WATERBORNE

WATERBORNE TECHNOLOGY ROADMAP

Competitive, resilient and sustainable cruise sector

September 2026

CRUISE TECHNOLOGY ROADMAP

01 THE SECTOR IN NUMBERS

97% of the world fleet of cruise ships has been built in Europe[1]

64.1 bn contributed to the European economy, of which €28B direct GDP[2]

445k jobs supported in 2024[2]

34.6M ocean-going cruise passengers in 2024, exceeding the 29.7M recorded in 2019[3]

310 VESSELS 2025

vessels in the CLIA-member ocean fleet in 2025, providing more than **651,000 lower berths** and accounting for roughly 92% of global ocean-going cruise lower-berth capacity. Cruise ships represent less than 1% of the world commercial fleet by vessel count, yet they are among the most complex and capital-intensive ship types. The European-controlled cruise fleet stands at around 6.0 million gross tonnes, about 19% of the world cruise fleet; European seas account for more than 30% of global cruise activity, and over 60% of cruise calls at EU ports in 2023 were by ships flying EU Member State flags.[3]

OPERATIONAL PROFILE

Cruise ships carry **continuous hotel loads of 1–20 MW at berth**, which can exceed the propulsive load, because power for accommodation, catering and services is required at all times. Passenger capacity reaches several thousand on the largest vessels, and **most modern cruise ships use electric-drive propulsion.**

THE FLEET IS SEGMENTED[3]

Large vessels 3,000 berths and above	27,4%
Luxury more than tripled since 2010	~97
Expedition capacity +150% 2019 to 2029	~40

Bar lengths indicative.

FLEET RENEWAL IS CONTINUING[3]

56 vessels on order

168k lower berths by 2036

+27% capacity increase

$56.7B capital commitments

The orderbook is a key opportunity to embed **fuel flexibility, energy efficiency, shorepower readiness, digital integration, safety-by-design and lifecycle adaptability** into the next generation of cruise vessels.

FUEL & TECHNOLOGY BASELINE

Largely conventional, but the direction of change is clear: solar installed on **five** vessels and wind-assistance on **three; eleven fuel-cell vessels** on order for EU Member State flags within the next five years; passenger ships account for **23%** of EU Member State LNG-ready and **48%** of battery-equipped vessels.

SOURCES

1 EU Industrial Maritime Strategy.
2 European economic contribution and employment, 2024.
3 CLIA-member ocean fleet and orderbook, 2025. Description of the sector, drivers and constraints: Waterborne Technology Roadmap – Cruise, Ch. 1-2, Tables 2-3

02 POLICY DRIVERS AND CONSTRAINTS

2.1. POLICY AND MARKET DRIVERS

Climate neutrality – the European Climate Law establishes at least a 55% net reduction GHG emissions by 2030, a 90% net reduction by 2040 and climate neutrality by 2050. Cruise newbuilds and major retrofits must be compatible with this trajectory.

EU ETS and FuelEU Maritime – since 2024 the EU ETS covers CO_2 from ships of 5,000 GT and above entering EU ports; FuelEU limits the yearly GHG intensity of energy used, with reductions increasing to 2050.

Onshore power and AFIR – adequate shore-side electricity supply required in TEN-T maritime ports for seagoing passenger and container ships by 2030.

Grid decarbonization and renewable energy targets – shore-power deployment must align with regional grid timelines; energy management systems must operate efficiently under variable supply.

IMO decarbonisation – the 2023 IMO GHG Strategy aims for net-zero by or around 2050, with indicative checkpoints for 2030 and 2040.

Energy efficiency and power quality standards – converter efficiency, power management algorithms and thermal control directly determine regulatory compliance.

Air quality, ECAs and pollution to water – the Mediterranean Sea became a MARPOL SOx ECA on 1 May 2025, reducing permitted sulphur content to 0.10%; directives set air- and water-quality objectives.

Local market mechanisms – e.g. the Environmental Port Index, influencing port tariffs in various ports.

Destination access e.g. Norway's World Heritage fjord zero-emission requirements apply to passenger ships below 10,000 GT from 2026 and larger ships from 2032.

Public perception – high visibility in city centres, islands, heritage sites and Arctic and protected destinations public perception increasingly determines market developments.

Cybersecurity, digital services and standards – digital twins, ship-shore data exchange and automated systems require certified cybersecurity frameworks, trusted data sharing and interoperability across shipyards, manufacturers, ports and service providers.

Industrial competitiveness – RD&I must reduce first-of-a-kind risk, support lifecycle retrofits, keep high-value integration capability in Europe and strengthen strategic autonomy.

Ports strategy – the EU Ports Strategy, published in March 2026, sets the EU's direction on port investment, energy governance and digitalisation.

2.2. CONSTRAINTS AND BOTTLENECKS

High hotel-load demand – large continuous electricity and heat demand at berth makes OPS, thermal management, HVAC efficiency, hotel-load optimisation and port grid reinforcement critical.

Heterogeneous vessels and itineraries – large contemporary vessels, luxury vessels and expedition ships have different space, range, port, safety and passenger-experience constraints.

Infrastructure and grid – shore-power capability and capacity, grid capacity, grid stability and frequency control, renewable procurement, berth allocation and connection procedures vary strongly; many historic ports cannot dredge or extend berths.

Fuel uncertainty and availability – sustainable methanol, bio- and synthetic methane, hydrogen-based fuels and renewable electricity will differ by region in availability, price, lifecycle emissions and safety requirements.

Safety approval – sustainable alternative fuels, batteries, fuel cells, carbon capture, high-voltage OPS and autonomous functions require harmonized safety cases for passenger-carrying service; limited harmonised validation evidence for integrated cruise fire safety.

Cyber and data risk – digitalization expands the attack surface across navigation, machinery, hotel systems, passenger services, suppliers and port interfaces, and increasing cybersecurity risks require significant investments in resilient data infrastructure.

Digital standards – fragmented standards and insufficient interoperability between ships, ports and destinations reduce efficiency and hinder data-driven optimisation.

Standardisation and certification – interoperability standards and certification pathways for new electrical, fuel-cell and energy-storage systems are not yet established for cruise service; fragmented national and international standards across EU ports further complicate implementation.

Capital intensity – newbuilds and major retrofits are high-cost, long-lived investments; financing requires confidence in regulations, fuels, infrastructure and future market access.

Supply chain resilience for critical components – global supply chains are concentrated in non-EU regions; disruption, export restrictions or geopolitical shifts create deployment risks.

Social license – concentrated passenger arrivals, local pollution, underwater noise, congestion and waste management affect community acceptance and destination access.

Skills availability and workforce shortages – crews, port personnel, responders, maintenance teams, shipyard and equipment workers and shore-side operators will need new competences, training, certification, human-centred design and social dialogue.

DEPLOYMENT LOGIC

the roadmap differentiates between technology readiness and deployment readiness. A technology may be technically mature but undeployable at scale if port grids are unavailable, safety cases are unresolved, crew training absent, fuel supply uncertified, or destination authorities have not accepted the operating model.

CRUISE TECHNOLOGY ROADMAP

03 TARGET CAPABILITIES

2035 • Early deployment phase

Energy and emissions – zero-emission-at-berth capability in principal European cruise ports; production strategy for sustainable alternative fuels; shore-power ready retrofits; modular energy spaces; fuel-flexible newbuilds; batteries for peak shaving and zero-emission manoeuvring; verified energy-saving devices

Ship-port-destination integration – deployment packages covering OPS, passenger flows, waste, provisioning, local transport and emergency response; cyber-secure ship and port connectivity; tariff and financing frameworks for recovering the cost of OPS and grid reinforcement

Safety, security and resilience – harmonised safety baselines; joint drills with ports and responders; representative fire and release tests; reusable safety case modules; shift from redundancy to quantitative reliability analysis

Digital and lifecycle systems – operational digital twins; secure data exchange; digital commissioning for complex systems; predictive maintenance

People and skills – training for fuels, batteries, OPS, cyber security and emergency response; remote support roles; recognised qualifications for seafarers and hotel-service personnel

2040 • Scale-up phase

Energy and emissions – multi-energy architectures combining low- and zero-carbon fuels, batteries, fuel cells, heat recovery and advanced electrical systems; cruise corridors with shore power and sustainable alternative-fuel supply; near-zero local emissions in sensitive areas; lifecycle-based circularity

Ship-port-destination integration – integrated cruise corridors and destination clusters with shared energy scheduling, just-in-time arrival, berth reliability, visitor-flow management and transparent environmental performance

Safety, security and resilience – predictive safety ecosystems, dynamic risk models, polar-ready safety cases and certified AI-assisted decision support under human accountability; digital safety twins verified through joint ship-port exercises

Digital and lifecycle systems – lifecycle data thread from design and production to operation and retrofit; automated compliance reporting; supervised automation; automated onboard energy management

People and skills – standardized competence frameworks and XR/simulation-based recurrent training; transparent human-AI teaming and new shore/ship roles

2050 • Full transformation

Energy and emissions – net zero-emission cruise operations over full itineraries, with zero-emission operation wherever technically and operationally feasible; lifecycle-optimized energy systems; exploratory assessment of bidirectional ship-port energy interfaces and high-density energy sources; closed-loop circular ship design

Ship-port-destination integration – seamless ship-port-energy destination system with ports acting as clean-energy, logistics, safety and visitor-flow hubs

Safety, security and resilience – continuous safety and cyber assurance; robust degraded modes; human-centred automation; resilient European supply chains for critical maritime technologies

Digital and lifecycle systems – system-of-systems digital integration across vessel, port, energy and destination; machine-verifiable compliance embedded in operations; integrated European digital maritime infrastructure

People and skills – future-ready workforce with continuous learning, safer working environments, clear accountability and attractive hybrid careers

CRUISE TECHNOLOGY ROADMAP

04 TECHNOLOGY PATHWAYS

Five cruise-specific pathways, each presented through an operational objective, horizon-specific priority actions and key research gaps.

