operators deploy technologies with limited operational disruption: hybridisation, battery-electric on short routes, OPS at port, fuel-flexible retrofits, energy-saving devices and digital voyage optimisation. In the second phase, the sector moves from pilot routes to multi-port, multi-fuel networks where vessels, ports, energy suppliers and grid operators share planning assumptions. By 2050, ferries are treated as an integrated low-emission passenger and dual-use transport system embedded in the European Maritime Space.[45]

The capability pathway is differentiated by operating range. An urban harbour shuttle of a few miles, a Greek inter-island ferry on a 60-mile route, a Helsinki-Tallinn RoPax on a 50-mile high-frequency crossing, and a Civitavecchia-Palermo overnight RoPax on a 250-mile crossing do not follow the same transition trajectory. Route predictability, berth-time window, hotel-load share, passenger and vehicle capacity, port readiness and PSO status determine technology selection, financing design and infrastructure investment timing.[46]

Three transversal capability features apply across all segments. Dual-use readiness: newbuilds intended for strategic routes should incorporate military specifications consistent with NATO standards and the Military Mobility Regulation. Climate-resilience by design: terminals, grid connections and approach areas should be designed against sea-level rise, coastal storms and saline intrusion under the European Integrated Framework for Climate Resilience. Affordability for island users: technology cost must remain compatible with the public service obligation framework and the cost-of-insularity reduction trajectory.[47]

The target capabilities should be translated into measurable deployment packages per route or sea-basin cluster. Each package should define expected emissions reduction, fuel and electricity demand, port infrastructure readiness, digital interoperability level, safety and emergency-response readiness, dual-use specifications, training requirements and financing model, with explicit consideration of the PSO and cost-of-insularity dimension where applicable.

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[44] Waterborne Technology Platform, *Waterborne Technology Leadership*, section 3.2.2 (human-centred transition) and 3.2.4 (by 2050); European Commission, *An EU Industrial Maritime Strategy*, COM(2026) 111 final, Pillar VI "Access to skills and quality jobs".

[45] Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, Part 2 "Research and Innovation Strategy", implementation pathways.

[46] European Commission, *Study on Short Sea Shipping's Contribution to the European Transport Network*, 39 (Reggio Calabria-Messina, Helsinki-Tallinn, Helsingborg-Helsingør as benchmark passenger volumes); Waterborne Technology Platform, *Strategic Research and Innovation Agenda*, 30 (ferry range categories)

[47] European Commission, *An EU Industrial Maritime Strategy*, COM(2026) 111 final, section 4.3; European Commission, *Communication on the EU Ports Strategy*, section 4.2 (European Integrated Framework for Climate Resilience, 2026); OECD, *Policy Pathways Beyond the Shoreline*, Chapter 5

4. Technology Pathways

4.1 Future propulsion and energy systems enabling a climate-neutral ferry fleet

4.1.1. Operational Objective

Enable scalable, safe and efficient zero-emission propulsion systems for ferry operations, including battery-electric, fuel-cell and sustainable alternative fuel solutions. Solutions must support high-frequency ferry routes, multimodal connections, short turnaround times and integration with port energy infrastructure, while ensuring energy efficiency, operational reliability and cost competitiveness.

4.1.2 Target capability

By 2035

- Battery-electric ferries widely deployed on short routes, with initial expansion to longer routes enabled by improved energy systems and charging, addressing energy supply, charging and energy efficiency. (All key systems matured to TRL 9)
- High-power charging and/or energy replenishment systems deployed at key terminals, supporting short turnaround operations, addressing system design, power density, charging effect, coupling/decoupling speed. (All key systems matured to TRL 8–9)
- Hydrogen-based ferries (ICE or fuel-cell) operating on routes where battery solutions are insufficient, addressing safety, bunkering, fuel handling and storage. (All key systems matured to TRL 8–9)
- Hybrid propulsion systems combining batteries and alternative energy sources, enabling flexible and zero-emission prioritized operations. (All key systems matured to TRL 8–9)
- Retrofit solutions for zero-emission operation demonstrated and scaled on existing vessels, addressing current limitations in cost, downtime and technical integration of existing fleets.
- Ferry designs optimised for energy efficiency, achieving ~25–30% reduction in energy use, compared to current vessel designs and operational baselines. (All key systems matured to TRL 9)

