WATERBORNE

WATERBORNE TECHNOLOGY ROADMAP

Competitive, resilient and sustainable short sea shipping

September 2026

SHORT SEA SHIPPING TECHNOLOGY ROADMAP

01 THE SECTOR IN NUMBERS

Europe's cargo-based short sea fleet today, and the geography it serves. Ferries, Ro-Pax and cruise are covered by separate Waterborne roadmaps.

6,184 cargo vessels in the European SSS fleet [1]

74% of the fleet sits in the 500–25,000 GT range [1]

~50% over 15 years old only ~17% newer than 5 [1]

~3,000 vessels below 5,000GT outside ETS & FuelEU, inside the Climate Law [2]

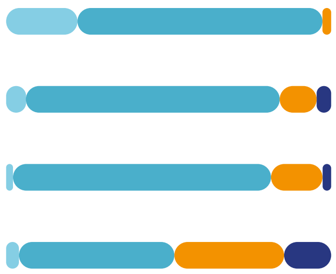
Fleet by segment and size — the mix decides the technology [1]

General cargo & multipurpose 2,918
47% · bulk, semi-bulk, packaged and project cargo

Tankers 1,599
26% · liquid bulk for energy supply and industry

Container (feeder) 1,442
23% · feeder services and intra-EU logistics chains

Bulk carriers 225
4% · dry bulk, long operating lifetimes



<500 GT · 500–25,000 GT · 25,000–60,000 GT · >60,000 GT · Freight-only Ro-Ro also in scope.

PRIMARY GATEWAY · CORRIDOR PORT · PRIORITY CORRIDOR

BALTIC
Winter-corridor test-bed: ice class, low-temperature fuels and electrified systems, remote and autonomous navigation.

NORTH SEA
Highest cargo density. Rotterdam, Antwerp-Bruges and Hamburg dominate throughput as primary gateways.

ATLANTIC
Long coastal legs, island and peripheral supply routes, exposed weather and climate resilience by design.

MEDITERRANEAN
Dense feeder and island networks; constrained mixed-use ports with short turnaround windows.

BLACK SEA
Strategic gateway region: cross-border trade, security of supply, crisis logistics and dual-use resilience.

02 DRIVERS AND CONSTRAINTS

2.1 DRIVERS

Climate neutrality & carbon pricing Climate Law (–55% by 2030, –90% by 2040), ETS extended to maritime, IMO measures and FuelEU Maritime.

Shore power & fuel infrastructure AFIR and Fuel EU drive port electrification, grid reinforcement, deployment of alternative fuel infrastructure and standardised OPS and charging interfaces.

Ports as energy & security hubs the EU Ports Strategy and STIP make ports the deployment platform for charging, bunkering and fuel supply.

Industrial competitiveness short sea ships are built and retrofitted in Europe: a key market for yards and equipment manufacturers

TEN-T & digital simplification — green corridors and hubs, port–hinterland integration and the upcoming Maritime Single Window options that cut repeated reporting.

Technology readiness & market demand battery/hybrid, OPS, renewable energy harvesting tecnhologies, ESDs and digital twins available now; cargo owners buying low-emission logistics.

Resilience & military mobility — redundancy against congested or disrupted land corridors; EU ports and SSS as dual-use infrastructure.

2.2 CONSTRAINTS

Fleet age & retrofit complexity no single solution fits; tramp and spot trades have no fixed rotation to anchor investment; yard and labour capacity is limited.

Fleet-port investment mismatch missing infrastructure at one port blocks clean propulsion across a whole corridor; permitting is slow.

Fuel cost unclear price, availability and lifecycle performance; risk of technology lock-in and stranded assets.

Financing SMEs and seasonal routes face high capex, charter structures, limited cost pass-through and weak bankability.

Administrative barriers repeated reporting, customs and border procedures at every port call make SSS less competitive than road.

Safety & approval readiness immature certification for batteries, high-power charging, new fuels, carbon capture and automation.

Grid, digital and skills gaps regional ports lack reinforcement; weak interoperability and cyber capacity; shortages across crews, ports and maintenance.

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03 TARGET CAPABILITIES - 2035 -> 2040 -> 2050

What cargo short sea shipping should be able to do at each milestone.

2035 • Early deployment

- **Green and Digital Short Sea Corridors and Hubs:** just-in-time port calls, interoperable reporting, data-driven voyage optimisation
- Battery-electric and hybrid propulsion mainstream on short, high-frequency routes, with OPS and standardised charging
- **Type-approved modular retrofit power packages** for representative vessel classes; common connector and communication requirements
- Alternative fuels, ESDs and hull and propulsor optimisation cut emissions across the existing fleet; differentiated green port tariffs
- Machine-verifiable MRV and ETS reporting generated from vessel energy-management systems
- Safety, cyber, emergency-response and training baselines for batteries, charging and new fuels

2040 • Scale-up & integration

- Clean propulsion commercially available across the main cargo segments, with harmonised OPS, charging and bunkering
- SSS fully connected with inland waterways, rail, road and ports through realtime digital exchange
- From single tools to **integrated corridor management:** predictive maintenance, automated compliance, energy planning
- Common multi-fuel safety-zoning standards applied consistently across the TEN-T port network
- Predictive risk management, cyber-resilient ship-shore systems and digital safety twins mature
- Regulatory harmonisation lets innovative operational concepts deploy consistently across Europe

2050 • Full transformation

- **Zero-emission cargo fleet:** greenhouse gases, air pollutants, water pollution and underwater noise eliminated
- Vessels, ports, offshore power zones, energy systems and hinterland logistics operate as integrated corridors
- Remote and automated functions improve safety, efficiency and resilience under clear human oversight
- Full multimodal integration: modal shift from road, stronger island and peripheral connectivity, circular flows
- Dual-use corridors adapt rapidly to disruption, extreme weather and geopolitical events
- Predictive safety, dynamic risk modelling and climate resilience — winterisation, extreme heat — embedded by design

SOURCES

1 European Commission, Study on Short-Sea Shipping's Contribution to the European Transport Network — fleet by vessel type and size (cargo segments only) and age profile.
2 Waterborne Technology Roadmap — Short Sea Shipping, §2.2.
3 Natural Earth 1:110m country geometry (public domain); gateways and corridors per Roadmap Ch. 1 and §5.1. Sector, drivers and constraints: Roadmap Ch. 1–2.
4 Enablers and impacts: Waterborne Technology Roadmap — Short Sea Shipping, Ch. 5–6. Expected impacts are targeted outcomes, not measured results.

GLOSSARY

OPS = onshore power supply
GT = gross tonnage
ESD = energy-saving device
MRV = monitoring, reporting and verification
ETS = EU emissions trading system
TEN-T = EU core transport network
MASS = maritime autonomous surface ships (IMO)
TRL = technology readiness level
XR = extended reality
HMI = human-machine interface
SME = small and medium-sized enterprise.

04 THE PATHWAYS — FIVE ROUTES TO 2050

Five parallel work streams: the technology, safety, digital, people and regulatory tracks. TRL ranges as stated in the roadmap.

4.1 Propulsion & energy Five parallel work streams: the technology, safety, digital, people and regulatory tracks. TRL ranges as stated in the roadmap.

4.2 Safety, security & resilience Harmonised battery, charging and new-fuel protocols in busy ports · multi-sensor hazard detection · SME cyber baselines · digital safety twins and certified "guardian AI" · zero-accident corridors by 2050

4.3 Connected, automated & data-driven Digital twins, condition-based maintenance and AI diagnostics standard · smart waterways · just-in-time arrival and cargo handling · machinery autonomy in cross-border corridors · self-negotiating port calls by 2050

4.4 Human-centred design & future-ready workforce Better HMIs and alarm strategies · training for new fuels, battery safety and automation · unmanned engine rooms and mixed-reality drills · onboard AI copilot by 2050

4.5 Regulation & standards Standardised OPS, charging and bunkering interfaces, fuel certification and well-to-wake accounting · MASS-aligned autonomy approval · corridor-level carbon budgets by 2050

KEY RESEARCH GAPS THAT DECIDE WHETHER THE TARGETS ARE REACHED

4.1 Propulsion

Fast-turnaround charging without schedule penalties · certifiable integrated energy architectures · battery degradation under fast charging and cold · ESD and wind-assist validation at sea · underwater radiated noise.

4.2 Safety

Simultaneous bunkering, charging and cargo handling in constrained ports · detection, suppression, ventilation and evacuation validated as one ship-port system · assurance for safety-critical AI · icing and extreme weather.

4.3 Digital

Certifiable AI diagnostics and autonomous maintenance decisioning with continuous assurance · resilient positioning and communications under degraded connectivity · autonomous navigation in ice and winter conditions.

4.4 People

Human-machine teaming: explainable decision support, responsibility allocation, intervention thresholds, alarm and workload management · low-complexity interfaces for SME operators · training for rare but critical events.

4.5 Rules

Safety-case and risk-assessment methods for integrated vessel-port systems · mutual recognition of approval evidence across class, flag states and Member States · certification of adaptive AI · carbon-capture and cyber standards.

SHORT SEA SHIPPING TECHNOLOGY ROADMAP

05 ENABLERS AND DEPLOYMENT

What has to be in place on shore — corridors, energy, industry, data, rules, finance and skills — for the fleet to change.

INFRASTRUCTURE & ENERGY

Corridor-based deployment Replicable packages of vessels, ports, energy, digital services, safety cases and financing — dense routes first, then seasonal and remote ones.

Clean energy, OPS & charging Shore power from hotel load to propulsion charging; offshore power zones; grid capacity reserved before vessel orders.

Alternative-fuel bunkering Strategic coastal hubs first; methanol and ethanol earlier, hydrogen and ammonia after safety validation; no premature lock-in.

Fleet renewal & industrial readiness Repeatable retrofit packages, pre-certified components, yard capacity, circular end-of-life and battery second life.

REGULATION, FINANCING & WORKFORCE

Digital infrastructure & data governance Interoperable corridor services for berth, charging, bunkering, cargo and emissions data — plus an EU port-readiness framework.

Regulation, standards & certification Goal-based, technology-neutral rules; sandboxes feeding permanent certification; mutual recognition of approvals.

Finance, business models & demand De-risking instruments, TEN-T and military-mobility funding, green transport contracts, battery-as-a-service, SME aggregation

Digital coordination and cybersecurity Coordination between passenger flows, vehicles & terminals

Tramp and spot-market vessels need a separate pathway: without a predictable rotation they cannot align investment with individual ports — verified energy efficiency, drop-in fuels and modular hybrids come first, while EU ports become dual-use infrastructure.

06 TOWARDS A COMPETITIVE, RESILIENT AND SUSTAINABLE SSS SECTOR — IMPACTS BY 2050

Indicative and scenario-based — monitoring should reward flexibility, modularity and interoperable infrastructure over convergence on a single fuel.