4.1 Future propulsion and energy systems enabling a zero-emission cruise fleet

High-voltage OPS interfaces and onboard systems compatible with cruise hotel loads, including electric boilers, heat pumps, heat recovery, thermal storage and integrated HVAC control · methanol-capable engines, hydrogen-based systems including LOHC in controlled use cases, verified wind-assisted concepts and other operational ESDs · integrated AC/DC electrical architectures and multi-MW fuel-cell modules · **modular, retrofit-ready multi-energy cruise platforms by 2050**

4.2 Intelligent safety, security and resilience as foundational enablers

Harmonised safety concepts and reusable evidence for methanol, batteries, fuel cells, OPS, charging, sustainable alternative-fuel bunkering and retrofit integration in passenger service · detection, ventilation, isolation, smoke control, fire suppression and safe shutdown for new energy systems · predictive safety ecosystems and certified AI-supported decision tools under human accountability · **continuous safety and cyber assurance by 2050**

4.3 Fully connected, automated and data-driven cruise systems

Operational digital twins for energy, emissions, hotel-load optimisation, voyage planning and condition-based maintenance · cybersecurity-by-design with authenticated interfaces, network segmentation and zero-trust access · standardised lifecycle data thread, digital handover and machine-verifiable reporting · **system-of-systems digital integration with continuous assurance by 2050**

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

Competence frameworks and recognised qualifications for seafarers and hotel-service personnel · XR and simulator-based training for rare but high-impact events · standardised human-automation teaming with auditable human accountability · **domain-specific, certified AI copilots and inclusive passenger-space design by 2050**

4.5 Forward-looking regulation, standardization and system-level integration

Standardised interfaces and approval practices for cruise OPS, onboard thermal systems, batteries, low-flashpoint fuels, charging, fuel documentation and emissions verification · reusable digital evidence, virtual commissioning, hardware-in-the-loop testing and regulatory sandboxes · cruise-specific green corridor frameworks · **machine-readable regulation, fuel passports and carbon ledgers by 2050**

05 ENABLERS AND DEPLOYMENT AT SCALE

Performance can be limited by one port without adequate shore power, one weak-grid island, one destination with access restrictions, one supply chain vulnerability or one unresolved safety approval.

5.1 Itinerary-based deployment packages
Defined as an itinerary and destination cluster package rather than a single vessel or single port project

5.5 Standards, certification and regulatory readiness
Harmonised technical standards, accelerated certification, reusable safety-case modules, sandboxes and corridor demonstrations

5.2 Shore power, hotel-load management and port energy readiness
The priority near-term deployment condition: reinforced grids, high-voltage shore power, power quality, renewable procurement

5.6 Data governance, interoperability and lifecycle integration
Trusted maritime data spaces, open standards, lifecycle asset identifiers, clear ownership and access rights, no proprietary lock-in

5.3 Fuel availability, bunkering and emergency-response readiness
Reliable, certified supply across repeated itineraries and destination clusters, not isolated bunkering opportunities

5.7 Workforce and change management
Training and change management integrated into demonstration and deployment projects from the start

5.4 Financing, industrial capacity and procurement
Instruments that reduce first-of-a-kind and integration risk and reward lifecycle performance rather than only capital expenditure

Deployment readiness
Funding and demonstration should prioritise large-scale, cross-sector implementation, and every project should assess technology, industrial and ecosystem deployment readiness

06 EXPECTED IMPACTS

ENVIRONMENTAL

2035 Approximately 14.5% reduction in GHG intensity relative to the applicable 2020 reference value; OPS availability or use at around 70% of relevant TEN-T cruise ports; 10–15 dB reduction in underwater radiated noise for applicable vessels and operating profiles; measurable reductions in local air pollutants

2040 Approximately 31% reduction in GHG intensity relative to the applicable 2020 reference value; zero-emission- at-berth operation for around 90% of relevant cruise port calls; near-zero local emissions in environmentally sensitive areas

2050 Approximately 80% reduction in GHG intensity relative to the applicable 2020 reference value, with residual emissions addressed through verified climate-neutral energy pathways; 100% zero-emission-at-berth operation at suitably equipped ports

ECONOMIC & INDUSTRIAL

2035 Approximately 40–60 vessel retrofits, supporting a European retrofit market of around €2–3 billion; annual fuel-cost savings of approximately €200,000–€300,000 per retrofitted vessel, where operating conditions permit; around 2,000 new jobs

2040 Approximately 120–150 vessel retrofits; a European cruise-equipment market of around €1.5–2 billion; approximately €500 million in shore-power and related energy services

2050 Cumulative transition value of approximately €30–40 billion; annual European cruise-equipment export market of around €3–4 billion; retention of more than 95% of Europe's current position in relevant high-value cruise technologies

TECHNOLOGICAL

2035 Certification and early commercial deployment of methanol engines and associated systems; batteries installed on more than 200 cruise vessels; more than 100 operational digital twins

2040 Fuel-cell systems operational in the 10–20 MW range; predictive-maintenance systems achieving around 90% accuracy for defined failure modes; remote or highly integrated operations at more than 15 cruise terminals

2050 Highly automated or autonomous energy orchestration with human oversight; integrated lifecycle digital systems across vessels, ports and destinations; approximately 95% recovery, reuse or recycling of applicable vessel materials

SOCIAL & WORKFORCE

2035 Approximately 5,000 personnel trained through at least five specialised training centres; improved passenger comfort, accessibility, connectivity, service continuity and safety

2040 Approximately 15,000 personnel trained; improvements of around 35–40% in defined operator-competence measures through simulation and extended-reality training

2050 More than 25,000 future-ready personnel supported by continuous learning and recognised competence frameworks; improved workforce diversity and attractiveness of maritime careers

COMPETITIVE, RESILIENT AND SUSTAINABLE CRUISE SECTOR

The implementation of this roadmap supports the transformation of European cruise into a zero-emission, digitally integrated, safe, resilient, competitive and passenger-centred sector.

GLOSSARY

OPS = onshore power supply
GT = gross tonnage
ESD = energy-saving device
ETS = EU emissions trading system
AFIR = Alternative Fuels Infrastructure Regulation
ECA = emission control area
TEN-T = EU core transport network
LOHC = liquid organic hydrogen carrier
TRL = technology readiness level
XR = extended reality
HVAC = heating, ventilation and air conditioning.

Target capabilities, pathways, enablers and impacts: Waterborne Technology Roadmap – Cruise, Ch. 3-6, Tables 4-10. Table 10 provides indicative expected impacts, which will be further refined at implementation.

CONTENT

LIST OF TABLES

ROADMAP POSITIONING WITHIN THE WATERBORNE TECHNOLOGY LEADERSHIP FRAMEWORK

This roadmap operationalises the Technology Leadership[1] framework for the cruise sector. It translates the overarching objectives, including competitiveness, resilience, sustainability, zero-emission operations[2], digitalisation, safety and security, human-centred innovation, standards, skills and deployment at scale, into the specific conditions of the cruise sector. 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 the cruise sector is closely interlinked with the following dedicated Technology Roadmaps: maritime technology sector, port ecosystems and blue economy.

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.

2 Throughout this roadmap, references to zero-emission may, depending on the context, encompass broader environmental performance objectives, including the elimination of local pollutant emissions. Net-zero emission refers specifically to greenhouse gas emissions from a lifecycle perspective and may include carbon neutral fuels, carbon capture pathways and other net-zero solutions

1. DESCRIPTION OF THE SECTOR

1. DESCRIPTION OF THE SECTOR

1.1. DEFINITION

Cruise shipping is the carriage of passengers by sea on multi-day leisure voyages that call at several ports and return to the port of embarkation[3]. In cruise, the vessel is both the means of transport and the principal tourism product, which distinguishes it from ferry and Ro-Pax services, which primarily provide point-to-point passenger and vehicle transport. Cruise operations combine waterborne transport, hospitality, destination access, logistics, energy use, passenger services and safety management.

This Technology Roadmap covers ocean-going cruise ships, including large contemporary vessels, mid-size and premium ships, luxury vessels and purpose-built expedition ships. River cruise is addressed under the Inland Waterway Transport roadmap, and ferry and Ro-Pax services under the Ferries roadmap, because their power profiles, terminal interfaces and service obligations differ. The Strategic Research Agenda treats cruise as a distinct waterborne segment alongside inland waterway transport, ferries, short sea ships, oceangoing vessels and offshore shipping.[4]

1.2. STRATEGIC ROLE IN THE EUROPEAN WATERBORNE ECOSYSTEM

Cruise is strategically important for Europe for three reasons. First, it is a high value, complex shipbuilding segment in which European shipyards and equipment manufacturers retain a leading position. European cruise shipyards act as the lead system integrators responsible for the design, integration, validation, commissioning and certification of the vessel as a whole. The EU Industrial Maritime Strategy notes that 97% of the world fleet of cruise ships has been built in Europe[5], making cruise production central to Europe's complex shipbuilding capabilities and essential to strategic autonomy. Complex system integration is the key competitive strength of the European cruise industry: EU shipyards master capability to design, integrate, validate, certify and deliver highly complex multi-supplier onboard systems as the lead system integrator of the vessel. Second, cruise vessels are frequent users of European ports and waters, giving Europe a real deployment environment for shore power, sustainable alternative fuels, ship-shore digital systems, passenger-ship safety innovation and lifecycle services.

Third, cruise has high public visibility in city-centres, islands, heritages and Arctic and protected destinations, where environmental performance increasingly determines market access[6]. A successful cruise transition accelerates innovation transfer to ferries, offshore vessels, research vessels, naval auxiliaries and other complex ships.

Cruise is also a significant European economic activity. The segment contributed €64.1 billion to the European economy, of which €28 billion was gross domestic product, and supported 445,000 jobs in 2024.[7] Its supply chain reaches shipyards, equipment manufacturers, ports, logistics providers and hospitality operators[8], and it generates recurring income for coastal, island and peripheral regions, including in the off-season. European seas account for more than 30% of global cruise activity, and over 60% of cruise calls at EU ports in 2023 were by ships flying EU Member State flags.[9]

3 Definition adapted from UN Tourism (UNWTO), International Recommendations for Tourism Statistics 2008 (New York: United Nations, 2010), para. 2.34.
4 Waterborne Technology Platform, Strategic Research Agenda for the European Waterborne Sector (Brussels: Waterborne TP, June 2025), 2.
5 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final (Brussels, 2026), 3.
6 Waterborne Technology Platform, Strategic Research Agenda for the European Waterborne Sector (Brussels: Waterborne TP, June 2025), 11 (regional and climatic differentiation of waterborne infrastructure, including Arctic winter-navigation conditions).
7 Tourism Economics, Contribution of Cruise Tourism to the Global Economy 2024, produced for CLIA (Oxford: Tourism Economics, December 2025), 21 (output, Europe $69.2 billion), 22 (GDP, Europe $30.6 billion), 24 (employment, Europe 445,000 jobs). Report figures are in current US dollars; euro equivalents are converted at prevailing 2024 average USD/EUR exchange rates.
8 Tourism Economics, Contribution... 2024, 24 (employment supported across direct, indirect and induced channels).
9 European Maritime Safety Agency, The 2025 European Maritime Safety Report (Lisbon: EMSA, 2025), 128.

Cruise depends on a tightly coupled ecosystem of vessel, port and destination. Technology choices follow from itinerary structure, hotel-load profile, time at berth, port readiness, grid access, fuel availability and destination access conditions. Deployment therefore requires coordinated planning across shipowners, shipyards, equipment manufacturers, ports, energy suppliers and destination authorities.