By 2040

- Hydrogen fuel-cell ferries widely deployed on regional routes where battery solutions are insufficient, including variety of designs and operating conditions. (TRL 9)
- Standardised and interoperable modular battery systems widely adopted across ferry classes, enabling scalable deployment, streamlined maintenance and efficient retrofit solutions, moving beyond current specific systems and limited interoperability. (TRL 9)
- Retrofit solutions available for all ferry categories with lifetime beyond 2050, overcoming current technical and economic barriers for retrofit across vessel types.
- Hybrid propulsion systems combining batteries and alternative energy sources, enabling flexible zero-emission battery prioritized operations. (All key systems matured to TRL 9)

By 2050

- Fully climate-neutral ferry fleet across European ferry segments (newbuild and retrofit). (TRL 9), where operationally and economically feasible. (TRL 9)
- Standardised and commercial modular zero-emission propulsion systems deployable across ferry categories and exportable globally. (TRL 9)
- Highly energy-efficient ferry propulsion systems integrating advanced battery systems, internal combustion engines (ICE), fuel cells and battery prioritized propulsion, building on fully integrated and optimised system architectures beyond today's hybrid solutions. (TRL 9)

4.1.3 Required enablers:

- High-capacity shoreside charging infrastructure at ferry terminals to support large-scale electrification.
- Smart energy management at terminals, including local energy production, storage (e.g. BESS) and peak-load management.
- Close dialogue and coordination with grid providers to ensure sufficient grid capacity, resilience and operational flexibility for increasing electric ferry demand.
- Prescriptive and harmonised regulations for alternative fuel systems, reducing reliance on risk-based approvals, which are currently costly, time-consuming and unpredictable.
- Safe and standardised bunkering infrastructure, supported by reliable supply chains for alternative fuels.
- Energy-efficient vessel design and operations.
- Public procurement frameworks prioritising low- and zero-emission ferry solutions.
- Public financing instruments and risk-sharing mechanisms supporting fleet transition and infrastructure upgrades.
- Circular battery lifecycle systems, including monitoring, recycling and second-life applications.
- Deployment of large-scale maritime battery systems integrated with ferry and short-sea operations.
- Hybrid propulsion systems adaptable to different ferry sizes and route profiles.
- Cost competitiveness and availability of alternative fuels
- Reduced stakeholder fragmentation, enabling coordinated development of vessels, ports and energy infrastructure, addressing current fragmentation across actors, systems and standards.
- Viable business models and clear regulatory frameworks for deployment of energy and fuel infrastructure, addressing current fragmentation across actors, systems and standards.
- Technology-neutral approaches supporting deployment of the most suitable solutions for different ferry operations and operational profiles

4.1.4 Key research gaps:

- Research on megawatt-scale charging systems, including thermal management, automated interfaces and battery degradation under fast-charging cycles, addressing current limitations in charging speed, grid capacity and standardisation (TRL 6–8 → 8–9).

- Research on storage, handling, detection, ventilation and fire/explosion mitigation for sustainable alternative fuels in passenger ferry operations, as current solutions rely on case-by-case risk assessments and limited operational experience (TRL 5–7 → 7–9).
- Research on next-generation battery chemistries, lightweight systems and higher energy density while maintaining safety and vessel integration, beyond current lithium-ion performance limits (TRL 4–6 → 7–9).
- Research efficient, durable and scalable fuel-cell technologies, including lifetime performance and integration with hybrid systems, addressing current challenges related to cost, durability and maritime operational conditions (TRL 5–7 → 7–9).
- Research on safe high-voltage AC/DC systems, power electronics and onboard energy distribution, supporting increasing power demand and system complexity (TRL 6–8 → 8–9).
- Research on battery health monitoring, predictive maintenance, lifecycle optimisation and recycling/second-life applications, addressing current uncertainty in lifetime and total cost of ownership (TRL 5–7 → 7–9).
- Research on integration of batteries, fuel cells and alternative fuels to optimise efficiency, flexibility and cost across ferry operations, moving beyond current siloed system designs and enabling optimised efficiency and flexibility (TRL 5–7 → 7–9).
- Research on hull design and hydrodynamic optimisation to reduce energy consumption and support zero-emission propulsion, improving performance beyond current vessel designs and reducing energy demand (TRL 6–8 → 8–9).
- Research on intelligent energy management systems coordinating charging, grid capacity and port infrastructure, including booking and scheduling, addressing current lack of coordination between vessels and energy systems (TRL 5–7 → 7–9).
- Research on ship design methods and tools supporting complex operational profiles and multi-criteria optimisation, beyond current design practices (TRL 5–7 → 7–9).
- Research on energy-saving technologies, including drag reduction, efficient propulsion, energy harvesting (wind, wave, solar) and voyage optimisation, to further reduce overall energy demand (TRL 5–7 → 7–9).
- Research on ferry concepts and system integration, including public requirements and multimodal connectivity for zero-emission operations, ensuring alignment between vessel design, infrastructure and transport systems (TRL 5–7 → 7–9).
- Research on battery safety related to ferries transporting vehicles, including fire propagation risks connected to electric vehicles onboard car ferries.
- Research on lifecycle emissions and environmental impacts, including underwater noise and non-GHG emissions.
- Research on onboard carbon capture solutions as transitional emission-reduction measures for selected ferry segments.