	2035	2040	2050
ENVIRONMENTAL	15–20% average CO_2-intensity reduction vs the 2020 fleet baseline; zero emissions at berth at 50+ major SSS ports; shore power at 70%+ of TEN-T maritime ports	45–50% CO_2-intensity reduction; zero-emission operations on 60%+ of short-distance, high-frequency routes; methanol, ethanol or hydrogen at 30+ EU ports	Zero-emission SSS fleet; 90%+ CO_2 reduction vs 2020; full circular-economy integration; zero harmful discharges at all European SSS ports
ECONOMIC	100–150 vessels retrofitted with hybrid/battery, fuel flexible and energy efficiency systems; €300–500M/year fuel-cost savings through energy management	400–600 additional retrofits; €1B+ annual fleet-wide fuel savings; modal shift delivering a 5–10% cut in European road freight (100B tonne-km shifted to sea)	Transition value €25–35B (2026–2050); European shipbuilding and equipment exports €2B+/year; 25% more EU cargo carried than in 2020,1,500+ new jobs in retrofit services
TECHNOLOGICAL	Standardised shore-power interfaces deployed; automated MRV and ETS reporting on 500+ vessels; type-approved modular retrofit kits for three vessel classes	Integrated corridor-management platforms on 10+ major corridors; predictive maintenance on 80%+ of the fleet; machine-verifiable compliance reporting as standard	Full system-of-systems digital integration; remote and autonomous operations on selected low-traffic routes; 95%+ battery and component material recovery
SOCIAL	4,000+ SSS seafarers and port personnel trained in new technologies	10,000+ personnel trained; SME digital transformation complete for 80%+ of operators	20,000+ trained; improved island and peripheral-region connectivity and supply-chain resilience

TABLE 2 · Indicative expected impacts by 2035, 2040 and 2050. Waterborne Technology Roadmap — Short Sea Shipping, Ch. 6, Table 2; figures are targeted outcomes, not measured results. [4]

VISION FOR 2050

Cargo short sea shipping as a zero-emission, competitive and digitally integrated part of the European transport system — Europe's most resilient mode, with dual-use corridors and strong regional connectivity.

CONTENT

LIST OF FIGURES

ROADMAP POSITIONING WITHIN THE WATERBORNE TECHNOLOGY LEADERSHIP FRAMEWORK

This roadmap operationalises the Technology Leadership[1] framework for the short sea shipping (SSS) sector. It translates the overarching objectives, including competitiveness, resilience, sustainability, zero-emission operations, digitalisation, safety and security, human-centred innovation, standards, skills and deployment at scale, into the specific conditions of short sea shipping. It reflects the Technology Leadership document's ecosystem approach, linking shipowners, shipyards, equipment manufacturers, ports, energy, infrastructure and service providers, classification societies, financial institutions, authorities, research organisations and logistics users into a coordinated deployment pathway.

The roadmap on short sea shipping is closely interlinked with the following dedicated Technology Roadmaps: maritime technology sector, port ecosystems, and ferry sector.

1 Waterborne Technology Platform, Waterborne Technology Leadership: Towards a Competitive, Resilient and Sustainable Waterborne Sector — A Co-programmed Partnership under Framework Programme 10 (Brussels: Waterborne Technology Platform, January 2026), https://www.waterborne.eu/images/260115_Waterborne_Technology_Leadership_final.pdf.

1. DESCRIPTION OF THE SECTOR

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"Short Sea Shipping (SSS) is defined as "the movement of cargo and passengers by sea between ports situated in geographical waters of one or several Member States or between a port situated in waters of Member States and a port situated in waters of an adjacent third country having a coastline on the seas bordering waters of one or several Member States"[2] . On this basis, short sea shipping includes domestic and international maritime transport along European coasts and across regional sea basins[3], including the Baltic Sea, the North Sea, the Atlantic, the Mediterranean and the Black Sea, as well as maritime connections with islands, peripheral regions and neighbouring coast countries. For the purposes of this roadmap, the focus is limited to cargo-based short sea shipping, including vessels below 500GT. It covers feeder container vessels, general cargo and multipurpose vessels, coastal bulk carriers, coastal tankers and freight-only roll-on/roll-off vessels. Passenger-oriented segments, including ferries, Ro-Pax vessels and cruise vessels, are addressed in separate Waterborne technology roadmap documents. Short sea shipping is crucial for resilience, strategic autonomy, modal shift and supply-chain robustness, military mobility and offshore energy logistics.

1.1 FLEET COMPOSITION, AGE PROFILE AND OPERATING CONTEXT

The European short sea shipping (SSS) fleet is characterised by a high degree of functional diversity, reflecting the range of cargo types, vessel sizes and operational requirements across intra-European maritime transport. According to a recent study[4] the main cargo-vessel categories considered in this roadmap comprises approximately 6,184 vessels. Most of these vessels operate within the 500-25,000 gross tonnage (GT) range, which accounts for around 74% of the total fleet. This highlights the importance of small and medium-sized vessels adapted to short-distance, regional and high frequency services. Table 1 presents the distribution of the fleet by vessel type and size category.

Vessel type	< 500 GT	500-25,000 GT	25,000-60,000 GT	> 60,000 GT	Total
Bulk carriers	7	180	37	1	225
Container ships	3	540	396	503	1,442
General cargo vessels	30	2,546	239	103	2,918
Tankers	19	1,290	188	102	1,599
Total	**59**	**4,556**	**860**	**709**	**6,184**

Table 1: Table 1: Short Sea Shipping Fleet by Vessel Type and Size (Cargo Segments Only)

Source: Adapted from European Commission, Study on Short-Sea Shipping's Contribution to the European Transport Network and the Means to Support and Revitalize the Sector

2 Regulation (EU) 2024/1679 of the European Parliament and of the Council of 13 June 2024 on Union guidelines for the development of the trans-European transport network, amending Regulations (EU) 2021/1153 and (EU) No 913/2010 and repealing Regulation (EU) No 1315/2013, OJ L, 2024/1679.

3 European Commission, Eurostat Database, "Short Sea Shipping – Country Level – Gross Weight of Goods Transported to/from Main Ports, by Sea Region of Partner Ports (mar_sg_am_cws)," last modified March 24, 2026, accessed March 30, 2026, https://ec.europa.eu/eurostat.

4 European Commission, Directorate-General for Mobility and Transport, Study on Short-Sea Shipping's Contribution to the European Transport Network and the Means to Support and Revitalise the Sector: Final Report (Luxembourg: Publications Office of the European Union, 2025), https://doi.org/10.2832/8154948 (fleet data for 2022, based on Eurostat).

As shown in Table 1, general cargo vessels form the largest segment, representing close to half of the quantified fleet[5]. Their importance reflects the versatility of short sea shipping in carrying bulk, semi-bulk, packaged and project cargo across European sea basins. Container vessels also play a significant role, particularly in feeder services and intra-European logistics chains, where standardised cargo handling and integration with global container networks are important. Tankers and bulk carriers, although more specialized, remain essential for the transport of liquid and dry bulk commodities linked to energy supply, industrial production and regional supply chains.

A defining structural characteristic of the SSS fleet is its ageing profile. Nearly half of the vessels are over 15 years old, while only around 17% are newer than five years, indicating relatively slow fleet renewal. This creates important implications for the technology roadmap, as a significant share of the fleet will remain in operation for many years. Modernization will therefore depend not only on newbuilds, but also on retrofitting, modular solutions, fuel flexibility and technologies that can be integrated into existing vessels with limited downtime. The challenge is particularly relevant for bulk carriers and tankers, which typically have longer operating lifetimes, while container vessels tend to be newer and more closely linked to evolving logistics requirements.

The spatial distribution of short sea shipping activity is also uneven. Major European ports such as Rotterdam, Antwerp-Bruges and Hamburg dominate cargo throughput and act as primary gateways for intra-European and global trade flows. At the same time, secondary and regional ports in the Mediterranean, Baltic, Atlantic, North Sea and Black Sea basins play an important role in maintaining regional connectivity, supporting feeder services and linking peripheral and island regions to wider logistics networks. This port structure confirms the corridor-based nature of short sea shipping: large hubs, regional ports and hinterland connections must be considered together when planning clean-energy infrastructure, digital services and fleet deployment. Deployment of technologies is furthermore influenced by frequent port calls, fragmented cargo flows, many interfaces with authorities and a high dependency on port performance.

The composition and age of the fleet also shape its current energy profile. General cargo vessels, tankers and bulk carriers remain largely dependent on conventional marine fuels, while sustainable alternative fuels and electrified solutions are still concentrated in newer or more specialised applications. Cargo based short sea vessels also depend on integrated power and energy management systems coordinating main engines, generators, shaft generators, batteries, shore-power interfaces, waste-heat recovery and digital power optimization. Retrofit compatible architectures should support variable route lengths, cargo profiles and port call patterns while enabling progressive electrification and preserving efficiency across diverse duty cycles.

This means that the transition to zero-emission SSS will be constrained not only by technology availability, but also by vessel size, age, route profile, cargo requirements, port infrastructure and fuel availability. The roadmap therefore needs to combine near-term efficiency and retrofit measures for the existing fleet with longer-term deployment of zero- and near-zero-emission vessels on suitable short sea corridors.

5 Ibid (Note: the table covers bulk carriers, container ships, general cargo vessels, and tankers. Freight-only Ro-Ro vessels are included in the scope of this roadmap but are not quantified in this table)

2. DRIVERS AND CONSTRAINTS

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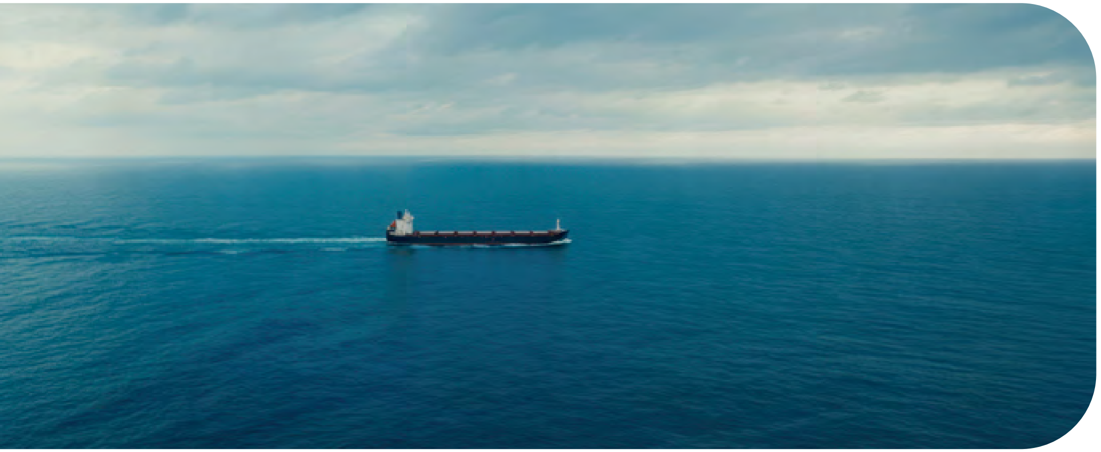
2.1 DRIVERS

The transformation of short sea shipping is driven by the convergence of legally binding climate, fuel and infrastructure requirements, policy frameworks for investment, industrial competitiveness and resilience, multimodal transport policy, digital simplification, safety and security requirements, and market demand for cleaner logistics[6]. Because SSS operates through frequent port calls and corridor-based services, these drivers need to be addressed as part of an integrated fleet-port-energy–logistics system, rather than through vessel technologies alone. The principal drivers are set out below.