1.3. OPERATIONAL PROFILE

The cruise operational profile differs from cargo and oceangoing shipping in several respects. Cruise ships carry continuous hotel loads of 1–20 MW at berth, which can exceed the propulsive load, because power for accommodation, catering and services is required at all times.[10] Itineraries combine frequent port calls with extended time at berth, often in city centres or environmentally sensitive areas, where local air quality, noise, traffic and visitor flow concerns are prominent. Passenger capacity reaches several thousand on the largest vessels, and most modern cruise ships use electric-drive propulsion.

Operations are geographically concentrated and seasonal. European cruise activity is concentrated in the Mediterranean, Baltic, Norway, Northern Europe, the Atlantic and selected island regions, while expedition cruise operates in polar and remote waters. The same vessel may face highly diverse conditions: a congested urban port, a weak-grid island port, a fjord with zero emission requirements, a polar itinerary with limited rescue capability, and a large homeport with airport, baggage, provisioning and waste interfaces. Furthermore, the typology of cruise ports drives different infrastructure requirements: homeport/turnaround ports require passenger terminals, baggage handling, provisioning, waste management, and airport-port connections; port-of-call-ports require primarily OPS and coordination of visitor flows with the destination, whereas multi-use ports compete for berths, draught and time windows with cargo traffic.[11] Technology deployment must therefore be planned by itinerary and destination cluster rather than only by vessel type.

This profile creates strong potential for shore power, onboard energy management and zero-pollutant technologies such as batteries and fuel cells for zero-emission arrival and departure. Cruise vessel operations encompass integrated power and energy management systems that coordinate propulsion, hotel loads, safety systems, navigation and passenger services. This includes electrical power distribution, energy storage, thermal management, shore-power interfaces, and integrated control automation across main engines, generators, fuel-cell systems, battery banks, shore connections and hotel electrical/HVAC systems. This scope encompasses both conventional and hybrid-electric architectures, particularly as vessels transition toward zero-emission operation.

Since existing vessels will remain in service for decades, energy efficiency, including digital energy management, will represent the largest immediate opportunity for emissions reduction.

10 European Maritime Safety Agency, Guidance on Shore-Side Electricity to Port Authorities and Administrations, Part 2: Planning, Operations and Safety, version 2 (Lisbon: EMSA, August 2022), 17 (Table 4.4: high-voltage shore-connection rating for cruise ships, 16 MVA, 20 MVA recommended).

11 European Sea Ports Organisation, EcoPorts Insights 2025 (Brussels: ESPO, 2025), 16.

Cruise also exposes operations to port infrastructure gaps, scarce high-voltage shore connection and destination access limits, where a single weak link can compromise an entire itinerary. AI, cybersecurity, data sharing and remote operational support are strategic capabilities which are becoming essential for safe, efficient and sustainable cruise operations. In addition, the cruise sector is key for technological sovereignty of the European maritime technology sector, whilst preserving resilience of European supply chains.

1.4. ROADMAP POSITIONING WITHIN WATERBORNE TECHNOLOGY LEADERSHIP

This roadmap translates the Waterborne Technology Leadership document[12] into cruise-specific Research, Development and Innovation (RD&I), upscaling and deployment priorities. It focuses on vessel capability and service-level integration, while recognising dependencies on the Port Ecosystems Technology Roadmap for shore-side infrastructure and energy systems and on the Maritime Technology Roadmap for components, production technologies, advanced materials and manufacturing processes.

Waterborne pillar	Cruise roadmap interpretation
Transformation of waterborne transport	Cruise-specific focus on zero emission propulsion, hotel-energy systems, zero-emission-at-berth operation, energy-efficiency measures, digital optimization and safe alternative-fuel integration.
Safe, secure and resilient waterborne operations	Passenger-ship safety, cyber-resilient ship-shore interfaces, emergency preparedness, polar operations and safe degraded mode operations for complex cruise vessels.
Connected, automated and data-driven systems	Lifecycle digital twins, operational data spaces, predictive maintenance, port-call coordination, energy scheduling, emissions verification and selected supervised automation.
Port ecosystems and blue economy	Cruise corridors and destination clusters integrating vessels, ports, grids, fuel supply, urban mobility, waste handling, tourism flows and local acceptance.
European maritime technology sector	Digital shipyards, modular production, advanced materials, lifecycle digital threads, certification capabilities and supply-chain resilience.

Table 1: Cruise roadmap interpretation of waterborne technology leadership document

12 Waterborne TP, Waterborne Technology Leadership, 2026, 11 (dedicated technology roadmaps by product category, including cruise ships).

1.5. SECTOR BASELINE AND MARKET CHARACTERISTICS

The cruise fleet is relatively small in vessel numbers but high in economic value, passenger capacity and technological complexity. In 2025, the CLIA-member ocean fleet comprised 310 vessels, providing more than 651,000 lower berths and accounting for roughly 92% of global ocean-going cruise lower-berth capacity.[13] Cruise ships represent less than 1% of the world commercial fleet by vessel count, yet they are among the most complex and capital-intensive ship types. The European-controlled cruise fleet stands at around 6.0 million gross tonnes, corresponding to about 19% of the world cruise fleet.[14]

Cruise demand has recovered strongly after the pandemic. Ocean-going cruise passengers reached 34.6 million in 2024, exceeding the 29.7 million passengers recorded in 2019. Cruise remains a relatively small share of global tourism, at 2.4% of international tourist arrivals in 2024, up from 2.0% in 2019,[15] but its concentration in specific ports, destinations and seasons gives it high local visibility and operational impact.

The fleet is increasingly segmented. Large vessels of 3,000 berths and above represented 27.4% of CLIA-member ships in 2025 and this segment continues to increase in importance. At the same time, the luxury and expedition segments are expanding rapidly. The luxury fleet has more than tripled since 2010, reaching around 97 vessels, while approximately 40 purpose-built expedition ships are now in operation. Expedition cruise capacity is projected to grow by about 150% between 2019 and 2029.[16] These trends are relevant for technology deployment because large contemporary cruise ships, luxury vessels and expedition ships have different energy profiles, itinerary patterns, port interfaces and environmental constraints.

Fleet renewal is continuing. The current orderbook includes 56 vessels and around 168,000 lower berths scheduled for delivery by 2036.[17] This represents a projected capacity increase of approximately 27%, supported by capital commitments of about USD 56.7 billion.[18] The orderbook is therefore a key opportunity to embed fuel flexibility, energy efficiency, shore-power readiness, digital integration, safety-by-design and lifecycle adaptability into the next generation of cruise vessels.

The current fuel and technology baseline remains largely conventional, but the direction of change is clear. Newbuilds increasingly incorporate dual-fuel engines and designs that can transition towards green methanol, bio- and synthetic LNG, hydrogen-based energy systems and fuel cells as fuel availability and safety frameworks mature. Solar installations and wind-assistance remain limited, with solar installed on five vessels and wind-assistance on three,[19] but they indicate growing experimentation with supplementary renewable energy and energy-saving technologies. Eleven fuel-cell vessels, predominantly cruise ships, are on order for EU Member State flags within the next five years. Passenger ships also account for 23% of the EU Member State LNG-ready and 48% battery-equipped vessels.[20]

13 Cruise Lines International Association, State of the Cruise Industry Report 2025 (Washington, DC: CLIA, 2025), 15.
14 European Community Shipowners' Associations, The Economic Value of European Shipping (Brussels: ECSA, 2026), 13.
15 CLIA, State of the Cruise Industry Report 2025, 14; Tourism Economics, Contribution... 2024, 10 (2.4% of international tourist arrivals in 2024, up from 2.0% in 2019, against UNWTO data).
16 CLIA, State of the Cruise Industry Report 2025, 63 (fleet size distribution by ship class), 29 (expedition fleet growth), 32–33 (luxury fleet growth).
17 Cruise Lines International Association, State of the Cruise Industry Report 2025 (Washington, DC: CLIA, 2025), 64.
18 Ibid , 64.
19 Ibid, 44.
20 European Maritime Safety Agency, The 2025 European Maritime Safety Report (Lisbon: EMSA, 2025), 84–85.

1.6. CRUISE AS A TECHNOLOGY-LEADERSHIP OPPORTUNITY

Cruise is a strategic technology-leadership segment for Europe. It is the vessel category in which European complex shipbuilding is most strongly positioned, with European shipyards maintaining a leading role in the design and construction of large, high-value cruise ships. Cruise vessels also operate frequently in European ports and waters, which makes them an ideal deployment environment for European shipyards, equipment manufacturers, classification societies, energy and digital service providers and ports. The cruise sector can act as an early deployment platform for technologies that are relevant across the wider waterborne sector. Demonstration in cruise can accelerate the development and validation of fuel-flexible engines, fuel cells, advanced energy storage, onboard energy management, high-voltage shore-power interfaces, integrated hotel-load optimisation, cyber-secure ship-shore data exchange, predictive safety systems, digital twins and human-centred automation[21]. Once proven in the demanding cruise environment, many of these solutions can be transferred to ferries, Ro-Pax vessels, offshore vessels and other complex passenger or service vessels.

Cruise also supports Europe's industrial base beyond newbuilding. The transition to zero emissions cruise will require substantial ship repair, conversion, retrofitting, system integration, lifecycle support and recycling capacity. These capabilities are central to safety, decarbonisation, circularity and strategic autonomy. Cruise therefore creates demand not only for new zero-emission-ready vessels, but also for retrofit packages, digital lifecycle services, equipment upgrades, safety certification, training and port-interface solutions.

Maintaining Europe's cruise-shipbuilding position is therefore both an environmental and industrial priority. Competitive pressure from non-European shipyards, including offers reported to be significantly below European price levels, creates a risk to Europe's complex-shipbuilding capability[22]. A strong cruise technology roadmap protects this position by linking European industrial leadership with the development, demonstration and deployment of advanced decarbonisation, safety, digitalisation and lifecycle solutions. In this sense, cruise is a platform through which Europe can retain and export high-value maritime technology.

21 Waterborne Technology Platform, Waterborne Technology Leadership (Brussels: Waterborne TP, 2026), 19 (intelligent safety, security and resilience; future propulsion and energy systems; human-centred design and a future-ready workforce).

22 Waterborne Technology Platform, Waterborne Technology Leadership (Brussels: Waterborne TP, 2026), 7 (Asian shipyards offering prices up to 30–40% below European levels), drawing on Mario Draghi, The Future of European Competitiveness (European Commission, 2024).