4.2 Intelligent safety, security and resilience as foundational enablers

4.2.1 Operational objective(s)

Enable safe, secure and resilient ferry operations through advanced safety systems, predictive monitoring and integrated emergency management solutions. Technologies must support high passenger volumes, short turnaround operations and increasingly complex propulsion systems, while ensuring zero-fatality and zero-incident ferry operations across European ferry networks, building on and advancing beyond current safety practices and regulatory frameworks.

4.2.2 Target capability 2035, 2040 and 2050

By 2035

- Advanced onboard safety monitoring systems supporting early detection of operational risks, expanding current alarm-based systems to predictive capabilities. (TRL 8–9)
- Improved sensing technologies for fire detection, fuel leak detection and passenger safety monitoring, enhancing performance in complex ferry environments and alternative fuel systems. (TRL 8–9)
- Initial predictive safety tools supporting operational risk assessment and incident prevention (TRL 6–7), moving beyond current reactive safety management approaches. (TRL 6–7)

By 2040

- Predictive safety ecosystems integrating onboard monitoring, fuel safety systems and operational risk modelling, building on fragmented systems currently in use. (TRL 7–8)
- Advanced emergency management systems supporting rapid incident detection and coordinated response, improving integration between vessels, ports and authorities. (TRL 8–9)
- Integrated cyber-resilient operational infrastructure for safe ferry operations and port connectivity, addressing increasing digitalisation and cyber risk exposure. (TRL 7–8)

By 2050

- Fully integrated predictive safety and resilience systems enabling zero-incident ferry operations. (TRL 9)
- Highly resilient ferry operations supported by advanced sensing, automated safety management and integrated emergency response systems. (TRL 9)
- Globally deployable European safety and resilience technologies for passenger ferry operations, positioning Europe as a leader in safe zero-emission ferry systems. (TRL 9)

4.2.3 Required enablers

- Harmonised safety regulations and certification frameworks for alternative fuels and advanced ferry systems, evolving beyond current risk-based and case-by-case approval processes.
- Advanced sensing technologies for early detection of fire, fuel leaks and operational hazards.
- Improved safety frameworks for battery systems, including vehicle transport and electric vehicle fire management onboard ferries.
- Integrated emergency response frameworks connecting vessels, ports and maritime authorities.
- Cyber-resilient digital infrastructure protecting ferry operations and port connectivity
- Training frameworks and safety management systems adapted to new propulsion technologies and operational environments.
- Investment support for deployment of advanced safety technologies across ferry fleets.
- Backup systems if the power disappears.

- Surveillance systems
- Improved openness and sharing of safety data, incident analysis and operational experience across the ferry sector.

4.2.4 Key research gaps

- Research on integrated safety monitoring and predictive risk modelling, addressing current reliance on reactive safety systems and enabling early hazard detection (TRL 5–7 → 7–9).
- Research on detection systems, ventilation, fire mitigation and emergency response for alternative fuels (e.g. hydrogen, ammonia and methanol), as current solutions are based on limited operational experience and case-by-case assessments (TRL 5–7 → 7–9).
- Research on battery safety, thermal runaway and fire management related to electric vehicles transported onboard ferries, addressing increasing battery capacities and limited operational experience with large-scale EV transport at sea (TRL 5–7 → 7–9).
- Research on multi-sensor systems for detection of fire, fuel leaks and onboard hazards, improving reliability and performance in complex ferry environments (TRL 6–8 → 8–9).
- Research on integrated systems enabling coordinated response between vessels, ports and authorities, addressing current fragmentation in emergency response systems (TRL 5–7 → 7–9).
- Research on cyber-resilient systems protecting digital ferry operations and vessel–port communication, responding to increasing cyber threats and system complexity (TRL 5–7 → 7–9).
- Research on dual-use preparedness, resilience planning and protection of critical ferry transport infrastructure under evolving security conditions.