- **Climate neutrality, carbon pricing and fuel regulation.** The European Climate Law establishes the long-term objective of climate neutrality by 2050, supported by a 2030 target of at least 55% net greenhouse-gas emissions reduction and a 2040 target of 90% net emissions reduction compared with 1990 levels[7,8]. For shipping, this direction is reinforced by the extension of the EU Emissions Trading System to maritime transport and its subsequent revision[9], the IMO's decarbonisation, energy efficiency and emissions standards for maritime shipping[10] and by FuelEU Maritime, which sets requirements for reducing the greenhouse-gas intensity of energy used on board ships.[11] This is further complemented by local, regional or national tightening environmental regulations, specifically in port areas. Together, these instruments make emissions performance, port-call optimization, just-in-time arrival, data sharing, shore power, smart cargo bundling, better hinterland integration, fuel choice, operational efficiency and fleet renewal central factors for the future of short sea shipping.
- **Alternative-fuel and shore-power infrastructure.** The Alternative Fuels Infrastructure Regulation (AFIR) and FuelEU Maritime create complementary obligations on port infrastructure and vessel energy use [12]. AFIR supports the deployment of alternative-fuel infrastructure, including shore-side electricity in maritime ports, while FuelEU Maritime strengthens the demand for renewable and low-carbon fuels and clean energy technologies on board ships. For short sea shipping, this accelerates the need for port electrification, grid reinforcement, standardised shore-power and charging interfaces, sustainable alternative-fuel bunkering and closer coordination between vessel investment and port infrastructure. This is particularly relevant for high-frequency services, where infrastructure availability at both ends of a route can determine whether clean propulsion solutions are operationally feasible.
- **Sustainable transport investment.** The Sustainable Transport Investment Plan (STIP) is a policy and investment framework aimed at scaling up renewable and low-carbon fuels for aviation and waterborne transport and mobilising investment for their production and uptake[13]. For SSS, this is a key driver because the availability, price and certification of sustainable alternative fuels will strongly influence retrofit decisions, newbuilding choices and the business case for zero- and near-zero-emission services.
- **Ports as energy, logistics and security hubs.** The EU Ports Strategy positions ports as strategic nodes for trade, logistics, energy transition, security and the blue economy[14]. For short sea shipping, ports are critical deployment platforms for shore power, charging, sustainable alternative-fuel bunkering, digital port-call optimization, safety procedures and multimodal connections. Port readiness, terminal processes, grid capacity and local energy systems must therefore be planned together with vessel modernization.

6 European Commission, Communication from the Commission, Sustainable and Smart Mobility Strategy - Putting European Transport on Track for the Future, COM(2020) 789 final (Brussels, 9 December 2020), 5-6, 15.
7 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 July 2021, arts. 2 and 4, as amended by Regulation (EU) 2026/667, of 11 March 2026 as regards the setting of a Union intermediate climate target for 2040, OJ L, 2026/667, 18 March 2026
8 European Commission, Securing our Future: Europe's 2040 Climate Target and Path to Climate Neutrality by 2050, COM(2024) 63 final (Brussels, 6 February 2024),
9 Directive (EU) 2023/959 amending Directive 2003/87/EC as regards, inter alia, the inclusion of maritime transport in the EU Emissions Trading System, OJ L 130, 16 May 2023
10 International Maritime Organization, 2023 IMO Strategy on the Reduction of GHG Emissions from Ships, Resolution MEPC.377(80) (adopted 7 July 2023).
11 Directive (EU) 2023/959 amending Directive 2003/87/EC as regards, inter alia, the inclusion of maritime transport in the EU Emissions Trading System.
12 Regulation (EU) 2023/1805 on the use of renewable and low-carbon fuels in maritime transport (FuelEU Maritime), OJ L 234, 22 September 2023
13 Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure, commonly referred to as the Alternative Fuels Infrastructure Regulation.
14 European Commission, Sustainable Transport Investment Plan, COM(2025) 664 final (Brussels, 5 November 2025), 1–2.
15 European Commission, EU Ports Strategy, COM(2026) 112 final (Brussels, 4 March 2026), 3–5.

- **Industrial maritime competitiveness.** The EU Industrial Maritime Strategy links the decarbonization and digitalization of shipping with European industrial competitiveness[16]. It highlights the importance of ship repair, retrofitting, conversion, recycling, advanced manufacturing and maritime technology supply chains. This is directly relevant to short sea shipping, where a large share of the existing fleet will remain in operation for many years and where scalable retrofit packages, modular propulsion systems and cost-effective conversion solutions will be essential. Short sea ships are retrofitted and build in Europe, serving as a key market for shipyards and equipment manufacturers.
- **TEN-T and the European Maritime Space.** The revised Trans-European Transport Network (TEN-T) Regulation integrates short sea shipping into the European transport network through maritime links, ports, hinterland connections and the European Maritime Space[17]. This strengthens the role of SSS in connecting regions, islands, peripheral areas and industrial clusters to the Single Market. It also supports the development of green maritime corridors and hubs, improved port-hinterland integration and better links between maritime transport, rail, road and inland waterways.
- **Digital simplification and single-market integration.** Short sea shipping is highly sensitive to administrative burdens because high-frequency services may face repeated reporting, customs and border procedures at each port call. The European Maritime Single Window environment provides a framework for interoperable and harmonized reporting for ships arriving at, staying in and departing from EU ports[18]. Wider digital harmonization can reduce duplication, improve data exchange and make SSS more competitive with land-based transport.
- **Industry and market demand.** European industry positions increasingly converge on the need to make short sea shipping more competitive, digitally integrated and easier to use within the Single Market. ECSA calls for measures to reduce administrative and reporting burdens for short sea shipping[19], while the importance of fleet renewal, retrofitting and European industrial capacity is also underlined. Cargo-owners' demand for lower-emission logistics can further strengthen the business case for investment in cleaner vessels, port readiness, green transport services and integrated multimodal solutions.



16 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final (Brussels, 4 March 2026), 8.
17 Regulation (EU) 2024/1679 of the European Parliament and of the Council of 13 June 2024 on Union guidelines for the development of the trans-European transport network, OJ L, 2024/1679.
18 Regulation (EU) 2019/1239 establishing a European Maritime Single Window environment.
19 European Community Shipowners' Associations (ECSA), ECSA Position Paper on a Single Market for Short Sea Shipping (2025), https://ecsa.eu/wp-content/uploads/2025/04/ECSA-Position-Paper-short-sea-shipping_final.pdf.

- **Technology readiness and deployment potential.** Several technologies are already available for selected short sea applications, including battery-electric and hybrid propulsion, onshore power, wind assisted propulsion supply, energy-saving devices, hull and propulsor optimization, digital twins, route optimization and condition-based maintenance[20,21]. Methanol and ethanol-capable engines and vessels are moving towards wider market uptake, while sustainable biofuels and other certified fuels can support transition pathways for parts of the existing fleet. LNG and biomethane may remain transitional options in certain segments, provided that methane slip and lifecycle emissions are properly controlled. Hydrogen, ammonia, fuel cells, onboard carbon capture, advanced autonomy and AI-supported operations require further infrastructure development, standards and corridor-based demonstration before broad deployment. Finally, safety innovation and safety validation are strategic deployment enablers whereas demonstrated safety performance accelerates market uptake, investment confidence and regulatory acceptance. Safety, standards, certification and assurance frameworks are critical deployment drivers for sustainable alternative fuels, electrification, automation and other novel technologies.
- **Resilience, strategic autonomy, military mobility and dual-use infrastructure.** Short sea shipping supports intra-EU trade and modal shift and is a strategic transport mode that increases redundancy, reduces dependency on congested road corridors and strengthens European strategic autonomy. Furthermore, it ensures continuity of logistics when land corridors are congested, disrupted or exposed to geopolitical risk. This is a policy and market driver for investment in vessels, port infrastructure, digitalisation and sustainable alternative fuels. It covers infrastructure investments with both civilian and defence functions, enhanced interoperability of ports with military logistics systems, and growing emphasis on resilience, redundancy, and security standards in transport infrastructure. In this context, EU Ports are "dual-use" infrastructure. It ensures they serve both commercial trade and military mobility.

2.2 CONSTRAINTS

The transition of short sea shipping is constrained by fleet, infrastructure, market, regulatory, digital and workforce barriers. These constraints are closely interlinked: investment in clean vessels depends on the availability of port infrastructure and fuels; infrastructure investment depends on predictable vessel demand; and both depend on stable regulation, finance, skills, national and regional differences and operational readiness. The principal constraints are set out below.

- **Fleet age, diversity and retrofit complexity.** A large share of the SSS fleet will remain in operation for many years, which limits the pace at which new zero-emission vessels can replace existing assets[22]. The fleet is also highly heterogeneous in terms of vessel type, size, cargo profile, age, route length and operational pattern and area. This makes it difficult to apply a single decarbonization solution across the sector. Retrofit ability, modularity, fuel flexibility and lifecycle-cost reduction are therefore essential, especially for older vessels, specialized cargo segments and lower-volume or seasonal routes where the business case for newbuilds is weaker. Limited shipyard capacity, supply-chain bottlenecks and shortages of skilled workers may further constrain the pace of large-scale retrofit and newbuild deployment, particularly if demand for vessel conversions accelerates across multiple shipping segments simultaneously. A significant part of the dry-bulk and tanker segments operates on a tramp basis, on unscheduled, spot-market voyages rather than fixed routes. This weakens the investment case: without a predictable rotation, operators cannot align vessel investment with the bunkering or shore-power infrastructure of individual ports, and sustainable alternative fuels become viable only once they are available across many ports in sufficient quantity and at competitive prices. For these segments, energy-efficiency measures remain the principal near-term lever, with the applicable solution depending on vessel type, route and business model.[23]

20 European Commission, Directorate-General for Mobility and Transport, Study on Short-Sea Shipping's Contribution to the European Transport Network and the Means to Support and Revitalise the Sector: Final Report (Luxembourg: Publications Office of the European Union, 2025), 91–95, https://doi.org/10.2832/8154948

21 European Commission, European Alternative Fuels Observatory (EAFO), "Vessels," accessed 6 April 2026, https://alternative-fuels-observatory.ec.europa.eu/transport-mode/maritime-sea/vessels.

22 European Commission, Directorate-General for Mobility and Transport, Study on Short-Sea Shipping's Contribution to the European Transport Network and the Means to Support and Revitalise the Sector: Final Report (Luxembourg: Publications Office of the European Union, 2025), 91–95, https://doi.org/10.2832/8154948.

23 Waterborne Technology Platform, Waterborne Technology Leadership: Towards a Competitive, Resilient and Sustainable Waterborne Sector (Brussels: Waterborne Technology Platform, January 2026), https://www.waterborne.eu/images/260115_Waterborne_Technology_Leadership_final.pdf., p. 9

- **Port Infrastructure and fleet-investment mismatch.** Port electrification, grid capacity, shore-power connections, charging systems, sustainable alternative-fuel bunkering and reception facilities remain unevenly deployed across European ports[24]. Electrification opportunities are particularly constrained in regional ports lacking planned grid reinforcement, high power connections or energy storage. Grid-connection, power-availability and energy-system lead times may further delay electrification and shore-power deployment even where investment is planned, creating a structural gap between major hubs and smaller ports serving coastal, island, and regional cargo routes. For high-frequency short sea services, the lack of suitable infrastructure at even one port on a route can prevent the deployment of clean propulsion solutions across the entire corridor. In the early deployment phase, limited charging capacity may also be prioritised for larger users, requiring cargo-based SSS vessels to retain operational flexibility through hybrid systems, sustainable alternative fuels or other onboard energy sources. These challenges are further complicated by long permitting procedures for energy and port infrastructure.
- **Fuel availability, cost and sustainability uncertainty.** Operators face uncertainty over the availability, price, certification, lifecycle-emission performance and safety requirements of sustainable biofuels, e-fuels, methanol, ethanol, hydrogen, ammonia and other future energy carriers[25]. Different fuels may be suitable for different vessel types and route profiles, but the timing and scale of fuel availability remain uncertain. Furthermore, many cargo ships (around 3000) within SSS are smaller than 5000 GT and not included in the EU ETS and FuelEU Maritime, however, targeted by the European Climate Law. A lack of technical standardization and interoperability across ports, vessels and energy systems, including shore power, charging, bunkering and digital interfaces complicates implementation.