2. DRIVERS AND CONSTRAINTS

2. DRIVERS AND CONSTRAINTS

2.1. POLICY AND MARKET DRIVERS

The transformation of the cruise segment is driven by the interaction of climate regulation, destination-led environmental requirements, industrial and competitiveness policy, port and energy strategy, passenger-ship safety rules, and sustained tourism demand. The principal drivers and their implication for cruise RD&I and deployment are presented below.

Driver	Implication for cruise RD&I and deployment
Climate neutrality	The European Climate Law establishes a 2030 target of at least a 55% net reduction in greenhouse gas emissions relative to 1990, a 2040 milestone of a 90% net reduction, and climate neutrality by 2050. Cruise newbuilds and major retrofits must be compatible with this trajectory.[23]
EU ETS and FuelEU Maritime	Since 2024, the EU ETS covers CO_2 emissions from large ships of 5,000 GT and above entering EU ports. FuelEU Maritime limits the yearly greenhouse-gas intensity of energy used by ships above 5,000 GT calling at European ports, with reductions increasing to 2050.[24]
Onshore power and AFIR	The Alternative Fuels Infrastructure Regulation requires adequate shore-side electricity supply in TEN-T maritime ports for seagoing passenger and container ships by 2030, subject to the regulation's conditions and traffic thresholds.[25]
Grid decarbonization and renewable energy targets	Shore-power infrastructure deployment must align with regional grid decarbonization timelines. System designers must account for variable renewable supply and grid stability. Energy management systems require capability to operate efficiently under variable supply conditions.
IMO decarbonisation	The 2023 IMO GHG Strategy aims for net-zero GHG emissions from international shipping by or around 2050, with indicative checkpoints for 2030 and 2040 and a 2030 target for zero- or near-zero-emission energy uptake.[26]
Energy efficiency and power quality standards	Electrical system design, converter efficiency, power management algorithms and thermal control directly determine regulatory compliance. Investment in energy management system capability becomes a regulatory compliance requirement.

Table 2: Drivers for cruise RD&I and deployment

23 Regulation (EU) 2021/1119 (European Climate Law), OJ L 243, 9.7.2021, arts. 2 and 4, as amended by Regulation (EU) 2026/667 of the European Parliament and of the Council of 11 March 2026 setting a binding 90% net reduction by 2040, OJ L, 2026/667, in force 7 April 2026;

24 Directive (EU) 2023/959, OJ L 130, 16.5.2023; and Regulation (EU) 2023/1805 (FuelEU Maritime), OJ L 234, 22.9.2023, art. 4.

25 Regulation (EU) 2023/1804 (AFIR), OJ L 234, 22.9.2023, art. 9.

26 International Maritime Organization, 2023 IMO Strategy on Reduction of GHG Emissions from Ships, Resolution MEPC.377(80) (London: IMO, 7 July 2023).

Driver	Implication for cruise RD&I and deployment
Air quality, ECAs and pollution to water	The Mediterranean Sea became a MARPOL SOx Emission Control Area on 1 May 2025, reducing the permitted Sulphur content of fuel oil to 0.10% in the area.[27] Furthermore, different European directives set objectives for air and water quality, like the Marine Strategy Framework Directive[28] and the Revised Ambient Air Quality Directive[29]
Local market mechanisms	E.g. Environmental Port Index (EPI), influencing port tariffs in various ports
Destination access	Destinations are moving from general environmental expectations to access conditions, such as Norway's World Heritage fjord zero-emission requirements for passenger ships below 10,000 GT from 2026 and larger ships from 2032.[30]
Public perception	Cruise has high public visibility in city centres, islands, heritages and Arctic and protected destinations and public perception increasingly determines market developments
Cybersecurity and digital resilience regulation	Digital twins, ship-shore data exchange and automated systems required certified cybersecurity framework.
Seamless digital services, operational efficiency and resilience	Digital transformation, cyber resilience, AI-supported operations and trusted data sharing across ships, ports and destinations.
Industrial digital standards and interoperability	System architects must design for interoperability across shipyards, equipment manufacturers, ports and service providers. Proprietary data formats create a regulatory risk.
Industrial competitiveness	Europe's cruise-building leadership is exposed to global shipbuilding competition. RD&I must reduce first-of-a-kind risk, support lifecycle retrofits and keep high-value integration capability in Europe.[31] Furthermore, European cruise shipbuilding will contribute to Europe's ambition to strengthen strategic autonomy by developing domestic clean maritime technologies and reducing dependency on non-European supply chains.
Ports strategy[32]	The EU Ports Strategy, as published in March 2026, sets the EU's direction on port investment, energy governance and digitalisation

Table 2: Drivers for cruise RD&I and deployment

27 International Maritime Organization, Resolution MEPC.361(79), Amendments to MARPOL Annex VI (Mediterranean Sea Emission Control Area for Sulphur Oxides and Particulate Matter), adopted 16 December 2022; the 0.10% m/m sulphur limit applies from 1 May 2025.

28 Directive 2008/56/EC (Marine Strategy Framework Directive), OJ L 164, 25.6.2008.

29 Directive (EU) 2024/2881 on ambient air quality and cleaner air for Europe, OJ L, 20.11.2024.

30 Norwegian Maritime Authority, "Zero-Emission Requirements for the World Heritage Fjords Adopted" (Haugesund: NMA, 15 April 2025).MEPC.377(80)(London: IMO, 7 July 2023).

31 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final (Brussels, 2026), 3; and Waterborne Technology Platform, Waterborne Technology Leadership (Brussels: Waterborne TP, 2026), 7, drawing on Mario Draghi, The Future of European Competitiveness (European Commission, 2024).

32 European Commission, EU Ports Strategy, COM(2026) 112 final (Brussels, 2026).

2.2. CONSTRAINTS AND BOTTLENECKS

The main constraints are set out below.

Constraint	Roadmap response
High hotel-load demand	Large continuous electricity and heat demand at berth makes OPS, thermal management, HVAC efficiency, hotel-load optimisation and port grid reinforcement critical.[33]
Heterogeneous vessels and itineraries	Large contemporary vessels, luxury vessels and expedition ships have different space, range, port, safety and passenger-experience constraints.[34]
Infrastructure and grid	Shore-power capability and capacity, grid capacity, grid stability and frequency control, renewable procurement, berth allocation and connection procedures vary strongly across cruise ports.[35] Furthermore, berth draught and length limitations relative to the growing average vessel size, whereas many historic ports cannot dredge or extend berths
Fuel uncertainty and availability	Sustainable methanol, bio- and synthetic methane, hydrogen-based fuels and renewable electricity will differ by region in (infrastructure) availability, price, lifecycle emissions and safety requirements.
Safety approval	Sustainable alternative fuels, batteries, fuel cells, carbon capture, high-voltage OPS and autonomous functions require harmonized safety cases for passenger-carrying service. Limited harmonised validation evidence for integrated cruise fire safety.
Cyber and data risk	Digitalization expands the attack surface across navigation, machinery, hotel systems, passenger services, suppliers and port interfaces and increasing cybersecurity risks require significant investments in resilient data infrastructure.
Digital standards	Fragmented digital standards and insufficient interoperability between ships, ports and destinations reduces operational efficiency and hinder data-driven optimisation.
Standardisation and certification	Technical interoperability standards and certification pathways for new electrical, fuel-cell, and energy storage systems are not yet established for cruise service. Fragmented national and international standards across EU ports further complicate implementation.

Table 3: Constraints influencing cruise RD&I and deployment

33 Waterborne Technology Platform, Strategic Research Agenda for the European Waterborne Sector (Brussels: Waterborne TP, June 2025), 15 (onshore power supply and Clean Power Supply Plans as a port-infrastructure priority).

34 Cruise Lines International Association, State of the Cruise Industry Report 2025 (Washington, DC: CLIA, 2025), 29, 32–33.

35 European Commission, EU Ports Strategy, COM(2026) 112 final (Brussels, 2026), 7 (62 % of surveyed ports offer onshore power at one or more berths; high-voltage supply for larger ships remains scarce).

Constraint	Roadmap response
Capital intensity	Cruise newbuilds and major retrofits are high-cost, long-lived investments. Financing requires confidence in regulations, sustainable alternative fuels, infrastructure and future market access. Furthermore, long investments cycles, high capital costs and uncertainty regarding future fuel pathways make investment decisions difficult.
Supply chain resilience for critical components	Global supply chains for technology components are concentrated in non-EU regions. Supply disruption, technology export restrictions, or geopolitical shifts create deployment risks for cruise operators planning multi-year retrofits or newbuilds. Uncertainty about component availability constraints investment confidence.
Social license	Concentrated passenger arrivals, local pollution, underwater noise, congestion and waste management affect community acceptance and destination access.[36]
Skills availability and workforce shortages are cross-cutting constraints	Crews, port personnel, emergency responders, maintenance teams, shipyard and maritime equipment workers and shore-side operators will need new competences. Automation, remote technical support and digital decision-support tools can improve safety and reduce workload. The transition will therefore require not only new technologies, but also training, certification, human-centred design and social dialogue[37].

Table 3: Constraints influencing cruise RD&I and deployment

36 BBC News, "Ever Given: Cargo Ship Blocking Suez Canal Partially Refloated," BBC News, March 29, 2021, https://www.bbc.com/news/world-europe-56592109; Jack Guy, "Barcelona Is Shutting Two of Its Cruise-Ship Terminals to Cut Tourist Numbers," CNN, July 21, 2025, https://edition.cnn.com/2025/07/21/travel/barcelona-cruise-terminal-closures-scli-intl; "Cannes to Ban Cruise Ships with More than 1,000 People," Le Monde, June 30, 2025, https://www.lemonde.fr/en/france/article/2025/06/30/cannes-to-ban-cruise-ships-with-more-than-1-000-people_6742854_7.html

37 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 21–22 (Pillar VI, "Access to skills and quality jobs"); SEA Europe, Setting Sail to Build in Europe: 10,000 Sustainable and Digitalised Vessels by 2035 (Brussels: SEA Europe, April 2024), 6–7, https://www.seaeurope.eu/wp-content/uploads/2025/08/2024.04.01_Setting-sail-to-build-in-Europe-10_000-sustainable-and-digitalised-vessels-by-2035_SEA-Europes-call-for-a-European-maritime-industrial-strategy.pdf; Waterborne Technology Platform, Waterborne Technology Leadership (Brussels: Waterborne TP, 2026), 16, 19.