4.3 Fully connected, automated and data-driven ferry systems

4.3.1 Operational objective(s)

Enable fully connected, data-driven and increasingly automated ferry operations, linking vessels, ports and transport infrastructure. Digital and automation technologies should support real-time coordination of ferry operations, passenger flows and energy systems, including remote operation and human-in-the-loop control, to improve efficiency, safety and reliability in high-frequency ferry services.

4.3.2 Target capability 2035, 2040 and 2050

By 2035

- Initial deployment of connected vessel–port data systems enabling operational coordination between ferries and terminals, moving beyond current siloed and operator-specific solutions (TRL 7–8)
- Digital platforms supporting schedule optimisation, energy planning and passenger flow management, improving coordination across ferry, port and transport systems. (TRL 7–8)
- Advanced sensing and communication systems improving situational awareness in busy ferry routes and ports. (TRL 8–9)
- Deployment of remote support and decision-support systems enabling shore-based operational assistance and improved situational awareness, , building on existing systems towards fleet-level monitoring capabilities. (TRL 8–9)

By 2040

- Integrated digital ferry ecosystems connecting vessels, ports and transport infrastructure for real-time coordination, overcoming current fragmentation across systems and stakeholders. (TRL 8–9)
- AI-supported fleet management systems optimising schedules, energy use and port operations, enabling fleet-level optimisation rather than single-vessel control. (TRL 7–8)
- Remote operation capabilities for selected functions, with human-in-the-loop safety systems, expanding beyond current pilot and demonstration projects. (TRL 7–8)
- Increased interoperability enabling ferry fleets, ports and operators to function as connected transport networks, supported by standardised communication and data exchange systems. (TRL 8–9)

By 2050

- Fully connected ferry networks integrating vessels, ports and transport systems with real-time data exchange. (TRL 9)
- Highly automated ferry operations, including remote supervision and fleet-based control systems, enabling one-to-many operational concepts and reduced onboard workload. (TRL 8–9)
- Fully synchronised vessel–port digital ecosystems optimising ferry schedules, passenger flows and energy use. (TRL 9)
- Scalable remote and autonomous ferry operations in defined routes and environments, ensuring high levels of passenger safety and operational reliability, supported by mature regulatory frameworks and validated operational concepts.

4.3.3 Required enablers

- Interoperable digital architectures enabling secure and seamless data exchange between vessels, ports and transport systems.
- Advanced communication systems ensuring reliable and continuous connectivity in coastal and port environments.
- Clear communication standards enabling faster, safer and interoperable exchange of operational data across systems and operators, reducing current fragmentation across digital ferry ecosystems. (TRL 7–9)
- High-performance sensing systems improving situational awareness and operational safety in congested ferry routes and terminals.
- Secure and standardised data frameworks enabling vessel–port interoperability and coordinated operations across operators and systems, addressing current fragmentation and lack of common standards.
- Harmonised regulatory frameworks enabling safe deployment of automation, remote operations and digital ferry systems.

- Adaptive and flexible regulatory approaches allowing testing, validation and deployment of new digital and automated ferry technologies while maintaining safety, moving beyond current restrictive or unclear regulatory conditions.
- Investment in digital infrastructure supporting connected ferry networks, smart ports and integrated vessel–port coordination systems.
- Public and passenger acceptance of automated ferry operations, supported by transparent communication, demonstrated safety performance and user-centred design.
- Testing and validation frameworks linked to IMO MASS developments and evolving autonomous operation standards, enabling scalable and trusted deployment of automated ferry operations. (TRL 6–8 → 8–9)

4.3.4 Key research

- Research on standardised and secure data frameworks, addressing current lack of interoperability and enabling real-time coordination across ferry, port and transport systems (TRL 5–7 → 7–9).
- Research on AI-supported tools for schedule optimisation, fleet management and energy-efficient operations, moving beyond current rule-based and fragmented optimisation approaches (TRL 5–7 → 7–9).
- Research on multi-sensor systems improving situational awareness, object detection and operational safety, enhancing reliability in complex and congested ferry environments (TRL 6–8 → 8–9).
- Research on on resilient communication technologies ensuring continuous vessel–port connectivity, addressing current limitations in bandwidth, latency and reliability (TRL 5–7 → 7–9).
- Research on assisted navigation, automated docking and remote operational support, including human-in-the-loop systems, advancing beyond current pilot deployments towards scalable operations (TRL 6–8 → 8–9).
- Research on passenger perception, trust, safety communication and human–machine interaction, addressing social acceptance barriers for automated and remotely operated ferry services (TRL 4–6 → 7–8).
- Research on the human role in increasingly automated ferry operations, including reduced bridge crew concepts, human intervention and operational acceptance, addressing current uncertainty related to safe crew reduction and operational trust. (TRL 4–6 → 7–8)
- Research on on alternative vessel concepts and fleet structures, enabling benefits from digitalisation, automation and autonomy beyond current vessel-centric operational models (TRL 4–6 → 7–8).