  This increases the risk of technology lock-in, stranded assets or delayed investment. For some existing vessels, sustainable drop-in fuels may provide a transitional option, but their availability and sustainability credentials will need to be verified.
- **Financing and business-case constraints.** Many SSS operators, including SMEs and companies serving regional, seasonal or lower-volume routes, have limited capacity to finance new vessels, retrofits or digital upgrades[26]. The business case is often weakened by high upfront costs, uncertain fuel-price differentials, charter arrangements, limited ability to pass costs to customers, uncertain residual values and fragmented demand for green transport services. Smaller ports may also lack the organizational capacity and financial resources to modernize infrastructure or access EU support mechanisms. Without de-risking instruments, predictable demand and European long-term financial tools, first movers may face disproportionate costs.
- **Administrative and single-market barriers.** Short sea shipping can face repeated reporting, customs and border procedures at each port call, even where cargo is moving within the Union[27]. These burdens are particularly problematic for high-frequency services and can make SSS less competitive than road transport. Administrative complexity also limits the attractiveness of SSS for shippers and logistics providers. Further harmonisation, digital reporting and simplification are therefore needed to reduce duplication and strengthen the role of SSS within the Single Market.

24 European Commission, Study on Short-Sea Shipping's Contribution, 89–90
25 Ibid, 91–95.
26 Ibid., 81–83, 95–97.
27 ECSA, ECSA Position Paper on a Single Market for Short Sea Shipping, 2.

- **Safety, certification and regulatory readiness.** Sustainable alternative fuels, onboard batteries, high-power charging, carbon capture, automation, remote operations and cyber-physical systems introduce new safety and operational risks. Certification pathways, emergency procedures, crew training, port preparedness and class and flag-state approval processes are not yet mature for all technologies and use cases[28] and uncertainty in approval processes and safety-case development may represent a significant deployment cost and investment barrier for innovative energy systems. This can delay deployment even where technologies are available. The challenge is particularly acute in short sea shipping because new fuel handling, charging, bunkering, cargo operations and port turnaround often occur within constrained port environments and tight schedules.
- **Digital fragmentation and cybersecurity exposure.** Digital systems used by ports, terminals, operators, authorities and logistics actors are not yet sufficiently interoperable. This limits real-time data exchange, port-call optimisation, just-in-time arrival, emissions reporting and integrated corridor management[29]. At the same time, greater digital connectivity increases exposure to cyber risks. Cybersecurity must therefore be treated as an operational safety and resilience issue, not only as an IT function, particularly where vessels depend on continuous interaction with ports, terminals, traffic systems and shore-support services. Furthermore, the lack of harmonization and coordination in the interpretation of European resilience directives (NIS2 and CER) and other European initiatives, as well as the NATO framework for Cybersecurity and Digitalization of critical infrastructures represent a significant barrier.
- **Electrical system integration and retrofit standardisation.** Many SSS vessels have diverse and ageing electrical architectures. Battery, hybrid and shore-power retrofits therefore require substantial vessel specific engineering. Type approved modular electrical upgrade packages and standardized interfaces are needed to reduce cost, downtime and engineering effort.
- **SME digital capacity and serviceability.** Smaller operators may lack dedicated IT, data management and cybersecurity resources. Digital compliance, energy management and maintenance solutions should therefore be interoperable, low-complexity and available through turnkey service models.
- **Insurance, liability, bankability and contractual risk.** Limited operational evidence for sustainable alternative fuels, batteries and automated systems can increase insurance costs and weaken bankability. Risk sharing, warranty, liability and contractual frameworks must develop alongside technical approval.
- **Skills availability and workforce shortages are cross-cutting constraints.** The safe deployment of new fuels, electrification, digital systems, automation and remote operations depends on the availability of suitably trained crews, shore operators, port personnel, emergency responders, inspectors and maintenance teams[30]. Automation, remote technical support and digital decision-support tools can improve safety, reduce workload and make short sea shipping operations more attractive for future generations of maritime professionals. Skills gaps may slow deployment or increase operational risk. Training systems, competence standards and certification requirements will need to evolve in parallel with fleet and infrastructure renewal, while human-centered design will be necessary to ensure that digital and automated systems support rather than overburden crews and shore-based operators.

28 European Commission, Study on Short-Sea Shipping's Contribution, 91–95.
29 Regulation (EU) 2019/1239 establishing a European Maritime Single Window environment.
30 European Commission, Study on Short-Sea Shipping's Contribution, 95–97.

3. TARGET CAPABILITIES

3. TARGET CAPABILITIES

Drawing on the Waterborne Technology Leadership document, this section summarises the current state of play and sets out the operational capabilities that cargo-based SSS should develop by 2035, 2040 and 2050, together with their cross-cutting implications.

3.1 CURRENT STATE OF PLAY AND ACHIEVED DEVELOPMENTS

Short sea shipping is entering the transition with an ageing and heterogeneous cargo fleet, continued dependence on conventional maritime fuels and uneven access to clean energy infrastructure. At the same time, important foundations have already been established. Battery-electric and hybrid propulsion, shore side electricity, energy-saving devices, hull and propulsor optimisation, digital voyage and port call optimisation, condition-based maintenance and wind assisted propulsion are available or being demonstrated in selected applications. Mehtanol- and ethanol-capable engines and vessels are moving towards wider uptake, while sustainable biofuels and other certified fuels offer near term options for parts of the existing fleet. These developments provide a basis for deployment, but broader uptake remains constrained by fuel availability and cost, charging and bunkering infrastructure, retrofit complexity, safety approval, financing, skills and the readiness of smaller ports and operators.

3.2. 2035: EARLY DEPLOYMENT PHASE

By 2035, multiple European Green and Digital Short Sea Corridors and Hubs are established, facilitating widespread implementation of Just-in-Time port calls, interoperable digital reporting across Member States, and routine use of data-driven voyage optimization to improve efficiency and reduce emissions. Core short sea shipping ports support regular low-emission services through shore-side electricity, digital port call systems, improved berth planning and better road-rail-water integration.

Short sea shipping deploys low- and zero-emission solutions on the routes and vessel segments where operational conditions are favourable. Battery-electric and hybrid propulsion are increasingly used on short-distance, high-frequency and predictable cargo services, supported by onshore and offshore power supply, standardized charging interfaces and improved port energy management. Across variable route and longer distance cargo operations, sustainable alternative fuels, fuel-flexible propulsion and hybrid systems play a more prominent role. Sustainable alternative fuels also contribute to emission reductions in the existing fleet, while energy-efficiency measures, hull and propulsor optimization, energy-saving devices and operational optimization deliver near-term reductions across a broader range of vessels. Ports operate differentiated or green port tariffs rewarding low- and zero-emission vessels.

By 2035, type-approved modular retrofit power system packages are available for representative SSS vessel classes, covering hybridization, batteries and shore-power interfaces. Common voltage, frequency, connector and communication requirements allow equipped vessels to use compatible shore-power systems across EU ports without bespoke engineering.

Operational integration between vessels, ports and logistics actors improved significantly by 2035. Short sea services are supported by better data exchange, digital reporting, route optimisation, just-in-time arrival, berth coordination, shore-power availability information and condition-based maintenance. Digital tools support crews and operators in improving reliability, port-call efficiency and energy management, while operations remain largely human-controlled.

By this stage, the sector has developed the basic safety, regulatory and workforce capabilities needed for early deployment. This includes safety procedures for batteries, shore power, charging and sustainable alternative fuels; cybersecurity measures; updated emergency-response arrangements; and training programs for crews, port and terminal personnel, shore operators and maintenance teams. However, transformation by 2035 may still be limited by fleet age, infrastructure gaps, fuel availability, financing constraints and the uneven readiness of ports, offshore power zones and corridors.

Automated, machine-verifiable MRV and EU ETS reporting are increasingly generated directly from vessel energy management systems, reducing manual reporting burdens, particularly for SME operators. To support deployment, standardized and interoperable ship-port interfaces for shore power, charging, bunkering and operational data exchange are established. Furthermore, safety, approval and certification capability for batteries, sustainable alternative fuels, hybrid systems and automated/remote functions, including scalable risk-based approval pathways for both retrofit and newbuild applications are in place.

Finally, the workforce has been educated and trained to be able to work with new technologies.

3.3. 2040: SCALE-UP AND SYSTEM INTEGRATION PHASE

By 2040, short sea shipping scales zero- and near-zero-emission solutions across a wider range of routes, vessel types and sea basins. Short sea shipping corridors are connected to a wider network of sustainable alternative fuel and energy infrastructure, with operability between vessels, ports and logistics operators. Furthermore, SSS is fully connected with inland waterways, rail, road and ports through real-time digital information exchange, ensuring integrated multimodal logistics. Clean propulsion options are commercially available for the main cargo-based SSS segments, supported by mature and harmonized shore-power, offshore power zones, charging and sustainable alternative-fuel bunkering infrastructure in major ports and selected short sea corridors. Sustainable alternative fuels, electrification, hybridization and fuel-flexible systems are integrated with vessel design, retrofit strategies and operational profiles. Remote support, predictive maintenance and advanced decision-support systems are standard operational practice. Ports will have common safety-zoning standards for multi-fuel bunkering applied consistently across the TEN-T port network, so that infrastructure siting decisions are not made port-by-port in isolation.

Digitalisation moves from individual tools to integrated corridor management. Vessels, ports, terminals, energy suppliers, authorities and hinterland operators exchange operational data securely and in near real time. This supports port-call optimisation, automated compliance reporting, emissions monitoring, predictive maintenance, energy planning and multimodal coordination. Remote support and partial automation are feasible in controlled environments, particularly for machinery monitoring, port approaches, maintenance support and selected corridor operations.

Safety, security and resilience capabilities are mature by 2040. Predictive risk management, cyber-resilient systems, harmonized safety procedures and improved emergency preparedness support the wider use of sustainable alternative fuels, electrification, digital systems and automated functions. The sector is capable of operating more reliably under disruption, including extreme weather, port congestion, energy-supply constraints and cyber incidents. Industrial capacity for repair, retrofitting, conversion and modular technology integration is sufficiently developed to support deployment beyond pilot projects. Furthermore, it is essential to ensure coordinated cross-sector and cross-border practices and disruption exercises between corridors and critical supply chains for cybersecurity and other good practices, including physical security.

By 2040, regulatory harmonization allows innovative operational concepts to be deployed consistently across Europe.

3.4. 2050: FULL TRANSFORMATION PHASE

By 2050, short sea shipping operates as zero-emission and Europe's most resilient and digitally integrated component of the European transport system, including dual-use corridors. The cargo-based SSS fleet uses zero- emission energy solutions at scale, supported by a mature port and energy ecosystem. Greenhouse-gas emissions, air pollutants and pollution to water (including underwater noises) are eliminated and systematically addressed through vessel design, operational optimization and port integration. Short sea shipping is capable of rapidly adapting to disruptions, extreme weather and geopolitical events.

Operations are connected, increasingly automated and seamless interoperable, with vessels, ports, offshore power zones, authorities, terminals, energy systems and hinterland logistics functioning as part of integrated short sea corridors. Digital systems support continuous optimization of routes, energy use, cargo flows, emissions performance, administration, maintenance and port-call planning. Remote and automated functions are used to improve safety, efficiency and resilience, while maintaining clear human oversight and robust regulatory control.

By 2050, short sea shipping is fully integrated into multimodal logistics chains and regional transport systems. It supports modal shift from road to sea where viable, strengthens island and peripheral connectivity, reduces congestion, improves supply-chain resilience and contributes to circular-economy flows. The sector combines clean and digital vessels, smart ports and shipyards, skilled workers, safe operations and competitive services and production supporting Europe's wider objectives for sustainable transport, industrial leadership and a resilient waterborne economy.

Predictive safety and dynamic risk modelling are embedded in SSS corridor operations, with climate resilience, including winterisation, extreme heat and severe weather performance, integrated into design across European sea basins

3.5. CROSS-CUTTING CAPABILITY IMPLICATIONS

The target capabilities depend on coordinated progress across vessels, ports, energy systems, digital infrastructure, regulation, finance and skills, Propulsion and fuel choices must therefore be matched to vessel type, route predictability, voyage length, cargo requirements and access to charging or bunkering. Fixed-route and high frequency cargo services may adopt electrification and deeper hybridization earlier, while variable route, longer distance and tramp operational will depend more strongly on sustainable alternative fuels, fuel-flexible systems and energy efficiency measures. Across all segments, deployment requires interoperable ship-port interfaces, harmonised safety and certification frameworks, cyber secure data exchange, European industrial and fuel supply capacity, appropriate financing and workforce prepared for new fuels, electrification, automation and integrated ship-shore operations.