2.3 DEPLOYMENT LOGIC

The roadmap differentiates between technology readiness and deployment readiness. A technology may be technically mature but undeployable at scale if port grids are unavailable, safety cases are unresolved, crew training absent, fuel supply is uncertified, or destination authorities have not accepted the operating model. Each roadmap action should therefore be tested against deployment questions, like:

- Can the vessel use the solution under real cruise duty cycles, including hotel loads, manoeuvring, weather, safety margins and passenger-service requirements?
- Is the required port, grid, fuel, waste, emergency-response and data infrastructure available across the itinerary, not only at one homeport?
- Can the solution be approved, insured, maintained and operated by trained personnel under passenger-ship safety requirements?
- Does it reduce lifecycle greenhouse-gas emissions and local environmental pressure, including air pollutants and underwater radiated noise?
- Does the solution apply for retrofits and/or newbuilds?
- Does it preserve or enhance passenger value, accessibility, comfort and social acceptance?
- Does it support European industrial capability, retrofit capacity and lifecycle service models?

3. TARGET CAPABILITIES

3. TARGET CAPABILITIES

Capability area	2035 early deployment	2040 scale-up	2050 full transformation
Energy and emissions[38]	Zero-emission-at-berth capability in principal European cruise ports; production strategy for sustainable alternative fuels with clear market, sufficient fuel quantities and pricing developed; shore-power ready retrofits; modular energy spaces, adaptable machinery and tank layouts; fuel-flexible newbuilds; batteries for peak shaving, spinning-reserve reduction, cold-start emission reduction and zero-emission manoeuvring; verified energy-saving devices; real-time hotel, thermal and voyage energy management[39]	Multi-energy architectures combining low- and zero-carbon fuels, batteries, fuel cells, heat recovery and advanced electrical systems where justified; cruise corridors with shore power, clean electricity and sustainable alternative-fuel supply; near-zero local emissions in sensitive areas; explicit design management of machinery-space, safety, passenger-capacity and passenger-value trade-offs; resilient multi-fuel solutions, lifecycle-based circularity of vessels and equipment.	Net zero-emission cruise operations over full itineraries, with zero-emission operation wherever technically and operationally feasible; lifecycle-optimized energy systems; exploratory assessment of bidirectional ship-port energy interfaces and high-density energy sources where safety, regulation and public acceptance allow; closed-loop circular ship design
Ship-port-destination integration[40]	Deployment packages for homeports and frequent call ports covering OPS, passenger flows, waste, provisioning, local transport and emergency response; cyber-secure ship and port connectivity; seamless data exchange between cruise ships, ports and destinations; tariff and financing frameworks for recovering the cost of OPS and grid reinforcement defined	Integrated cruise corridors and destination clusters with shared energy scheduling, just-in-time arrival, berth reliability, visitor-flow management, airport and ground-transport coordination for homeports, and transparent environmental performance.	Seamless ship-port-energy-destination system with ports acting as clean-energy, logistics, safety and visitor-flow hubs.

Table 4: Target Capabilities to 2035, 2040, and 2050

38 Waterborne TP, Waterborne Technology Leadership, 2026, 18 (zero-harmful-emissions vision), 19 (future propulsion and energy systems), 20 (development trajectories).

39 Regulation (EU) 2023/1805 (FuelEU Maritime), OJ L 234, 22.9.2023, art. 6 (TEN-T ports from 1 January 2030; all equipped ports from 1 January 2035). The 2035 energy-intensity capability corresponds to the –14.5% GHG-intensity limit against the 2020 baseline of 91.16 gCO_2e/MJ, ibid., art. 4 and Annex I. Near-zero-emission operation in sensitive areas reflects destination requirements such as Norway's World Heritage fjords: Norwegian Maritime Authority, "Zero-Emission Requirements for the World Heritage Fjords Adopted" (Haugesund: NMA, 15 April 2025).

40 Waterborne TP, Waterborne Technology Leadership, 2026, 18 (smart integration of vessels, ports and waterways), 21–23 (Port Ecosystems vision, priorities and development trajectories).

Capability area	2035 early deployment	2040 scale-up	2050 full transformation
Safety, security and resilience[41]	Harmonised safety baselines for batteries, methanol and other low-flashpoint fuels, OPS and cyber-secure ship-shore interfaces; joint drills with ports and responders; common performance criteria for detection, suppression and ventilation; representative fire and release tests for cruise arrangements; reusable safety case modules for batteries, sustainable alternative fuels, OPS and fuel cells; maintainability of hotel and safety systems; shift from current redundancy approach to quantitative reliability analysis approach	Predictive safety ecosystems, dynamic risk models, polar-ready safety cases and certified AI-assisted decision support under human accountability, including AI-supported safety orchestration and robotic support for inspection and emergency response; validated integration of fire control, evacuation and decision support; digital safety twins verified through joint ship-port exercises	Continuous safety and cyber assurance; robust degraded modes; human-centred automation; high resilience to cyber incidents, extreme weather, port disruption and emergency events; continuous assurance linking physical systems and software updates; resilient European supply chains for critical maritime technologies
Digital and lifecycle systems[42]	Operational digital twins for energy, emissions, maintenance and (AI supported) voyage optimisation; yard level digital twins supporting design, production, system integration and commissioning; secure data exchange; digital commissioning for complex systems, including virtual commissioning, hardware-in-the-loop testing, simulation-based safety cases and hybrid validation environments supporting fuel-flexible architectures, batteries, fuel cells, hotel-load systems, automation and AI-enabled safety functions; predictive maintenance	Lifecycle data thread from design and production to operation and retrofit; automated compliance reporting; supervised automation for machinery, mooring, energy and selected navigation support; privacy-preserving passenger-flow and service models for accessibility, crowd management and evacuation readiness; automated onboard energy management	System-of-systems digital integration across vessel, port, energy and destination; machine-verifiable compliance and lifecycle optimisation embedded in operations; integration of propulsion, electrical systems, HVAC, hotel services, automation, safety systems, digital platforms and passenger-facing functions through interface management, configuration control, digital handover and lifecycle continuity; autonomous decision-support systems; integrated European digital maritime infrastructure

Table 4: Target Capabilities to 2035, 2040, and 2050

41 Waterborne TP, Waterborne Technology Leadership, 2026, 18 (zero-fatalities vision), 19 (intelligent safety, security and resilience), 20 (development trajectories). Polar-ready safety cases follow the IMO Polar Code: International Maritime Organization, International Code for Ships Operating in Polar Waters (Polar Code), Resolution MSC.385(94), in force 1 January 2017.

42 Waterborne TP, Waterborne Technology Leadership, 2026, 15–16 (digital twins, lifecycle intelligence, cyber-secure interoperable systems), 19 (fully connected, automated and data-driven systems), 20 (development trajectories).

Capability area	2035 early deployment	2040 scale-up	2050 full transformation
People and skills[43]	Training for sustainable alternative fuels, batteries, OPS, cyber security, emergency response, digital twins and human-centred alarms; remote support roles established; development of recognised training qualifications for seafarers and hotel-service personnel, including alignment with IMO processes where relevant.	Standardized competence frameworks and XR/simulation-based recurrent training; transparent human-AI teaming and new shore/ship roles.	Future-ready workforce with continuous learning, safer working environments, clear accountability and attractive hybrid careers combining marine, hospitality, digital and sustainability skills.

Table 4: Target Capabilities to 2035, 2040, and 2050

43 Waterborne TP, Waterborne Technology Leadership, 2026, 16 (workforce transformation and human-centred design), 19 (human-centred design and a future-ready workforce). Recognised training qualifications align with the IMO training framework: International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978, as amended.

4. TECHNOLOGY PATHWAYS

4. TECHNOLOGY PATHWAYS

The cruise roadmap is organised around five cruise-specific technology pathways. Each pathway is presented through an operational objective, horizon-specific priority actions and key research gaps. The indicative TRLs refer to cruise-relevant applications under real operating conditions. Deployment at scale also depends on the enablers set out in Section 5. Across the five pathways, cruise vessels should be treated as complex passenger, hospitality and destination-interface platforms. Passenger comfort, accessibility, service continuity, connectivity, crowd-management and emergency readiness should therefore be assessed alongside safety, environmental performance, operational efficiency and lifecycle value.

4.1 FUTURE PROPULSION AND ENERGY SYSTEMS ENABLING A ZERO-EMISSION CRUISE FLEET

Objective: Enable zero-emission cruise propulsion and hotel-power systems through fuel-flexible, hybrid-electric and digitally integrated energy architectures. The pathway prioritises lower total energy demand, zero-emission-at-berth capability, safe integration of sustainable alternative fuels, and physical and digital upgradeability. Hotel and thermal loads, including cabins, HVAC, galleys, thermal storage and waste-heat recovery, should be treated as active elements of the energy architecture, with solutions adapted to hot climate and winterised operations without compromising safety, stability, passenger space or service continuity.

Target capability:

Horizon	Priority actions
2035: early deployment	Deploy high-voltage OPS interfaces and onboard systems compatible with cruise hotel loads, including electric boilers, heat pumps, heat recovery, thermal storage and integrated HVAC control (TRL 7-9). Make hotel-load, cold-start emission reduction, genset optimisation, battery peak shaving, spinning-reserve reduction and zero-emission manoeuvring standard retrofit and newbuild priorities (TRL 6-9). Deploy methanol-capable engines and associated fuel-handling systems on newbuilds and selected retrofits; introduce hydrogen-based systems, including liquid organic hydrogen carrier (LOHC) solutions, in controlled use cases; use LNG pathways only with credible methane-slip reduction and lifecycle accounting (TRL 6-9). Pilot and demonstrate onboard carbon capture and methane oxidation solutions, including associated monitoring and port side handling interfaces, under representative cruise operating conditions (TRL 5-7). Accelerate verified wind-assisted and, where operationally suitable, wind-powered cruise concepts alongside hull, propulsor, rudder, coating, air-lubrication, and other operational ESDs under real cruise duty cycles (TRL 5-9).