4.4 Human-centred design and a future-ready ferry workforce

4.4.1 Operational objective(s)

Enable safe and efficient human–machine cooperation in ferry operations through human-centred system design, advanced decision-support tools and next-generation training systems supporting crews and shore operators.

4.4.2 Target capability 2035, 2040 and 2050

By 2035

- Decision-support systems assisting crews in managing ferry operations and energy systems, moving beyond current manual and experience-based decision-making. (TRL 7–8)
- Digital training platforms for crews operating alternative fuel systems and advanced vessel technologies, addressing current gaps in training for new propulsion systems and digital operations. (TRL 7–8)

By 2040

- Advanced human–machine collaboration systems supporting interaction with automated vessel functions, enabling safe operation in increasingly automated ferry environments. (TRL 8–9)
- XR-based training environments widely used for crew training and operational simulation, expanding beyond current classroom and simulator-based training methods. (TRL 8–9)
- Remote operational support systems integrated with ferry operations through reliable high-capacity communication systems, enabling increased shore-based operational support. (TRL 7–8)

By 2050

- Fully integrated human-centred operational environments supporting automated ferry systems, ensuring safe and efficient human oversight in highly automated operations. (TRL 9)
- Continuous training ecosystems using simulation, digital twins and XR technologies, enabling lifelong learning and adaptation to evolving technologies. (TRL 9)

4.4.3 Required enablers

- Human-centred design standards for vessel bridges and operational interfaces, ensuring usability and safety in increasingly complex systems.
- Training frameworks for digital vessel operations and alternative fuel systems, addressing current lack of standardised training approaches.
- Simulation platforms and digital twins for training and operational testing, supporting validation of new technologies and operational concepts.
- Regulatory frameworks for responsible use of AI and human–machine interaction, including transparency, liability and ethical considerations.
- Reliable satellite communication and broadband connectivity supporting remote operations and data exchange in ferry operations.
- Continuous training, up-skilling and competence development frameworks supporting increasingly digital and automated ferry operations.
- Operational concepts supporting improved customer experience and passenger interaction in increasingly digital ferry services.

4.4.4 Key research gaps (linked to achieving the objectives, building on the current state-of-play).

- Human–machine collaboration in increasingly automated ferry operations, addressing current limitations in interaction, trust and role distribution (TRL 5–7 → 7–9).
- Decision-support tools to support safe operation of complex vessel systems, moving beyond current systems towards predictive and adaptive support (TRL 5–7 → 7–9).
- Workload management and ergonomic design for high-frequency ferry operations, addressing fatigue, cognitive load and safety risks in demanding operational environments (TRL 5–7 → 7–9).
- Next-generation training systems using simulation and XR technologies, enabling scalable, realistic and continuous training for future ferry operations (TRL 4–6 → 7–9).
- Research on remote operation centres, including operational control, required data flows and human oversight, enabling safe integration of shore-based support functions. (TRL 5–7 → 7–9)
- Research on reliable communication and satellite connectivity for remote and connected ferry operations, addressing current limitations in coverage, bandwidth and operational reliability. (TRL 5–7 → 7–9)

4.5 Forward looking regulation, standardization and system-level integration

4.5.1 Operational objective(s)

Enable rapid and safe deployment of zero-emission and digital ferry systems through harmonised regulatory frameworks, common technical standards and coordinated development of vessel, port and energy infrastructure.

4.5.2 Target capability 2035, 2040 and 2050

By 2035

- By 2035, existing regulatory frameworks are further developed to enable scalable deployment of zero-emission ferry propulsion systems, reducing reliance on case-by-case approvals, with alternative design (TRL 7–8)
- Pilot regulatory sandboxes enabling testing of new ferry technologies and operational concepts, building on limited current pilot initiatives. (TRL 6–7)

By 2040

- Harmonised European standards for alternative fuel systems, high-power charging infrastructure and digital ferry operations, replacing fragmented national and project-specific approaches. (TRL 8–9)
- Integrated planning tools supporting coordinated development of ferry routes, terminals and energy systems and grid infrastructure, addressing current lack of alignment between infrastructure and vessel deployment and energy availability. (TRL 7–8)
- More prescriptive and operationally predictable regulations reducing uncertainty in approval and certification processes. (TRL 7–9)