4. TECHNOLOGY PATHWAYS

4. TECHNOLOGY PATHWAYS

The Waterborne Technology Leadership priorities are translated into technology pathways for cargo-based short sea shipping. The focus is on the vessel categories and operations covered by this roadmap, while the pathways reflect the operational characteristics of short sea shipping, as these are described above.

4.1 FUTURE PROPULSION AND ENERGY SYSTEMS ENABLING A CLIMATE-NEUTRAL SHORT SEA FLEET

The transition of short sea shipping requires scalable, safe and efficient propulsion and energy systems that are suited to the diversity of short sea vessels, route lengths, cargo profiles and port-call patterns. Technology development should remain fuel- and technology-neutral, while prioritizing energy efficiency, retrofitability, operational reliability, cost competitiveness and integration with port and energy infrastructure.

4.1.1. Operational objective

Enable climate-neutral short-sea propulsion through scalable engine-hybrid electrification, OPS/charging, fuel flexibility, high-efficiency energy systems, renewable energy-harvesting technologies, and energy-saving devices. These solutions should reduce propulsion power demand and harmful emissions, including underwater noise, without sacrificing cargo capacity, turnaround time, route reliability or safe operation, including in winter and high-latitude conditions.

4.1.2. Target capabilities for 2035, 2040 and 2050

By 2035

- Battery-electric and hybrid propulsion are increasingly used on suitable short distance, high frequency and predicable routes, supported by standardised charging and OPS deployment. Modular and swappable energy systems are available. (TRL 6-9)
- Sustainable fuel-capable engines and retrofit solutions, including methanol, ethanol, hydrogen, sustainable biofuels, biomethane and, where technically and operationally justified, ammonia, expand across vessel classes as fuel supply and safety frameworks emerge. Biomethane may serve as a long-term renewable fuel in vessels with suitable methane-capable systems, subject to methane-slip control and verified lifecycle performance. (TRL 7-9)
- LNG and biomethane may remain transitional options for certain segments, provided that methane-slip reduction and lifecycle emission control are properly addressed. (TRL 7-9)
- Energy Saving Devices (ESDs), including friction-reduction systems, propulsor, rudder, and hull improvements, become "standard options" where they deliver verified operational and economic benefits. (TRL 5-9)

- Renewable assisted propulsion and onboard energy harvesting technologies, including wind-assisted propulsion systems such as rotor sails, as well as solar and wave-assisted systems, achieve wider adoption where there are compatible with short sea vessel design and operations. (TRL 5-9)
- Smart waste heat recovery systems developed to increase energy efficiency. (TRL 5-8)
- Fuel cells adopted selectively for auxiliary power and extended zero-emission port operations in corridor contexts. (TRL 4-7)
- Exhaust aftertreatment solutions developed and piloted for on-board capture and port-wise handling of harmful emissions, e.g. carbon capture, methane slip, ammonia slip, nitrous oxide etc. (TRL 3-8)
- Development of propulsion systems reducing underwater noise pollution. (TRL 5-8)

By 2040:

- Widening ammonia deployments on suitable cargo and freight-only Ro-Ro vessels operating on longer or higher-energy corridors , supported by robust safety and aftertreatment integration. (TRL 5-9)
- Deeper hybridisation: larger storage, improved controls, more zero-emission near-port operation and reduced engine running hours. (TRL 5-9)
- Tailored integrated, modular and software driven energy systems for vessel propulsion. (TRL 5-9)
- Short Sea vessels operating in Arctic/ high-latitude regions implement winterisation and operational limitations (low temperature, icing, remoteness), extended to new fuels and electrified systems. (TRL 5-9)
- Modular and conversion-ready vessel designs are increasingly available, enabling major energy system upgrades during scheduled renewal cycles. Adaptable arrangements may accommodate batteries, sustainable alternative fuel systems and future energy conversion packages where technically and economically justified, while recognising vessel specific safety, space, stability, structural and operational constraints.

By 2050

- Climate-neutral fleet with modular engine-hybrid-electric architectures on sustainable fuels plus selective fuel-cell modules, integrated into zero-emission port ecosystems. Increased range for fully electric propulsion. Onboard wind, solar and wave energy technologies to contribute to on-board energy supply.

4.1.3 Key research gaps

- Fast turnaround charging / battery logistics without cargo or schedule penalties.
- Integrated power and energy-management systems combining main engines, generators, shaft generators, batteries, variable-speed gensets, waste-heat recovery, shore power and voyage optimisation across variable SSS duty cycles.
- Offshore power zones and electrified anchorage solutions, including grid connection, safety, interoperability, environmental effects and commercial viability.
- Seawater-lubricated shaft-line and other oil-free propulsion-interface solutions that can reduce the risk of oil discharges and underwater radiated noise.

- Monitoring, mitigation and verification of wastewater, cargo-residue wash water, noise, erosion and other non-GHG environmental impacts.
- Fuel flexibility integration for mid-size vessels with minimal retrofit downtime.
- ESD savings validation under real coastal conditions and integration into routing/ EMS.
- Validation of contribution of energy harvesting technologies (wind, solar and wave) under real short sea shipping conditions.
- Arctic/low-temperature operation for new fuels & electrification: cold impacts on fuel systems, batteries, sensors and materials.
- Battery performance, degradation and lifecycle durability under short sea shipping duty cycles, including repeated fast charging, partial state-of-charge operation, seasonal and low-temperature conditions, variable port-call patterns, thermal-management effectiveness and end-of-life state-of-health prediction.
- Circular, modular and upgradeable short sea vessel design, including design for disassembly, reusable machinery and energy-system modules, material traceability, product passports, component remanufacturing and safe end-of-life recovery.
- Integrated and certifiable short sea vessel energy architectures combining main engines, generators, shaft generators, batteries, fuel cells, waste-heat recovery, renewable-assisted systems, shore power, safety systems and voyage optimisation across variable operating profiles.
- Underwater radiated noise from short sea vessels, including propeller and cavitation performance, hull and machinery vibration, operational noise under variable loading and shallow-water conditions, effects on marine biodiversity, and methods for measuring and verifying quiet-vessel performance.

4.2 INTELLIGENT SAFETY, SECURITY AND RESILIENCE AS FOUNDATIONAL ENABLERS

As short sea vessels and operations become more digital, energy-intensive and interconnected, safety, security and resilience become defining conditions for competitiveness. Short sea shipping operates in dense coastal waters, busy port approaches, constrained terminals and weather-exposed environments. The safe deployment of sustainable alternative fuels, electrification, automation and connected systems therefore requires predictive safety tools, cyber-resilient ship-shore systems, emergency preparedness and harmonised operational procedures. Advanced safety technologies, including detection, suppression, digital safety engineering and risk-management systems, will also strengthen European industrial competitiveness and technology leadership.

4.2.1 Operational objective

Enable safe and resilient short sea corridor operations by deploying safety frameworks for sustainable alternative fuels and electrification, cyber-resilient ship-shore systems, predictive risk management and emergency preparedness suited to dense coastal traffic, frequent port calls, and winter/ice conditions relevant to Nordic and Arctic-adjacent routes.

4.2.2 Target capabilities for 2035, 2040 and 2050

By 2035:

- Harmonised safety protocols for batteries, charging, electrification and future fuel related operations in busy coastal ports; improved emergency coordination and drills.
- Advanced multi-sensor fire and hazard-detection systems deployed for battery-electric and sustainable alternative-fuel vessels, supporting earlier detection of thermal runaway, fuel leaks and fire while reducing false alarms and improving emergency response.
- SSS-specific safety frameworks validated for constrained, mixed-use ports, including simultaneous cargo handling and bunkering, minimum-manning arrangements and coordinated ship-port emergency procedures.

- Cyber resilience baselines scaled for SMEs/operators, plus safe lifecycle integration as systems become more complex.
- Operational resilience increasingly includes port disruption, weather volatility, and energy availability (including dual use related disruptions).

By 2040:

- Predictive safety and dynamic risk modelling integrated into corridor operations and port interfaces.
- Digital safety twins support real-time hazard assessment, emergency-response optimisation, exercises, stress testing and continuous validation of safety performance.
- Integrated fire-suppression systems are validated for battery-electric and alternative-fuel operations and linked with predictive risk modelling and coordinated ship-shore response.
- Predictive maintenance and condition-based monitoring are becoming standard features.
- Winterisation/extreme weather safety integrated into design and operational limitations.
- Cyber risk management is increasingly treated as operational safety, not only IT hygiene, because short sea vessels depend heavily on frequent digital exchange with ports, terminals, agents, traffic systems, and shore support, all of which expand the cyber-attack surface.
- Safety systems become more integrated across ship and shore, with common data models for arrival windows, power availability, bunkering readiness, berth status, and emergency planning.
- Certified "guardian AI" that continuously combines machinery signals, weather, port readiness, cargo stability, battery health, and cyber anomalies into a single live risk picture for master and shore control.

By 2050:

- Zero-accident/zero-pollution corridor operations supported by continuously assured safety and cyber security.
- Robotic onboard response teams handle battery-room inspection, toxic leak detection, confined-space checks, and first-fire intervention before human crews enter hazardous spaces.
- Integrated detection, suppression, ventilation and decision-support architectures support autonomous or remotely assisted hazard management and coordinated emergency response.
- Introducing a "safe-harbor autonomous mode" that automatically reconfigures speed, power, ventilation, and communications when severe weather, cyber incidents, or grid-side failures compromise the voyage plan.

4.2.3 Key research gaps

- Safe simultaneous and sequential operations at the interface of electrification, fuel bunkering and cargo handling in constrained ports, including detection optimisation, suppression effectiveness, ventilation, evacuation, cargo interaction, human response and integrated safety-system performance
- Assurance/certification for safety-critical AI systems and cyber-physical resilience.
- Extreme weather safety of batteries and fuel systems (icing, ventilation, leak detection, emergency response).
- Integrated fire- and hazardous-release safety architectures combining detection, suppression, ventilation, cargo protection, evacuation support, decision-support systems and coordinated ship-shore emergency response for battery-electric and alternative-fuel short sea vessels.
- Sensor placement, hazard identification, false-alarm reduction and AI-supported early warning for battery, methanol, ethanol, hydrogen, ammonia and cargo-related hazards under short sea operating conditions.
- Digital safety twins integrating machinery, energy-system, cargo, weather, port and operational data to support dynamic risk assessment, emergency planning, validation of mitigation measures and coordinated ship-shore response.

4.3 FULLY CONNECTED, AUTOMATED AND DATA-DRIVEN COASTAL SYSTEMS

The future short sea system will rely on secure and interoperable data exchange between vessels, ports, terminals, energy providers, authorities and hinterland logistics nodes. Digitalization, automation and AI-supported decision-making can improve reliability, reduce emissions, optimize port calls and support new service models, provided that systems are interoperable, cyber-secure and designed for real short sea operating conditions.

A realistic automation pathway should progress from decision support and remote assistance to condition-based monitoring, reduced administrative workload, remote operational support and, only where safe and legally accepted, reduced-crew or uncrewed concepts.

4.3.1 Operational objective

Enable data-driven, automated corridor operations through secure connectivity, smart waterways, digital twins, and expanded autonomy in machinery condition monitoring and maintenance, improving reliability and reducing operating cost and emissions across high-frequency services.