Table 5: Future propulsion and energy systems enabling a zero-emission cruise fleet

Horizon	Priority actions
2040: scale-up and system integration	Scale integrated AC/DC electrical architectures, including DC distribution where appropriate, and advanced energy intelligence coordinating engines, batteries, fuel cells, shore power, heat recovery, HVAC and hotel services (TRL 6-8). Develop high-efficiency isolated and non-isolated power converters for fuel-cell, battery and alternative energy integration, validated under representative cruise duty cycles. Demonstrate interoperable ship-shore electrical interfaces that support safe connection across different ports through automatic compatibility checks, voltage and frequency adaptation, power quality management and coordinated protection. Demonstrate and certify multi-MW fuel-cell modules for hotel power and zero-emission operating windows in ports, fjords and sensitive areas, including their possible use as a regulated net-zero equivalent alternative where OPS is unavailable and lifecycle performance is verified (TRL 6-8). Mature safe methanol, ethanol, hydrogen-based and other sustainable-fuel systems for cruise applications, including detection, ventilation, aftertreatment and emergency-response interfaces (TRL 6-9). Scale up, certify and commercially deploy onboard carbon capture and methane oxidation solutions where verified well-to-wake GHG benefits are demonstrated (TRL 7-9). Develop design methods that explicitly balance machinery space, fuel volume, stability, safety, passenger capacity and passenger value (TRL 5-8). Advance hot climate and winterised energy systems. For advanced high-density energy sources, undertake reliability, safety and regulatory assessment and, where credible approval pathways emerge, representative scale or early ship demonstration (TRL 4-8).
2050: full transformation	Deploy modular, retrofit-ready multi-energy cruise platforms with adaptable machinery and tank arrangements, plug-and-play energy bays, software-defined energy management, cybersecurity update capability, digital configuration records and lifecycle data continuity (TRL 7-9). Embed lifecycle energy optimisation across propulsion, hotel, thermal and auxiliary loads, supported by renewable electricity and sustainable alternative fuel integration at itinerary level (TRL 8-9). Advance verified energy-harvesting and energy saving concepts, including photovoltaic surfaces, solar glazing, wind-assisted or wind-powered solutions, seawater heat exchange and waste-heat cascades where they deliver verified value (TRL 5-8). Assess bidirectional ship-port energy interfaces for island, emergency and grid-resilience use cases where safety, regulation and market rules allow (TRL 4-7). Deploy advanced high-density energy sources where feasibility, safety, regulation and public acceptance support cruise-specific deployment (TRL 7-9).

Table 5: Future propulsion and energy systems enabling a zero-emission cruise fleet

Key research gaps:

Research should focus on integrated hotel-plus-propulsion optimisation under real cruise duty cycles; thermal management, smart cabin control and cabin-level demand response; cold-start emission reduction; safe fuel, battery and fuel-cell integration for high-occupancy passenger vessels, including LOHC options; machinery-space and passenger-space trade-offs; physical and digital upgradeability; validated wind-assistance and other ESD savings; lifecycle assessment of carbon capture and methane-slip solutions; port-side handling interfaces; hot climate, Arctic and low-temperature impacts on sustainable alternative fuels, batteries, sensors and materials; bidirectional ship-port energy models; and feasibility, reliability, marinization, safety, regulation, certification and acceptance pathways for advanced high-density energy sources, including nuclear power.

4.2 INTELLIGENT SAFETY, SECURITY AND RESILIENCE AS FOUNDATIONAL ENABLERS

Objective: Ensure that decarbonisation and digitalisation strengthen passenger-ship safety across design, construction, system integration, commissioning, operation and retrofit. Cruise deployment must address the combined risks of high occupancy, sustainable alternative fuels, batteries, OPS, fuel cells, onboard carbon capture, automation, cyber-physical systems, polar operations, passenger mobility and remote or disrupted port conditions. Design phase safety integration, shipyard-level emergency preparedness, virtual pre-commissioning and structured commissioning risk management are prerequisites for safe deployment.

Target capability:

Horizon	Priority actions
2035: early deployment	Establish harmonised safety concepts and reusable evidence for methanol, batteries, fuel cells, OPS, charging, sustainable alternative-fuel bunkering, onboard thermal systems and retrofit integration in passenger service (TRL 6-9). For lithium-ion and emerging battery chemistries, define requirements for cell-level monitoring, battery-management systems, thermal-event detection and mitigation, cooling, compartmentation, state-of-charge balancing, degradation monitoring and safe isolation. Deploy detection, ventilation, isolation, smoke control, fire suppression and safe shutdown concepts for new energy systems (TRL 6-8). Use simulation, virtual pre-commissioning validation, yard and crew familiarisation (TRL 5-8). Introduce human-centred alarm management and cybersecurity-by-design across navigation, machinery, hotel systems, passenger-facing systems and ship-shore interfaces (TRL 6-9). For expedition cruise, validate polar and remote area resilience, emergency response procedures and extended rescue time assumptions under representative operating conditions (TRL 5-8).

Table 6: Intelligent safety, security and resilience as foundational enablers

Horizon	Priority actions
2040: scale-up and system integration	Deploy predictive safety ecosystems combining machinery data, passenger density, fire signals, weather, security feeds, cyber anomalies and route conditions into a single operational risk picture under human accountability (TRL 5-8). Certify AI-supported decision tools for emergency management, evacuation, crowd movement, safe degraded modes and polar operations through formal verification, validation and safety-case processes appropriate to the function and risk level. Maintain operator situational awareness, clear override capability and explicit human confirmation for critical safety decisions, with crew competence requirements covering system limitations, failure modes and degraded operation (TRL 5-8). Develop dynamic evacuation twins that can use privacy-protected information on passenger distribution, mobility constraints, route availability and smoke propagation (TRL 4-7). Demonstrate robotic and drone-based inspection and emergency support for enclosed spaces, toxic leak detection, firefighting support, medical supply delivery and damage assessment before human entry (TRL 4-7).
2050: full transformation	Achieve continuous safety and cyber assurance for complex cruise vessels, with self-diagnosing and gracefully degrading systems able to isolate, re-route and maintain critical functions during cyber, communication, positioning, weather, port-closure or infrastructure-disruption events (TRL 7-9). Deploy mature AI-supported safety orchestration and robotic emergency-support capabilities where certified and operationally justified (TRL 7-9). Integrate climate-resilient safe-harbour modes that prioritise power, HVAC, water production, food preservation, medical facilities, hotel operations, navigation and shelter functions during prolonged disruption (TRL 6-9).

Table 6: Intelligent safety, security and resilience as foundational enablers

Key research gaps:

Priorities include sustainable alternative-fuel emergency response for passenger vessels; battery thermal-event mitigation, degradation prediction and safe second-life qualification; harmonised representative scale validation methods for integrated detection, suppression, ventilation, smoke control, evacuation support and emergency decision systems; common performance criteria and reusable safety evidence for batteries, sustainable alternative fuels, fuel cells, onboard carbon capture storage or usage, high-voltage OPS and retrofit solutions; formal validation and certification of AI-enabled safety functions, including human oversight and operator competency; safe degraded-mode operation under cyber, communication or positioning disruption; predictive reliability data; dynamic evacuation and crowd-modelling methods; robotic emergency response; polar rescue-time assumptions; construction and commissioning risks; and human factors under high system complexity.

4.3 FULLY CONNECTED, AUTOMATED AND DATA-DRIVEN CRUISE SYSTEMS

Objective: Create cyber-secure, interoperable and lifecycle-oriented digital systems that improve efficiency, maintenance, safety, compliance, shipyard and equipment manufacturer feedback, passenger-flow management and port-call coordination from design and production through operation, retrofit and end-of-life. Open standards, semantic interoperability, data portability and clear ownership and access rights should allow operators to combine multi-supplier solutions without long-term dependence on proprietary platforms.

Target capability:

Horizon	Priority actions
2035: early deployment	Deploy operational digital twins for energy, emissions, hotel-load optimisation, voyage planning and condition-based maintenance (TRL 6-9), together with yard level digital twins supporting design, production, system integration and commissioning of complex cruise vessels (TRL 5-8). Establish secure ship-shore data exchange, remote diagnostics, software-update procedures and digital commissioning for first-of-a-kind systems (TRL 5-9). Apply cybersecurity-by-design aligned with applicable EU and maritime requirements, including authenticated interfaces, end-to-end protection of sensitive data, network segmentation between control, operational and passenger systems, zero-trust access principles, continuous threat monitoring and incident-response procedures. Establish standard vessel-to-port authentication and API requirements that enable secure integration with multiple port and service-provider systems without exposing safety-critical vessel controls. Develop emissions detection, including air emissions and underwater radiated-noise monitoring, to support active control of propulsion and energy systems (TRL 5-8). Introduce privacy-preserving passenger-flow analytics to support safety, accessibility, service planning and evacuation readiness without compromising passenger data protection (TRL 4-7).

Table7: Fully connected, automated and data-driven cruise systems

Horizon	Priority actions
2040: scale-up and system integration	Develop a standardised lifecycle data thread and digital handover linking design, production, suppliers, commissioning, operation, class, retrofit, maintenance and compliance, while maintaining validated as-designed, as-built, as-commissioned and as-maintained configurations (TRL 5-8). Use machine-readable data models and agreed semantic structures, based on recognised standards where appropriate, so that equipment specifications, performance characteristics, failure modes and maintenance history can be transferred with semantic integrity. Define data ownership, access rights, liability, semantic interoperability and secure information sharing across the lifecycle. Scale machine-verifiable reporting for emissions, sustainable alternative fuel use, safety barriers and maintenance records, reducing audit and port-call friction (TRL 6-9). Certify supervised automation for energy balancing, machinery optimisation, smart mooring, dynamic positioning, approach/berth support and selected protected-corridor navigation (TRL 4-8). Integrate privacy-preserving passenger-behaviour and service models with crowd management, accessibility, evacuation readiness and adaptive onboard services (TRL 4-7).
2050: full transformation	Operate system-of-systems digital integration with continuous assurance across vessels, ports, energy networks, suppliers, logistics and destinations (TRL 8-9). Use floating real-time digital twins to optimise hull, machinery, hotel systems, energy flows, emissions, waste, safety barriers and passenger operations (TRL 7-9). Embed machine-readable compliance interfaces, fuel passports and carbon ledgers into vessel operating systems where regulatory frameworks allow (TRL 6-9).

Table7: Fully connected, automated and data-driven cruise systems

Key research gaps:

Research should address data standards for multi-supplier cruise systems; data ownership, access rights, portability and avoidance of proprietary lock-in; cyber-secure interoperability and trusted maritime data spaces; digital-twin credibility and validation; resilient connectivity under jamming, spoofing or degraded communications; verification and validation of autonomy beyond navigation; integration of operational, safety and passenger-service data under privacy safeguards; automated compliance records; validated configuration management; and feedback loops from vessels to shipyards and equipment manufacturers.

4.4 HUMAN-CENTRED DESIGN AND A FUTURE-READY CRUISE WORKFORCE

Objective: Ensure that future cruise vessels remain operable, safe and attractive working environments as systems become more energy-complex, digital and automated. The pathway covers maritime crew, hotel personnel, shore-support teams, shipyard and maritime equipment engineers, port personnel, emergency responders and destination actors.