By 2050

- Fully harmonised regulatory frameworks enabling large-scale deployment of zero-emission ferry fleets across Europe, ensuring predictable and efficient approval processes. (TRL 9)
- Standardised system architectures supporting interoperable vessel–port–energy integration, enabling scalable and globally competitive solutions. (TRL 9)

4.5.3 Required enablers

- Harmonised European safety regulations for alternative fuel propulsion systems, evolving beyond current risk-based and case-specific approaches.
- Standardised interfaces for charging infrastructure, fuel bunkering and digital vessel–port connectivity, addressing current lack of interoperability.
- Regulatory sandboxes enabling testing and validation of new ferry technologies and operational concepts.
- System-level planning tools supporting coordinated infrastructure development across ferry networks, ensuring alignment between vessels, ports and energy systems.
- Collaboration between regulators, industry and infrastructure providers, reducing fragmentation and enabling coordinated deployment.
- Closer dialogue and coordination between IMO, European institutions, class societies and industry stakeholders, supporting harmonised and operationally practical regulatory development
- Development of maritime-adapted standards and practical implementation frameworks for digital and zero-emission ferry operations, improving interoperability, safety and regulatory predictability

4.5.4. Key research gaps

- Research supporting certification and operational approval pathways for vessels using sustainable alternative fuels and energy carriers, addressing current reliance on risk-based approvals and enabling safe, predictable and technology-neutral deployment (TRL 5–7 → 7–9).
- Research supporting standardised interfaces for vessel energy supply, including charging, bunkering and energy management systems across ferry terminals and ports, enabling interoperability across ferry terminals and ports (TRL 5–7 → 7–9).
- Research on integrated planning tools linking ferry routes, port infrastructure, energy networks and fuel supply chains, addressing current lack of coordinated system-level planning (TRL 4–6 → 7–8).
- Research on standardised operational interfaces and procedures supporting safe handling of alternative fuels, energy systems and advanced vessel, improving safety, usability and cross-system integration (TRL 5–7 → 7–9).
- Research supporting more prescriptive and harmonised regulatory approaches, reducing reliance on project-specific risk-based approval processes and improving predictability for deployment. (TRL 5–7 → 7–9)
- Research on interoperability standards and clarification of which operational and digital systems should be standardised across the ferry sector, enabling scalable and interoperable ferry ecosystems. (TRL 5–7 → 7–9)

5. Enablers and Deployment

The technology pathways identified in Section 4 show that ferry transformation cannot be delivered through vessel innovation alone. Ferry deployment depends on the coordinated readiness of vessels, ports, terminals, grids, charging or bunkering infrastructure, safety systems, digital tools, financing models, public authorities and the workforce. This is particularly important for ferries because they operate on fixed routes, with frequent port calls, high passenger volumes, short turnaround times and, in many cases, public-service obligations. The ferry sector has already demonstrated the technical feasibility of battery-electric, hybrid and shore-power-based solutions on suitable routes. The next challenge is to move from individual pilots and first-of-a-kind deployments towards replicable route packages that can be scaled across urban, harbour, inter-island, coastal and RoPax services.

5.1. Route-based deployment packages

The primary deployment model should be the route-based package. Each package should combine the vessel, terminal infrastructure, shore-side electricity or charging system, grid connection, energy supply contract, digital coordination tools, safety procedures, financing model and workforce training required for a specific ferry route or group of routes. This approach is particularly suitable for ferries because route endpoints, timetables, energy demand and turnaround windows are normally known in advance. Urban and harbour routes can be used as early deployment environments for full battery-electric operation. Inter-island and short coastal routes can demonstrate battery-electric, plug-in hybrid and modular energy-storage solutions across more complex multi-port networks. Medium- and long-distance RoPax routes should be used to validate hybrid-electric architectures, sustainable alternative fuels, shore-power use, hotel-load optimisation and zero-emission port operations. Priority should be given to routes with high traffic density, predictable operations, repeated daily rotations, public-service relevance or strong replication potential. These include urban waterborne mobility services, island lifeline routes, archipelagic networks, high-frequency cross-border corridors and strategic RoPax connections. Once validated, deployment packages should be adapted to lower-volume, seasonal, remote or more technically complex services.