4.3.2 Target capability 2035, 2040 and 2050

By 2035:

- Digital twins and smart maintenance become standard: condition-based maintenance, AI diagnostics & optimization, energy efficiency optimization, remote support. (TRL 4-8)
- Smart waterways services improve safety and predictability in dense traffic; secure standard communication and decision-making solutions underpin corridor operations and allows for remote piloting/operation. (TRL 4-8)
- Just-in-time arrival, just-in-time connection to port infrastructure, and coordinated offloading and loading deployed at major logistics hubs. (TRL 4-8)
- Automated and secure exchange of voyage, cargo and port-call documentation before, during and after port calls. (TRL 4-8)
- Shore-based support, including VTS and land-based sensors, enriches onboard situational awareness, provides redundant monitoring and supports guided or remotely assisted navigation in challenging coastal conditions. (TRL 5-8)
- Emission & Pollutant (airborne and underwater) detection enhanced to support active control of energy and propulsion systems. (TRL5-9)
- Automated berth approaches, smart mooring, and semi-automated manoeuvring introduced.

By 2040:

- Partial autonomy expands from navigation into machinery system autonomy (automated reconfiguration, safe fallback), validated in cross-border corridors. (TRL 5-8)
- Just-in-time arrival, just-in-time connection to port infra, and just-in-time offloading and loading becomes standard practice. (TRL 7-9)
- Demonstrations of higher degrees of remote or uncrewed operation may be undertaken on suitable predictable corridors by 2040, subject to the IMO MASS regulatory framework, robust shore-control arrangements, human oversight, resilient positioning and communications, and verified safety performance.
- Fleet-level orchestration becomes more sophisticated, with operators balancing ETAs, berth windows, energy prices, charging slots, carbon costs, and intermodal connections across entire route networks.
- Compliance will become digital by default, with FuelEU, ETS, MRV-style reporting, fuel certification, and real-time emissions accounting integrated directly into ship and fleet software.

By 2050:

- Fully integrated digital corridor ecosystems (ship-port-tugs-waterway-energy), with continuous assurance through continuous exchange of machine-readable planning data. AI used to help optimize the whole corridor rather than just one vessel.
- "Self-negotiating" port calls emerge, where vessels automatically bid for arrival slots, shore power windows, and loading priorities based on energy state, cargo urgency, emissions cost, and downstream connections.
- Semi-autonomous feeder and coastal vessel convoys become viable on selected routes, using geofenced autonomy and shore supervision to reduce crew workload while preserving safety and regulatory control.

4.3.3 Key research gaps

- Certifiable AI diagnostics and autonomous maintenance decisioning (continuous assurance).
- Resilient positioning and communications for safe operations under interference/degraded connectivity.
- Autonomous and remotely assisted navigation under ice and severe winter conditions, including sensing, route selection, fallback, shore support and certification.

4.4 HUMAN-CENTRED DESIGN AND A FUTURE-READY WORKFORCE

The transition of short sea shipping depends on people as much as on technology. Sustainable alternative fuels, electrification, digital tools, remote support and automation will change tasks, responsibilities and competence requirements both on board and ashore. Human-centred design, intuitive decision-support systems, training and social sustainability must therefore be embedded in technology development and deployment.

4.4.1 Operational objective

Enable a human-centred workforce transition by reducing cognitive load via better HMIs and alarm strategies, building competencies for new fuels/electrification and digital tools, and supporting sea-to-shore operational models that sustain safety and reliability under labour shortages. The attractiveness of short sea careers will depend increasingly on decent work, connectivity, training, and skills portability, because the sector will compete for digitally literate and technically adaptable talent.

4.4.2 Target capability 2035, 2040 and 2050

By 2035:

- Training ecosystems for sustainable alternative fuels, battery safety, charging, and automated systems; improved HMIs and alarm handling, boosting the development of efficient emergency response solutions for vessels and ports.
- Routine remote diagnostics and shore support integrated into operations

By 2040:

- Fully skilled workforce operating advanced systems safely and efficiently.
- Human-AI resilience procedures established.
- Unmanned engine room concept deployed, with introduction of robotic maintenance capabilities. Machinery, cybersecurity, and cargo specialists joining through secure remote systems.
- Mixed-reality maintenance and emergency training embedded into daily work, allowing crews to rehearse charging faults, fuel leaks, cyber incidents, and port-approach failures.

By 2050:

- Mature human-automation teaming practices across navigation and machinery operations. Every officer and engineer work with an onboard AI copilot that explains alarms, recommends responses, checks procedures, translates technical information, and tailors guidance to the vessel's route and energy system.

4.4.3 Key research gaps.

- Research on human-machine teaming and mixed-autonomy operations, including explainable decision support, operator trust, allocation of responsibilities, intervention thresholds, workload and alarm management, safe fallback and coordination between onboard crews, shore-control centres.
- Human factors and trust in AI for maintenance/autonomous functions.
- Design and validation of standardised, low-complexity digital interfaces for SME operators, including automated compliance reporting, energy monitoring, maintenance alerts, secure updates and explainable decision support.
- Demonstrating training effectiveness for rare-but-critical events.

4.5 FORWARD LOOKING REGULATION, STANDARDIZATION AND SYSTEM-LEVEL INTEGRATION

Regulation, standardization and certification will shape the speed and scale of deployment in short sea shipping. New fuels, electrification, automation, data governance, cyber resilience and system-level integration require harmonized frameworks that provide safety, investment certainty and cross-border acceptance. Regulatory development should advance alongside technology development, while supporting deployment through goal-based rules, technical standards and regulatory sandboxes.

For autonomous and remotely operated SSS, the pathway should align with the IMO MASS Code and related EU, class and flag-state implementation, while preserving technology-neutral and risk-based approval.

4.5.1 Operational objective

Enable rapid corridor-scale deployment by creating harmonised standards and certification pathways for electrification, methanol/ethanol/ammonia/hydrogen/new fuels bunkering, autonomy beyond navigation, and cyber resilience, ensuring system-level integration of vessels, ports, waterways, and energy networks.

4.5.2 Target capability 2035, 2040 and 2050

By 2035:

- Standardised OPS and charging interfaces, including where relevant offshore or anchorage charging, battery safety, fuel certification and reporting/compliance processes support wide uptake.
- Adopting lifecycle, well-to-wake, GHG accounting.

By 2040:

- Mature safety standards for sustainable alternative fuels, carbon capture and handling, autonomous operations, and corridor data exchange, enabling multi-country operations.
- Regulation itself becomes machine-readable, with vessels consuming live digital rulebooks, fuel passports, charging rights, and verifier interfaces through APIs so that compliance becomes continuous rather than retrospective.

By 2050:

- Fully harmonised system-of-systems regulation and standards across the EU waterborne ecosystem.
- Future coastal regulation shift from ship-by-ship rules to corridor-level carbon budgets, where ports, operators, cargo owners, and energy providers jointly optimize total emissions for a whole regional logistics chain.

4.5.3 Key research gaps

- Standardised verification for alternative energy sources such as solar, wind and wave, ESD performance and inclusion in compliance/finance.
- Certification frameworks for adaptive AI and continuously updated software systems.
- Carbon capture and handling related standards.
- Safety related development of standards in all areas.
- AI-systems safety and risk analysis.
- Cybersecurity standards and regulations development.
- Methodologies for safety-case development, quantitative and qualitative risk assessment, alternative-design approval and validation of integrated vessel-port safety systems for batteries, sustainable alternative fuels, automation and remote operations.
- Mutual recognition and transferability of approval evidence across classification societies, flag states, ports and Member States, reducing the need to repeat equivalent demonstrations for each vessel, corridor or jurisdiction.
- Regulatory and assurance approaches for integrated and continuously evolving vessel-port-energy systems, including methods for updating approvals when software, fuels, energy modules or operating concepts change.

5. ENABLERS AND DEPLOYMENT

5. ENABLERS AND DEPLOYMENT

The pathway-specific enabling conditions noted above identify what is needed for each technology area. This section highlights the enabling conditions required to move from research, pilots and first-of-a-kind applications towards wider deployment across short sea corridors, fleets, ports and logistics chains.

5.1. CORRIDOR-BASED DEPLOYMENT AND SYSTEM INTEGRATION

Deployment should be organised around short sea corridors and port networks rather than around individual vessels alone. The Baltic, North Sea, Atlantic, Mediterranean and Black Sea basins differ in terms of cargo flows, route length, weather exposure, vessel size, port density, energy availability and hinterland connections. For this reason, clean and digital short sea corridors and hubs for bulk/ tramp shipping will be used as practical deployment environments where shipowners, ports, terminal operators, energy, infrastructure and service suppliers, shipyards, equipment manufacturers, classification societies, authorities, logistics providers and cargo owners develop scalable solutions together.

Strategic gateway regions, including the Black Sea, should be treated as deployment environments where SSS supports cross-border trade, neighbouring-region connectivity, security of supply, crisis logistics and strategic resilience. A Baltic/ Nordic winter corridor should also test ice-class, low-temperature and autonomous or remotely assisted navigation solutions under demanding seasonal conditions.

Early deployment should prioritise routes with high traffic density, predictable operations and repeated port calls, including feeder container services, freight-only Ro-Ro services, general cargo routes, coastal tanker movements, bulk flows and island supply routes. These corridors should validate shore-side electricity, fast charging, sustainable alternative-fuel bunkering, fuel certification, battery and modular energy systems, just-in-time arrival, port-call optimisation, cargo handling, emissions reporting, safety procedures and commercial arrangements. Corridor packages should explicitly involve shipyards, equipment manufacturers and system suppliers, grid and energy providers, insurers, financiers and classification societies, in addition to operators, ports, cargo owners and hinterland actors.

Port authorities should act as spatial planners and safety-zone coordinators, determining where charging, bunkering, storage and offshore or anchorage power infrastructure can be located without conflicting with cargo operations, urban proximity, navigation safety or existing concessions.

Feeder vessels operating on fixed and predictable routes are particularly suitable early adopters of electrification, hybrid systems and integrated corridor energy management.

The objective should be to move from isolated demonstrations to replicable corridor packages. These packages should combine vessels, port infrastructure, energy supply, digital services, safety procedures, financing models and operational rules. Once validated on high-potential routes, they can be adapted to lower-volume, seasonal, remote or more operationally complex services.

Deployment should also include a distinct pathway for tramp and spot-market vessels that cannot depend on fixed-route infrastructure. This pathway should prioritise verified energy-efficiency measures, sustainable drop-in fuels, modular hybrid systems and broad multi-port fuel availability.

These deployment packages should be developed as Short Sea Green and Digital Corridors and Hubs combining low- or zero-emission vessels, port energy and fuel readiness, digital port-call optimisation, interoperable reporting, authority-approved safety cases, cargo-owner commitments and multimodal hinterland links.

5.2. CLEAN-ENERGY SUPPLY, REFUELLING AND CHARGING INFRASTRUCTURE

Clean-energy availability is a central condition for decarbonising short sea shipping. Battery-electric and hybrid propulsion are relevant for short-distance, predictable and high-frequency services, but their deployment depends on port charging capacity, shore-side electricity, grid readiness and sufficient turnaround time. For much of the cargo fleet operating on longer, variable or tramp routes, sustainable alternative fuels and fuel-flexible hybrid systems will be essential. Certified biofuels, renewable methanol, ethanol, ammonia and other low- and zero-carbon fuels, can support emission reductions in existing vessels and newbuilds where fuel supply, safety frameworks and lifecycle-emission performance are assured. For suitable routes, shore-side electricity and, where technically and environmentally appropriate, offshore power zones or electrified anchorage areas should gradually evolve from hotel-load supply towards high-capacity charging for propulsion batteries.