Target capability:

Horizon	Priority actions
2035: early deployment	Develop competence frameworks and training modules for sustainable alternative fuels, batteries, fuel cells, high-voltage OPS, cyber security, digital twins, emergency response, polar operations and human-centred alarms (TRL 5-8). Establish recognised training qualifications for seafarers and hotel-service personnel, in cooperation with IMO and other competent bodies where relevant. Deploy XR and simulator-based training for rare but high-impact events such as fuel leaks, battery thermal events, cyber incidents, evacuation, passenger crowding and severe weather (TRL 5-8). Expand remote expert support for diagnostics, maintenance, cyber response and voyage support (TRL 4-8).
2040: scale-up and system integration	Standardise human-automation teaming with clear allocation of responsibilities, transparent AI decision support and auditable human accountability (TRL 5-8). Embed mixed-reality recurrent drills into everyday ship operations for fuel, cyber, passenger-management, medical, dual-use emergency and severe-weather scenarios (TRL 5-8). Develop lifecycle design methods that enable retrofits, upgrades and circularity without excessive engineering intensity or loss of passenger value (TRL 5-8). Support shore-based expert centres able to assist maintenance, medical, cyber, hotel and emergency operations through secure immersive interfaces (TRL 5-8).
2050: full transformation	Shift workforce roles toward systems supervision, exception management, passenger care, safety leadership, sustainability accounting and data-informed decision-making (TRL 8-9). Deploy domain-specific AI copilots for bridge, engineering, hotel, medical, safety and maintenance roles where transparent, certified and subordinate to human accountability (TRL 6-9). Use wellbeing and fatigue monitoring, ergonomic design and workload analytics as safety and retention tools, subject to ethical governance and worker privacy safeguards (TRL 6-9). Make inclusive passenger-space design a core competitiveness feature, supporting age, disability, sensory, language and wellness needs (TRL 7-9).

Table 8: Human-centred design and a future-ready cruise workforce

Key research gaps:

Priority topics include human factors in highly automated cruise operations; human-AI resilience, trust, workload and alarm design; transparent and accountable AI copilots; training effectiveness for rare high-impact events; competence requirements for hotel personnel as part of the safety and energy system; ethical use of wellbeing and fatigue monitoring; standardised interfaces and procedures across shipyards and suppliers; lifecycle adaptability, retrofit and circularity methods for passenger vessels; and skills pathways for hybrid marine-hospitality-digital roles.

4.5 FORWARD-LOOKING REGULATION, STANDARDIZATION AND SYSTEM-LEVEL INTEGRATION

Objective: Enable rapid and safe deployment of zero-emission and digitally advanced cruise operations through harmonised regulation, standards, certification, reusable evidence, virtual validation, regulatory sandboxes and system-level planning across vessels, ports, energy systems, destinations and supply chains.

Target capability:

Horizon	Priority actions
2035: early deployment	Standardise interfaces and approval practices for cruise OPS, onboard thermal systems, batteries, low-flashpoint fuels, charging, sustainable alternative fuel documentation and emissions verification (TRL 6-9). Develop common methods for ESD performance verification, underwater-radiated-noise assessment and lifecycle GHG accounting (TRL 5-8). Establish configuration control, interface management and change-management methods for complex cruise systems, including first-of-a-kind integrations, software baselines and cybersecurity patching. Develop reliability analysis methods and evaluate regulatory requirements for advanced high-density energy sources, including nuclear power (TRL 2-6).
2040: scale-up and system integration	Develop mature certification pathways for fuel cells, sustainable alternative fuel systems, onboard carbon capture, advanced batteries, AI-enabled safety functions, supervised automation and cyber-secure ship-shore interfaces (TRL 5-8). Use reusable digital evidence, virtual commissioning, hardware-in-the-loop testing and hybrid validation to complement physical trials and reduce first-of-a-kind risk. Apply regulatory sandboxes and corridor demonstrations for technologies with high potential but incomplete approval pathways, including development of certification pathways, class rules, demonstration frameworks and regulatory preparations for advanced high-density energy sources, including nuclear power, where justified (TRL 3-8). Develop cruise-specific green corridor frameworks that include vessels, ports, destinations, airports, ground transport, fuel suppliers, grid operators, waste systems, safety authorities and tourism bodies (TRL 6-9). Establish lifecycle data-governance rules linking shipyards, suppliers, owners, class, flags, ports and retrofit providers (TRL 5-8).
2050: full transformation	Move toward harmonised system-of-systems standards across ship, port, energy, logistics, tourism and destination systems with continuous assurance (TRL 8-9). Develop machine-readable regulation, digital rulebooks, verifier interfaces, fuel passports and carbon ledgers that can be embedded into operational software where legally accepted (TRL 6-9). Define standards and market rules for bidirectional ship-port energy interfaces and emergency island-support use cases where safety, grid protection and liability are resolved (TRL 5-8). Extend regulation and procurement toward full lifecycle carbon, safety, circularity and destination-impact accountability (TRL 7-9).

Table 9: Forward looking regulation, standardization and system-level integration

Key research gaps:

Research should support harmonised ESD verification methods; reusable certification evidence, virtual validation and continuous compliance; certification of AI systems that evolve over time; approval pathways for fuel cells, hydrogen-based fuels, onboard carbon capture, robotics, supervised automation and advanced high-density energy sources, including nuclear power; standards for bidirectional ship-port energy interfaces; machine-readable compliance and fuel-passport systems; lifecycle carbon and circularity accounting; software baseline and cybersecurity update assurance; data governance for cross-stakeholder cruise corridors; and standardisation of user interfaces to reduce integration risk and improve safety.

5. ENABLERS AND DEPLOYMENT AT SCALE

5. ENABLERS AND DEPLOYMENT AT SCALE

The RD&I priorities in Section 4 will only translate into operational impact if deployment conditions are aligned across vessels, shipyards, equipment manufacturers, system integrators, classification societies, ports, grid and fuel providers, regulators, insurers, destinations and the workforce. Cruise deployment is particularly sensitive to itinerary structure: performance can be limited by one port without adequate shore power, one weak-grid island, one destination with access restrictions, one supply chain vulnerability or one unresolved safety approval. Funding and demonstration should therefore prioritise large-scale, cross-sector implementation, and every project should assess technology, industrial and ecosystem deployment readiness. In this context, industrial readiness includes the capacity of shipyards, equipment manufacturers, suppliers, system integrators and classification societies to design, integrate, validate, commission and certify complex cruise systems, in alignment with the Maritime Technology Roadmap.

5.1 ITINERARY-BASED DEPLOYMENT PACKAGES

Each cruise deployment project should be defined as an itinerary and destination cluster package rather than a single vessel or single port project. A deployment package should identify the vessel type, route structure, homeport and call port sequence, berth times, hotel load demand, shore-power needs, fuel strategy, grid constraints, passenger flows, airport and ground transport interfaces, baggage and provisioning logistics, waste interfaces, local mobility, emergency response arrangements, destination limits, data sharing rules, industrial readiness and financing models. Deployment planning should also include fleet segmentation and retrofit pathway that assesses technical feasibility, vessel age and remaining life, space and stability constraints, route relevance, downtime, costs and benefits relative to replacement, and priorities for phased uptake across strategic routes and ports. Each package should include a dedicated safety validation work package with integrated ship-port-city exercises covering fuel or battery fire, toxic release, shore power failure, cyber disruption, extreme weather, accessible evacuation and prolonged safe-harbour operation, with results fed back into design, approval and training. For urban homeports, airport-port connectivity, passenger flow management and port-city spatial planning, including terminal access, coach parking and expansion interfaces, should be treated as part of the cruise energy, congestion and destination impact system.

5.2 SHORE POWER, HOTEL-LOAD MANAGEMENT AND PORT ENERGY READINESS

High power shore connection is the priority near-term deployment condition for cruise, because cruise ships maintain substantial hotel and thermal loads at berth. Deployment requires reinforced grids, microgrid control systems, active harmonic filters, power-quality requirements, high voltage shore power systems, frequency conversion where needed, safe connection procedures, renewable power procurement, viable and transparent pricing models, energy storage and backup capacity where valuable, and compatible onboard electrical and thermal systems. Planning should assess regional renewable energy availability, grid constraints and reinforcement needs, and align cruise shore-power investments with national and regional grid decarbonisation strategies. Shore power projects should be combined with hotel load optimisation, HVAC efficiency, heat recovery, thermal storage, smart cabin control and integrated energy management. Deployment should also consider shore side thermal energy interfaces, including the direct transfer of heating or cooling through suitable thermal media where technically and economically justified. Longer term deployment projects may also assess bidirectional ship-port energy interfaces where they can support island grids, emergency resilience or port energy balancing without compromising safety, grid protection or commercial operation.

5.3 FUEL AVAILABILITY, BUNKERING AND EMERGENCY-RESPONSE READINESS

Cruise deployment requires reliable and certified fuel supply across repeated itineraries and destination clusters, not isolated bunkering opportunities. Planning should cover supplier reliability, fuel provenance, well-to-wake accounting, lifecycle emissions documentation, bunkering infrastructure mapping and exposure to supply chain vulnerabilities across homeports and repeated routes. Ports, suppliers and cruise lines should develop harmonised procedures for sustainable methanol, certified bio- and synthetic methane, hydrogen-based fuels including LOHC, and other sustainable alternative fuels, including emergency response, crew training and port authority approval. Where LNG remains in use, methane slip reduction and lifecycle accounting should be deployment conditions. Fuel-cell operation in port may qualify as a net-zero-equivalent alternative where OPS is unavailable, subject to applicable regulation and verified well-to-wake GHG performance. Onboard carbon capture requires compatible port side handling, storage, transport and accounting systems. Exploratory work on advanced high density energy sources, including nuclear or other options, should first address feasibility, reliability, safety, regulatory readiness, public acceptance and cruise specific integration; it may progress to representative-scale demonstration and deployment as credible approval pathways emerge.

5.4 FINANCING, INDUSTRIAL CAPACITY AND PROCUREMENT

Support for prototype development, integration, validation in the first series of ships and early industrial deployment of new classes of ships may include support for upfront investment and capital requirements. This should later be complemented by lifecycle performance mechanisms that reward operational benefits and facilitate market adoption. Future programmes should prioritise large-scale projects involving vessels, ports, grid operators, fuel suppliers, destinations, shipyards, equipment manufacturers, system integrators, classification societies, insurers and research organisations. Deployment packages should assess industrial capacity to design, integrate, qualify, validate, commission, certify, retrofit and support cruise-specific solutions, including alignment with construction schedules, supply-chain capacity, spare parts provision and lifecycle service. Dedicated financing mechanisms should support fleet-wide retrofit uptake where technically and economically justified. Insurance and risk-management frameworks should address underwriting, liability and coverage for novel propulsion, electrical, battery, cyber and automated systems, including passenger safety, property damage and business interruption, and should be developed with classification and regulatory processes. Priorities include shore power retrofits, fuel flexible newbuilds, retrofit ready machinery and tank layouts, digital production and commissioning tools, representative-scale safety validation, class approval, port grid reinforcement, renewable power procurement and training infrastructure. Lifecycle-oriented procurement should include verified energy performance, physical and digital upgradeability, digital handover and data continuity, maintainability, cybersecurity, residual value, circularity, sustainable sourcing, end-of-life planning and adaptability to future rules. Environmental incentive and tariff mechanisms, including port-dues differentiation for OPS use, sustainable alternative fuels or recognized environmental indices, can help align benefits and costs across actors.