5.2. Port, grid and energy infrastructure readiness

Ports and ferry terminals are central deployment enablers. For short-distance and high-frequency ferries, the availability of shore-side electricity, high-power charging, grid capacity and safe automated or semi-automated connection systems will determine whether full electrification is possible. For medium- and long-distance RoPax services, ports must also be prepared for shore power, alternative-fuel bunkering, energy storage, emergency response and the management of complex hotel-load and vehicle-deck requirements. Ferry ports should therefore evolve into integrated energy nodes. Infrastructure planning should link vessel renewal plans with grid reinforcement, renewable electricity procurement, port energy management, battery-buffer systems, charging schedules, berth allocation and safety procedures. Where grid capacity is limited, deployment should consider phased reinforcement, local energy storage, smart charging, demand management and coordination with regional energy authorities. Because ferry services depend on paired or networked ports, infrastructure must be available at all operationally relevant terminals.

5.3. Investment, financing and procurement models

Ferry decarbonisation requires high upfront investment in vessels, retrofits, charging infrastructure, shore power, grid upgrades, digital systems, safety equipment and workforce training. These investments are especially challenging for smaller operators, public-service routes, island services and seasonal markets with limited revenue potential. Deployment therefore requires financing models that reduce risk and align vessel, port and energy investments. Public procurement and Public Service Obligation contracts should become key deployment instruments. Where ferry services are publicly supported or regulated, contracts should progressively include requirements or incentives for zero- and near-zero-emission operation, shore-power use, energy efficiency, accessibility, resilience, cybersecurity and passenger-service quality. At the same time, contracts should recognise the cost of transition and avoid placing disproportionate financial pressure on operators or island users. Blended finance, green public procurement, innovation funding, guarantees, leasing models, infrastructure grants and route-based investment partnerships can help bridge the gap between demonstration and commercial deployment. Financing should support both newbuilds and retrofits, since many existing ferries will remain in service for years. Retrofit support should prioritise modular upgrades, shore-power readiness, hybridisation, onboard energy management, hotel-load reduction, battery safety, digital monitoring and fuel-flexible architectures.

5.4. Regulation, standards and safety approval

Deployment at scale requires predictable, harmonised and operationally practical regulatory frameworks. Batteries, high-voltage charging, shore power, methanol, hydrogen, fuel cells, ammonia, biofuels, automation and cyber-physical ferry systems all introduce safety, certification and operational approval challenges. If these continue to be addressed mainly through project-specific approval processes, deployment will remain slow, expensive and fragmented. European deployment should therefore be supported by harmonised standards for charging interfaces, shore-power connection, alternative-fuel bunkering, battery safety, vehicle-deck fire risk, fuel-cell integration, emergency shutdown systems, digital vessel–port communication and cybersecurity. Regulatory sandboxes and structured demonstration corridors should be used to test new technologies and operational concepts under controlled conditions, while generating evidence for wider regulatory acceptance. Passenger safety must remain central. Ferry deployment frameworks should address evacuation, crowd management, passenger registration, accessibility, fire detection and suppression, electric-vehicle fire risk, alternative-fuel hazards, emergency response and coordination between vessels, terminals and authorities. Safety approval should be integrated into route-based deployment packages from the beginning rather than treated as a late-stage compliance step.

5.5. Digital deployment and interoperability

Digital systems are essential for efficient and safe ferry transformation. Ferry operators and ports will need interoperable tools for voyage optimisation, port-call planning, berth management, passenger-flow management, ticketing integration, emissions monitoring, condition-based maintenance, energy scheduling and disruption management. These systems should support both operational efficiency and regulatory compliance. Deployment should avoid fragmented digital solutions that are specific to one vessel, operator or terminal. Interoperable data standards, common interfaces and secure vessel–

port communication protocols are needed so that ferry systems can be scaled across networks and operators. This is particularly important for archipelagic and cross-border ferry networks, where multiple operators, ports, public authorities and transport modes interact. Cybersecurity must be embedded in ferry digitalisation. Passenger information, ticketing, navigation, propulsion control, energy management, shore-power connection, charging systems and port coordination are increasingly connected. Deployment must therefore include cyber-risk assessment, secure-by-design systems, incident response, staff training and practical compliance support for smaller operators and island ports.