Grid planning should begin before final vessel orders. Where appropriate, corridor-level capacity-reservation arrangements with transmission and distribution system operators can secure future electricity supply for OPS and charging, while local storage, port microgrids and renewable generation can reduce peak demand.

Alternative-fuel bunkering infrastructure should first be developed in strategic coastal hubs and green corridors where vessel demand, fuel supply, safety procedures and port capacity can be aligned. Methanol and ethanol may be deployed earlier in some segments, while ammonia, hydrogen and other future fuels require further safety validation, infrastructure development and operational experience before broader deployment. LNG and biomethane may remain transitional options in selected cases, provided that methane slip and lifecycle emissions are properly controlled. Infrastructure planning should therefore be fuel-flexible and corridor-based, avoiding premature lock-in while supporting technologies that are ready for deployment.

5.3. FLEET RENEWAL, RETROFITTING AND INDUSTRIAL READINESS

The SSS fleet is heterogeneous and ageing, and a large share of existing vessels will remain in operation for many years. Deployment must therefore combine newbuilds with retrofitting and conversion of existing vessels. Retrofitability, modularity, fuel flexibility and lifecycle-cost reduction are essential, especially for small and medium-sized operators, specialised cargo segments and lower-volume routes where the business case for newbuilds is weaker.

Standardised and repeatable retrofit packages should be developed for different vessel categories, including feeder container vessels, general cargo and multipurpose vessels, coastal tankers, bulk carriers and freight-only Ro-Ro vessels. These packages may combine hybridisation, batteries, methanol and ethanol-ready or fuel-flexible engines, after-treatment systems, energy-saving devices, renewable energy-harvesting technologies, hull and propulsor optimisation, waste heat recovery, digital energy-management systems and onboard monitoring.

Shipyards, repair yards, equipment manufacturers and classification bodies should prepare for repeated conversion programmes rather than one-off prototypes. This requires modular designs, pre-certified components, standardised interfaces, yard capacity, skilled workers and predictable demand. Strengthening European ship repair, retrofitting, conversion and equipment supply capacity will be a key condition for turning the roadmap into industrial deployment.

Deployment planning should also include circular-economy and end-of-life pathways, including battery second life and recycling, component remanufacturing, material traceability and safe vessel recycling.

5.4. DIGITAL INFRASTRUCTURE, DATA GOVERNANCE AND SMART CORRIDOR MANAGEMENT

Digitalisation is a prerequisite for efficient, reliable and low-emission SSS operations. Current tools such as port community systems, maritime single window reporting, digital twins, route optimisation, condition-based maintenance and emissions monitoring provide an important basis, but they need to be connected into interoperable corridor services.

Priority should be given to secure data exchange between vessels, ports, terminals, authorities, energy providers, logistics operators and cargo owners. This should include real-time port-call information, berth and terminal readiness, shore-power availability, charging slots, bunkering readiness, cargo status, weather conditions, emissions data and hinterland connections. Interoperability is essential: digital systems should reduce administrative complexity rather than create new fragmentation.

A European SSS port-readiness framework could support deployment decisions by assessing OPS and charging, alternative-fuel availability, berth planning, digital reporting, cybersecurity, safety preparedness and hinterland connectivity.

By 2035, digital corridor services support major short sea hubs and high-frequency services through improved reporting, port-call optimisation, just-in-time arrival and condition-based maintenance. By 2040, these systems enable predictive maintenance, automated compliance reporting, fleet-level optimisation, energy planning and remote support. By 2050, SSS corridors function as integrated digital ecosystems in which vessels, ports, terminals, energy systems and logistics chains exchange machine-readable planning and operational data continuously.

5.5. SAFETY, SECURITY AND CLIMATE RESILIENCE

Safety, security and resilience must be treated as deployment conditions from the beginning. Short sea vessels operate in dense coastal traffic, busy port approaches, constrained terminals, exposed sea areas and, in some regions, winter, ice and low-temperature conditions. New fuels, electrification, high-power charging, batteries, carbon capture, automation and remote operations introduce new risks that must be addressed through harmonised safety cases, emergency procedures, crew training and port-level preparedness.

Sustainable alternative-fuel bunkering, battery charging, cargo handling and port operations should be assessed together because these activities may occur in constrained port environments and within short turnaround windows. Corridor-level emergency preparedness should involve ports, terminal operators, shipowners, fuel suppliers, emergency responders, authorities and classification societies.

Integrated safety engineering should be applied throughout deployment so that hazard identification, detection, suppression, ventilation, evacuation, emergency response and operating procedures are validated as a unified ship-port system rather than as separate compliance activities.

Cybersecurity must also become part of operational safety. As vessels depend increasingly on digital exchange with ports, terminals, agents, traffic systems and shore-support centres, cyber incidents may affect safety, reliability and supply-chain continuity. Climate resilience should be integrated into vessel design, route planning, port infrastructure, cargo handling and emergency response, particularly for services exposed to extreme weather, icing, port disruption and energy-supply constraints.

5.6. REGULATION, STANDARDS AND CERTIFICATION

A stable, goal-based and technology-neutral regulatory framework is essential for investment certainty. SSS will need harmonised standards and certification pathways for shore-side electricity and charging, batteries, methanol, ethanol, hydrogen, ammonia, fuel-flexible engines, onboard carbon capture, energy-saving devices, renewable energy-harvesting technologies, digital reporting, automation, remote operations and cyber resilience.

Regulatory sandboxes should be used to test new operational concepts in controlled corridor environments and should feed into permanent certification pathways as technologies mature. This is particularly important for sustainable alternative fuels, machinery autonomy, remote support, digital compliance and ship-shore data exchange. Cross-border acceptance is also essential, because short sea shipping often operates between Member States and across regional sea basins.

Common standards are needed for lifecycle and well-to-wake greenhouse-gas accounting, verification of energy-saving devices, verification of wind, solar, wave and other renewable-assisted technologies, fuel certification, fuel passports, digital reporting and cybersecurity. Consistent interpretation of EU requirements will reduce fragmentation, support investment and help operators deploy solutions across multiple routes and jurisdictions.

5.7. FINANCE, BUSINESS MODELS AND MARKET UPTAKE

The main deployment barrier is often not technological readiness alone, but the lack of a positive business case. Zero-emission vessels, renewable fuels, shore-power connections, charging systems, retrofits, digital integration and safety upgrades require significant investment, while many SSS operators face uncertain payback periods, charter constraints, fuel-price volatility and limited ability to pass additional costs to customers.

Deployment will require a combination of EU, national, regional and private financing. Grants, guarantees, low-interest loans, de-risking instruments, green corridor and hub funding, port infrastructure support and revenue recycling from market-based instruments should be considered. Support should be designed to address the needs of SMEs, regional services, seasonal operations, island supply routes and smaller ports, where investment capacity is more limited.

Funding for port and corridor infrastructure should be coordinated with TEN-T, and applicable funding instruments, and, where appropriate, Military Mobility instruments, covering grid reinforcement, storage, OPS and charging, bunkering safety systems, berth adaptation, cybersecurity, digital platforms and hinterland connections.

Dedicated fleet-renewal and retrofit instruments should recognise the ageing SSS fleet and the different investment profiles of newbuilds and conversions as well as liner versus bulk/tramp shipping. First-mover investments may require guarantees, insurance support, risk-sharing and contractual frameworks addressing technology, fuel, infrastructure and residual-value uncertainty. Market demand should also be strengthened through green transport contracts, public procurement, cargo-owner commitments, pooling mechanisms, long-term fuel offtake agreements and cooperative infrastructure models. Business models such as energy-as-a-service, battery-as-a-service, shared charging infrastructure and corridor-level fuel procurement can reduce first-mover risk and support wider uptake. Deployment should therefore link technology investment with predictable demand and shared benefits across the logistics chain.

Transparent differentiated port tariffs, where consistent with competition and state-aid rules, may help recover infrastructure investment while rewarding vessels that adopt cleaner technologies early. Port energy, storage and flexibility services may also create new revenue streams and improve local energy-system resilience.

SME aggregation and fleet-grouping models can enable joint procurement of vessels and retrofit packages, shared infrastructure investment, pooled insurance and improved access to finance. EU-supported turnkey digital compliance and cybersecurity services may help smaller operators meet regulatory requirements without disproportionate cost.

Research and demonstration should also address business and operating models for clean and digital short sea shipping, including the effects of lower operating speeds, cargo urgency, schedule frequency, vessel utilisation, charter structures, shared infrastructure, energy-as-a-service, fuel-price uncertainty and competition with road and rail transport. The analysis should distinguish between fixed-route feeder and freight Ro-Ro operations, contractual industrial cargo flows, and tramp or spot-market bulk and general-cargo services.

5.8. SKILLS, WORKFORCE TRANSITION AND SOCIAL ACCEPTANCE

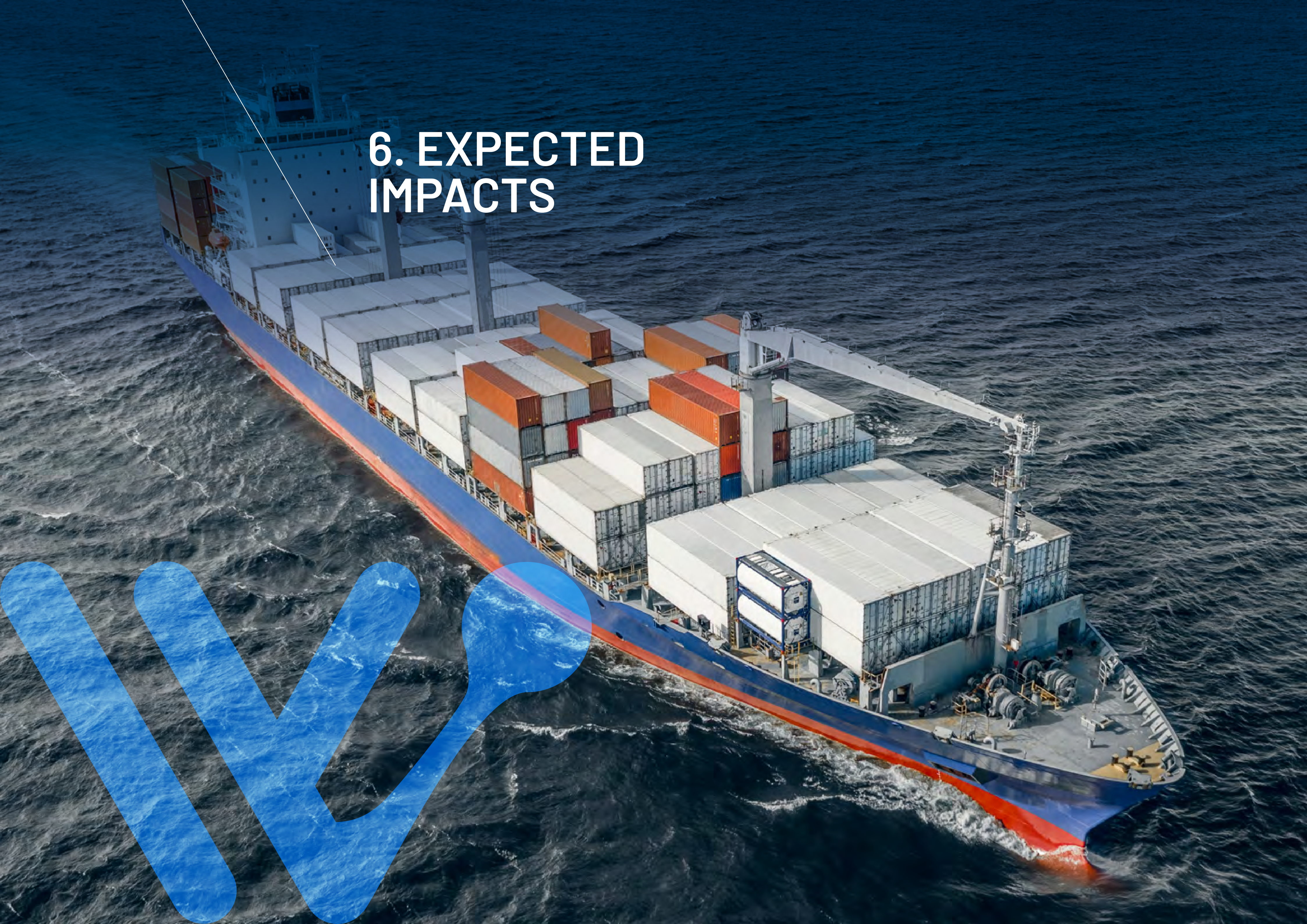
The deployment of clean and digital SSS depends on a workforce able to operate, maintain and supervise new systems safely. Crews, shore-based operators, port workers, terminal personnel, emergency responders, inspectors, shipyard and equipment manufacturers workers and authorities will need competences in sustainable alternative fuels, electrification, high-voltage systems, battery safety, methanol, ethanol, hydrogen and ammonia handling, digital reporting, cybersecurity, remote support, automated systems and emergency response.