5.5 STANDARDS, CERTIFICATION AND REGULATORY READINESS

The sector needs harmonised technical standards and accelerated certification pathways. Standards and approval pathways for high-voltage shore connections, battery systems, low flashpoint fuels, fuel cells, sustainable fuel documentation, onboard carbon capture, verified energy-saving devices, underwater radiated noise assessment, cyber resilience, AI-enabled decision support, robotic emergency support systems, machine readable compliance interfaces, bidirectional ship-port energy interfaces, selected automated functions and, where technically credible, advanced high-density energy sources including nuclear power. Battery frameworks should also address second-life qualification, traceability, safe reuse and recycling. Representative full-scale passenger-ship test environments, common validation protocols, reusable safety-case modules and a shared evidence base should link technical testing with approval, insurer participation, crew competence, accessible evacuation and port emergency planning. Digital evidence packages, virtual commissioning, hardware-in-the-loop and hybrid validation should support reuse across vessels and retrofits, while complementing required physical tests and trials. Regulatory sandboxes and corridor demonstrations should be used where approval pathways are not mature. Standards should also cover interface management, software baselines, cybersecurity updates, configuration control and lifecycle data exchange.

5.6 DATA GOVERNANCE, INTEROPERABILITY AND LIFECYCLE INTEGRATION

Digital deployment must avoid fragmented supplier systems that are difficult to maintain, secure, combine or upgrade. The roadmap requires trusted maritime data spaces, common and open digital standards, interoperable ship-port interfaces, secure connectivity, data quality rules, digital twin credibility methods, lifecycle asset identifiers, clear ownership and access rights, data portability, cybersecurity-by-design and privacy safeguards for passenger related information. Lifecycle data should maintain validated as-designed, as-built, as-commissioned and as-maintained configurations and link design, production, commissioning, operation, maintenance, class approval, retrofit and end-of-life planning. Secure information sharing among shipyards, equipment manufacturers, owners, ports, class and retrofit providers should allow operational lessons to improve future cruise designs while avoiding long-term dependence on proprietary platforms. Data and asset records should support component refurbishment, battery reuse and recycling, material recovery, disassembly and extended producer responsibility where applicable.

5.7 WORKFORCE AND CHANGE MANAGEMENT

Training and change management must be integrated into demonstration and deployment projects from the start. Crew, hotel personnel, shore teams, port staff, emergency responders, shipyard and equipment engineers, system integrators, energy providers and classification personnel require practical training in sustainable alternative fuels, batteries, fuel cells, high voltage systems, cyber incidents, digital twins, robotic emergency support, remote support, passenger management, polar operations and emergency response. Training should combine formal competence frameworks, recognised qualifications, IMO-aligned processes where relevant, simulation, XR, representative test facilities, joint ship-port-city drills and lessons learned from operational data. Stronger collaboration among operators, ports, shipyards, equipment manufacturers, technology and energy providers, insurers, classification societies and research organisations should align technology qualification, certification, supply-chain readiness, digital maintenance ecosystems and lifecycle support. Investment in digital skills and human-centred AI should support knowledge transfer and market uptake. Change management should address workload, alarm fatigue, ethical AI use, fatigue and wellbeing monitoring, accessibility, and the transition toward hybrid marine-hospitality-digital roles.

6. EXPECTED IMPACTS

6. EXPECTED IMPACTS

The implementation of this roadmap supports the transformation of European cruise into a zero-emission, digitally integrated, safe, resilient and passenger-centred sector. Because cruise operations depend on the interaction between vessels, ports, energy systems, destinations and passenger services, impacts should be assessed at vessel, fleet, port-call, itinerary and destination-cluster levels. Table 10 provides indicative expected impacts, which will be further refined at implementation.

Impact area	2035 early deployment	2040: Scale-up and integration	2050 full transformation
Environmental	14.5% reduction in GHG intensity relative to the applicable 2020 reference value; OPS availability or use at around 70% of relevant TEN-T cruise ports; 10–15 dB reduction in underwater radiated noise for applicable vessels and operating profiles; measurable reductions in local air pollutants through OPS, hotel-load optimisation, sustainable fuels and hybridisation.	31% reduction in GHG intensity relative to the applicable 2020 reference value; zero-emission-at-berth operation for around 90% of relevant cruise port calls; near-zero local emissions in environmentally sensitive areas; wider deployment of fuel-flexible vessels, sustainable alternative fuels, batteries and fuel cells.	80% reduction in GHG intensity relative to the applicable 2020 reference value[44], with residual emissions addressed through verified climate-neutral energy pathways; 100% zero-emission-at-berth operation at suitably equipped ports; near-zero- or zero-emission performance across representative itineraries; substantially improved circularity and lifecycle environmental performance. Monitoring should also cover lifecycle carbon, embedded carbon in materials and equipment, shipyard decarbonisation performance, and verified supply-chain emissions data.

Table 10: Expected Impacts

44 Regulation (EU) 2023/1805 (FuelEU Maritime), OJ L 234, 22.9.2023, art. 4 and Annex I (GHG-intensity reduction requirements of 31% by 2040 and 80% by 2050 against the 2020 reference value of 91.16 gCO_2e/MJ).

Impact area	2035 early deployment	2040: Scale-up and integration	2050 full transformation
Economic and industrial	Approximately 40–60 vessel retrofits, supporting a European retrofit market of around €2–3 billion; annual fuel-cost savings of approximately €200,000–€300,000 per retrofitted vessel, where operating conditions permit; around 2,000 new jobs in retrofit, equipment, digital and lifecycle services.	Approximately 120–150 vessel retrofits; a European cruise-equipment market of around €1.5–2 billion; approximately €500 million in shore-power and related energy services; stronger lifecycle-service, system-integration and retrofit activity.	Cumulative transition value of approximately €30–40 billion; annual European cruise-equipment export market of around €3–4 billion; retention of more than 95% of Europe's current position in relevant high-value cruise technologies and system-integration capabilities.
Technological	Certification and early commercial deployment of methanol engines and associated systems; batteries installed on more than 200 cruise vessels; more than 100 operational digital twins; improved digital commissioning, reusable safety evidence and lifecycle data management.	Fuel-cell systems operational in the 10–20 MW range; predictive-maintenance systems achieving around 90% accuracy for defined failure modes; remote or highly integrated operations at more than 15 cruise terminals; interoperable ship-port-destination systems increasingly deployed.	Highly automated or autonomous energy orchestration with human oversight and continuous safety assurance; integrated lifecycle digital systems across vessels, ports and destinations; approximately 95% recovery, reuse or recycling of applicable vessel materials.
Social and workforce	Approximately 5,000 personnel trained through at least five specialised training centres; improved passenger comfort, accessibility, connectivity, service continuity and safety; better destination acceptance through reduced local emissions and noise.	Approximately 15,000 personnel trained; improvements of around 35–40% in defined operator-competence measures through simulation and extended-reality training; stronger emergency readiness, passenger-flow management and service resilience.	More than 25,000 future-ready personnel supported by continuous learning and recognised competence frameworks; improved workforce diversity and attractiveness of maritime careers; stronger passenger and destination confidence in safe and sustainable cruise operations.

Table 10: Expected Impacts

The first impact is a substantial reduction in greenhouse-gas emissions, fuel consumption, local air pollutants and underwater radiated noise. OPS, hotel-load optimisation, HVAC efficiency, heat recovery, sustainable alternative fuels, hybridisation, batteries, fuel cells, energy-saving devices and digital voyage optimisation reduce impacts during port stays, manoeuvring, operation in sensitive areas and full itineraries. These benefits are particularly important for city-centre ports, islands, fjords, heritage destinations and protected areas, where environmental performance increasingly affects public health, destination acceptance and market access.

The roadmap also improves cruise competitiveness and passenger value. More efficient energy and hotel systems, reliable port calls, transparent environmental information, quieter operations, improved accessibility, dependable connectivity and service continuity strengthen the passenger experience. Operators benefit from improved compliance readiness, lower exposure to fuel-price volatility, greater itinerary reliability and better whole-life cost predictability.

A further impact is the integration of vessels with ports, grids, fuel suppliers, destinations and city systems. Itinerary- and destination-cluster planning improve the coordination of OPS, grid capacity, fuel supply, smart port infrastructure, passenger and baggage flows, airport and ground-transport connections, local mobility, waste handling, destination capacity and emergency response. Interoperable ship-port-destination systems and common standards support replication across European cruise corridors and destination clusters.

The roadmap strengthens safety, security and operational resilience across design, construction, commissioning, operation and retrofit. Harmonised safety cases, common performance criteria, reusable validation evidence, cyber-secure ship-shore interfaces, predictive safety systems, digital safety and evacuation twins, human-centred automation and joint ship-port-city exercises accelerate the safe deployment of sustainable alternative fuels, batteries, high-voltage shore connections, fuel cells, onboard carbon capture and automated systems. Expected benefits include lower incident severity and downtime, improved containment, evacuation and recovery performance, stronger cybersecurity and more predictable approval processes.

Industrial and economic impacts extend across European shipbuilding, repair, conversion, equipment manufacturing, systems integration, energy supply, classification, insurance, digital services and lifecycle support. Cruise provides a demanding deployment environment for fuel-flexible engines, hybrid-electric architectures, fuel cells, wind-assisted systems, high-voltage interfaces, digital twins, virtual commissioning, predictive maintenance, cyber resilience and lifecycle retrofits. Standardised and exportable solutions with strong international market potential will reinforce European technological leadership, supply-chain resilience and high-value employment.

The transition also generates significant workforce and organisational impacts. Crews, shore teams, shipyard personnel, equipment manufacturers, port actors and destination organisations require new competences in sustainable alternative fuels, batteries, fuel cells, high-voltage systems, automation, cybersecurity, digital twins, emergency response, passenger-flow management and sustainability accounting. Simulation, extended reality, remote expert support and harmonised competence frameworks improve preparedness, reduce cognitive load and support safer and more attractive working environments.

Monitoring should cover GHG and energy intensity, OPS availability and utilisation, local air pollutants, underwater radiated noise, retrofit uptake, fuel and battery certification, digital-twin deployment, approval duration, safety and cybersecurity performance, passenger experience, trained personnel, employment, export performance, circularity and investment mobilised.

WATERBORNE

WATERBORNE TP
De Meeussquare 35
1000 Brussels, Belgium

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