5.6. Workforce, skills and human-centred deployment

Ferry transition will only succeed if crews, port and terminal workers, maintenance teams, emergency responders, shipyard and maritime equipment manufacturers workers, digital-service providers and public authorities have the skills to operate and support new systems safely. Training requirements will expand from traditional ferry operations to battery systems, high-voltage charging, alternative fuels, fuel cells, digital monitoring, cybersecurity, automated systems, emergency response and passenger-service management. Deployment should therefore include training and certification as core project components. Simulation, digital twins, extended reality training and practical emergency drills should be used to prepare crews and shore-side personnel for new technologies and operational procedures. Human-centred design should guide the development of bridge systems, decision-support tools, charging interfaces, passenger information systems and remote-support functions. Skills development should also support social acceptance. Ferry services are highly visible to passengers and local communities. Clear communication, reliable service, accessible passenger interfaces and confidence in safety are essential for public acceptance of new propulsion systems, automated functions and digital services.

5.7. Governance, coordination and monitoring

Ferry deployment requires coordinated governance across the full value chain. Shipowners, ferry operators, shipyards, equipment manufacturers, ports, terminal operators, grid operators, energy suppliers, classification societies, safety authorities, regional governments, public transport authorities, financial institutions, research organisations and passenger representatives should be involved in deployment planning. At European level, deployment should be supported through shared monitoring of route readiness, technology performance, infrastructure availability, safety experience, emissions reduction, financing barriers and skills needs. Lessons from early deployment routes should feed back into standards, regulation, procurement models and future research priorities.

A practical deployment sequence is needed. By 2035, route-based packages should support early deployment on the most suitable urban, harbour, inter-island and selected RoPax routes. By 2040, deployment should scale to wider ferry networks through interoperable infrastructure, harmonised safety procedures and mature financing models. By 2050, ferry services should operate as climate-neutral, digitally integrated, safe and resilient mobility systems within the European Maritime Space.

6. Expected Impacts

The implementation of this roadmap is expected to support the transformation of the European ferry sector into a climate-neutral, digitally integrated, safe, resilient and passenger-centred component of the European Maritime Space. Because ferries operate on fixed routes and depend on close interaction between vessels, ports, terminals, energy systems and passengers, the expected impacts will depend on coordinated deployment across the full ferry ecosystem.

The first expected impact is a substantial **reduction in greenhouse-gas emissions and local air pollution**. Battery-electric and plug-in hybrid ferries, shore-side electricity, zero-emission port operations, energy-efficiency measures, hotel-load optimisation, digital voyage optimisation and sustainable alternative fuels should reduce emissions both during voyages and in ports. These benefits are particularly important for urban ferry terminals, high-frequency island routes, coastal communities and densely used passenger ports.

The roadmap is also expected to **strengthen passenger mobility, island connectivity and public-service continuity**. Cleaner and more reliable ferry services can improve access to employment, education, healthcare, tourism, trade and essential goods, while supporting territorial cohesion for islands, archipelagos, outermost regions and coastal communities. For Public Service Obligation routes, deployment models should ensure that decarbonisation is compatible with affordability, reliability and service continuity.

A further expected impact is the **transformation of ferry ports and terminals into clean-energy and digital coordination nodes**. Shore-side electricity, high-power charging, grid reinforcement, renewable electricity procurement, energy storage, alternative-fuel bunkering where relevant, safe connection procedures and digital port-call coordination can improve both ferry operations and wider port decarbonisation. Route-based deployment should reduce the risk of mismatches between vessel investment and port readiness.

The roadmap also **improves safety, security and resilience**. Harmonised procedures for batteries, high-voltage charging, shore power, alternative fuels, vehicle-deck fire risks, fuel cells, cybersecurity and emergency response can accelerate deployment while maintaining passenger safety. Modern ferry assets and terminals can also support crisis response, evacuation, civil protection and, where relevant, military mobility on strategic routes.

Industrial and economic impacts are expected across the European waterborne value chain. Ferry renewal and retrofitting create demand for shipyards, repair yards, equipment manufacturers, battery and fuel-cell suppliers, electrical-system integrators, port-energy providers, classification societies and digital-service companies. Standardised and replicable ferry solutions can strengthen European technology leadership and support export opportunities in global ferry, RoPax and urban waterborne mobility markets.

The transition will also generate **workforce and skills** impacts. Crews, port personnel, shipyard workers, emergency responders and maintenance teams will need new competences in battery systems, high-voltage operations, shore power, alternative fuels, digital monitoring, cybersecurity and emergency procedures. Human-centred design, simulation-based training and harmonised certification should support safe adoption and improve the attractiveness of ferry-related professions.

Finally, implementation should generate evidence for **future policy, regulation, standards, procurement and R&I priorities**. Monitoring should cover emissions reduction, shore-power and charging availability, renewable electricity use, service reliability, passenger satisfaction, safety performance, cybersecurity readiness, workforce training, retrofit uptake and investment mobilised.