Training and certification should evolve in parallel with technology deployment. Simulation, XR tools, digital training platforms and corridor-level emergency drills can support preparation for rare but critical events, such as fuel leaks, charging failures, battery incidents, cyber disruptions, severe weather and port-approach failures. Competence standards should be aligned across onboard, port and shore-based roles, particularly where operations become more integrated.

Training should cover hybrid roles spanning vessel operations, remote support, port planning, data analysis, cyber resilience and advanced maintenance, with particular support for SMEs and smaller ports.

Human-centred design should guide the introduction of automation and AI-supported decision-making. New systems should reduce workload, improve situational awareness and support safe collaboration between crews, remote support centres and port actors. Social dialogue, clear career pathways, decent working conditions and skills portability will be needed to ensure that the transition improves the attractiveness of short sea shipping careers.

6. EXPECTED IMPACTS



6. EXPECTED IMPACTS

The implementation of this roadmap will support the transformation of cargo-based short sea shipping into a zero-emission, competitive, digitally connected and resilient component of the European transport system. Its impacts will depend on the coordinated deployment of fleet technologies, port infrastructure, clean-energy supply, digital services, safety frameworks, financing instruments and workforce capabilities across short sea corridors. Because fuel pathways, vessel demand and port-infrastructure lead times remain uncertain, expected impacts should be treated as directional and scenario-based. Monitoring should reward flexibility, modularity and interoperable infrastructure rather than assume premature convergence on a single fuel or propulsion solution. Table 2 provides indicative expected impacts, which will be further refined at implementation.

ENVIRONMENTAL	ECONOMIC
2035: 15-20% average CO2 intensity reduction versus 2020 fleet baseline; zero-emissions at berth at 50+ major SSS ports; shore-power available at 70%+ of TEN-T maritime ports **2040:** 45-50% CO_2 intensity reduction; zero-emission operations on 60%+ of short-distance, high-frequency SSS routes; methanol/ethanol/hydrogen/ammonia fuel available at 30+ EU ports **2050:** Zero-emission SSS fleet; 90%+ CO_2 reduction vs. 2020; full circular economy integration; zero-harmful discharges at all European SSS ports	**2035:**100 – 150 SSS vessels retrofits with hybrid/battery, fuel-flexible and energy efficiency systems; fuel cost savings of €300 – 500M/year through energy management deployment; 1,500+ new jobs in retrofit services **2040:** 400 – 600 additional retrofits completed; €1B+ annual fuel savings fleet-wide; modal shift delivering 5-10% reduction in European road freight (100B tone-km shift to sea) **2050:** Total transition value €25 – 35B (2026 -2050); European SSS shipbuilding and equipment export market €2B+/yr; SSS carrying 25% more EU cargo volumes vs. 2020; +5,000 jobs in EU-based energy and sustainable fuel production
TECHNOLOGICAL	**SOCIAL**
2035: Standardized shore-power interfaces deployed; automated MRV/ETS reporting on 500+ vessels; type-approved modular retrofit kits for 3 vessel classes **2040:** Integrated corridor management platforms on 10+ major SSS corridors; predictive maintenance on 80%+ of fleet; machine-verifiable compliance reporting standard **2050:** Full system of systems digital integration; remote/autonomous operations on selected low-traffic routes; 95%+ battery and component material recovery	**2035:** 4,000+ SSS seafarers and port personnel trained in new technologies **2040:** 10,000+ trained; SME digital transformation complete for 80%+ of operators **2050:** 20,000+ trained; improved island and peripheral region connectivity and resilience

Table 2: Indicative Expected Impacts (2035-2040-2050)

6.1. IMPACTS ON SHORT SEA COMPETITIVENESS AND MODAL SHIFT

The central expected impact of the roadmap is to strengthen the competitiveness of short sea shipping within European logistics chains. Cleaner vessels, improved port-call efficiency, reliable digital reporting, better cargo visibility and closer integration with hinterland transport can make SSS more attractive to shippers and logistics providers. This is particularly important for feeder container services, general cargo, coastal bulk flows, coastal tankers, freight-only Ro-Ro operations and island supply chains. By improving reliability, transparency and environmental performance, the roadmap supports modal shift from road to sea where short sea services are operationally and commercially viable. This reduces land-side congestion, improves the resilience of European freight transport and strengthens the role of SSS as a core element of multimodal logistics.

6.2. ENVIRONMENTAL AND CLIMATE IMPACTS

The roadmap eliminates greenhouse-gas emissions, air pollutants and pollution to water from short sea shipping through a combination of energy efficiency, electrification, hybridisation, sustainable alternative fuels, renewable-assisted propulsion, shore-side electricity and operational optimisation. In the near term, the main benefits are expected from measures that can be applied to the existing fleet, including energy-saving devices, hull and propulsor optimisation, route optimisation, shore-side electricity and sustainable alternative fuels where available. In the longer term, deeper emission reductions will depend on the deployment of zero- and near-zero-emission propulsion solutions on suitable routes and vessel segments. The roadmap aims to reduce environmental pressures in ports and coastal areas, including emissions at berth, underwater noise and other local impacts. Its environmental impact will therefore depend not only on vessel technologies, but also on port readiness, fuel availability, electricity supply and corridor-level deployment.

6.3. PORT, CORRIDOR AND CLEAN-ENERGY IMPACTS

Short sea shipping has frequent interaction with ports, terminals and hinterland logistics systems. One of the main expected impacts of the roadmap is therefore the development of ports as deployment platforms for clean and digital SSS. Ports will increasingly need to provide shore-side electricity, charging capacity, sustainable alternative-fuel bunkering, energy management, safety coordination, digital port-call services and efficient links to rail, road and inland waterways. The roadmap improves alignment between vessel investment and port-energy planning. Coordinated corridor deployment reduces the risk that vessels are built or retrofitted without the necessary infrastructure, or that ports invest in infrastructure without sufficient vessel demand. This will be particularly important for smaller and regional ports, where the capacity to finance and implement clean-energy infrastructure may be more limited. Ports may also diversify revenue through energy, storage and flexibility services. When integrated with local grids and renewable generation, port energy systems can improve electrical-supply resilience and create measurable system value.

6.4. IMPACTS ON REGIONAL CONNECTIVITY AND SUPPLY-CHAIN RESILIENCE

Short sea shipping plays a strategic role in connecting islands, peripheral regions, industrial clusters and regional markets to the Single Market. The roadmap strengthens this role by improving the reliability, efficiency and environmental performance of short sea services. This is important not only for major hubs, but also for secondary ports and regional corridors that support territorial cohesion and essential supply chains. A more resilient SSS system provides additional capacity and redundancy when road, rail or port systems are disrupted. Better digital coordination, port-call management, predictive maintenance and climate-resilient operations can help maintain services under conditions of congestion, extreme weather, energy-supply constraints or other disruptions.

6.5. FLEET RENEWAL, RETROFITTING AND INDUSTRIAL IMPACTS

The roadmap will stimulate fleet renewal and retrofitting in the European short sea sector. Because much of the fleet will remain in operation for many years, a significant impact will come from scalable retrofit solutions, modular propulsion systems, fuel-flexible engines, batteries, energy-saving devices, after-treatment systems, digital monitoring and onboard energy-management systems. This creates opportunities for European shipyards, repair yards, equipment manufacturers, technology suppliers, classification societies and digital-service providers. The development of standardized retrofit packages, pre-certified components and repeatable conversion models reduces costs, shortens yard time and improves the bankability of clean SSS investments. In this way, the roadmap supports both maritime decarbonisation and European industrial competitiveness.

6.6. DIGITALISATION AND ADMINISTRATIVE-EFFICIENCY IMPACTS

The roadmap accelerates the development of digitally connected short sea corridors. Improved data exchange between vessels, ports, terminals, authorities, energy suppliers and logistics operators can support just-in-time arrival, berth coordination, shore-power planning, charging slots, bunkering readiness, emissions reporting, cargo visibility and hinterland integration. Digitalization reduces administrative burdens. More interoperable reporting systems and better use of the European Maritime Single Window environment reduces duplication and makes SSS easier to use within the Single Market. Over time, digital corridor management, automated compliance reporting, condition-based maintenance and fleet-level optimization improve reliability, reduce waiting times, lower fuel consumption and support better use of port and vessel capacity.

6.7. SAFETY, SECURITY AND OPERATIONAL RESILIENCE IMPACTS

The roadmap improves safety and operational resilience through harmonised safety procedures, predictive maintenance, digital risk management, cyber-secure systems, improved emergency preparedness and better coordination between vessels, ports and authorities. These impacts are particularly important because SSS operates in dense coastal waters, constrained port environments and weather-exposed sea basins. At the same time, the deployment of batteries, high-power charging, methanol, ethanol, hydrogen, ammonia, onboard carbon capture, automation and remote support introduces new risks. The roadmap therefore supports safer deployment by linking technology uptake with certification, crew training, port preparedness, emergency drills and cyber-resilience requirements. This will increase confidence among operators, regulators, crews, port communities, cargo owners and the public.

Expected safety impacts include improved fire and leak-detection performance, more effective suppression and emergency response, lower incident frequency, faster and more predictable approvals, and increased confidence among operators, regulators, insurers, cargo owners and port communities.

6.8. WORKFORCE AND SOCIAL IMPACTS

The transition of short sea shipping creates new skills requirements both on board and ashore. Crews, shore operators, port personnel, emergency responders, inspectors, maintenance teams and shipyard and equipment manufacturer workers will need competences in sustainable alternative fuels, electrification, digital systems, cybersecurity, automation, remote support and environmental compliance. If properly managed, the roadmap contributes to safer, cleaner and more attractive jobs in the SSS sector. Human-centred design, simulation-based training, social dialogue and skills portability will be important to ensure that new technologies support workers rather than increasing complexity or workload. The transition also creates new high-skilled roles in shore support, digital operations, clean-energy services, retrofit engineering and safety management.

6.9. IMPACT MONITORING AND DEPLOYMENT FEEDBACK

Relevant indicators include greenhouse-gas emissions and intensity, fuel and electricity consumption, share of vessels using renewable or zero-emission energy solutions, retrofit and newbuild uptake, availability and use of OPS, charging and alternative-fuel bunkering, automated compliance coverage, port-call efficiency, corridor reliability, modal shift, at-berth emissions, safety and fire-system performance, cybersecurity readiness, workforce training, SME digital uptake, European industrial capacity and the availability of bankable and insurable technology packages.

WATERBORNE

WATERBORNE TP
De Meeussquare 35
1000 Brussels, Belgium

+32 493 835 626
info@waterborne.eu
www.waterborne.eu