Technology Roadmap

Competitive, resilient and sustainable cruise sector

Contents

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[1]. 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 maritime transport, hospitality, destination access, logistics, energy use, passenter 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 public-service obligations differ. The Strategic Research Agenda treats cruise as a distinct waterborne segment alongside inland waterway, ferry, short sea, oceangoing and offshore shipping.[2]

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 segement in which European shipyards and equipment manufacturers retain a leading position. The EU Industrial Maritime Strategy notes that 97% of the world fleet of cruise ships has been built in Europe[3], making cruise production central to Europe's complex shipbuilding capabilities and essential to strategic autonomy. Second, cruise vessels are frequent users of European ports and waters, giving Europe a real deployment environment for shore power, clean fuels, ship-shore digital systems, passenger-ship safety innovation and lifecycle services. Third, cruise has high public visibility in city-centre, island, heritage, Arctic and protected destinations, where environmental performance increasingly determines market access[4]. A successful cruise transition can accelerate 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 direct gross domestic product, and supported 445,000 jobs in 2024.[5]** Its supply chain reaches shipyards, equipment manufacturers, ports, logistics providers and hospitality operators, and it generates recurring income for coastal, island and peripheral regions, including in the off-season.[6] 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.[7]

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[1] Definition adapted from UN Tourism (UNWTO), *International Recommendations for Tourism Statistics 2008* (New York: United Nations, 2010), para. 2.34; and Waterborne Technology Platform, *SRIA*, version 1.2 (Brussels: Waterborne TP, 2021), 47, which treats cruise as a distinct waterborne segment.

[2] Waterborne Technology Platform, *Strategic Research Agenda for the European Waterborne Sector* (Brussels: Waterborne TP, June 2025), 3.

[3] European Commission, *EU Industrial Maritime Strategy* (Brussels: European Commission, 2025), 3.

[4] Ibid, 29.

[5] Cruise Lines International Association, *Economic Impact Study: The Contribution of Cruise Tourism to the European Economy (2024 data)* (Brussels: CLIA Europe, 2026).

[6] CLIA, *Economic Impact Study* (2024 data), 2026.

[7] European Maritime Safety Agency, *The 2025 European Maritime Safety Report* (Lisbon: EMSA, 2025), 124.

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.[8] 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. 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 batteries for zero-emission arrival and departure. It 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.

1.4. Roadmap positioning within Waterborne Technology Leadership

This roadmap translates the Waterborne Technology Leadership document[9] into cruise-specific RD&I 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, 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 operation for complex cruise vessels.

[8] Waterborne TP, *SRIA*, 2021, 47.
[9] Waterborne Technology Platform, *Waterborne Technology Leadership* (Brussels: Waterborne TP, 2025).

Waterborne pillar	Cruise roadmap interpretation
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	Protection and renewal of Europe’s complex shipbuilding, retrofit, repair, equipment and lifecycle-service capabilities.

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**.[10] 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.**[11]

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 around 3%[12],** but its concentration in specific ports, destinations and seasons gives it high local visitility 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 approximatly 40 purpose-built expedition ships are now in operation. Expedition cruise capacity is projected to grow by about 150% between 2019 and 2029.[13] These trends are relevant for technology deployment because large conteporary 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[14].** This represents a projected **capacity increase of approximately 27%, supported by capital commitments of about USD 56.7 billion**.[15] The orderbook

[10] Cruise Lines International Association, *State of the Cruise Industry Report 2025* (Washington, DC: CLIA, 2025), 15.
[11] CLIA, *State of the Cruise Industry Report 2025*, fleet profile; and European Community Shipowners' Associations, *The Economic Value of European Shipping* (Brussels: ECSA, 2025), 13
[12] CLIA, *State of the Cruise Industry Report 2025*, 14; CLIA, *Economic Impact Study* (2024 data), 2026.
[13] CLIA, *State of the Cruise Industry Report 2025*, 14 (passenger volumes); Tourism Economics, *Contribution... 2024*, 11 (cruise = 2.4% of international tourist arrivals in 2024, up from 2.0% in 2019).
[14] EMSA, *2025 European Maritime Safety Report*, 124.
[15] CLIA, *State of the Cruise Industry Report 2025*, 64.

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[16], 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.[15]

The main challenge is the existing fleet. EU Member State-flagged passenger ships are older than the world average, and around 36% of passenger ships entering the EU between 2019 and 2023 were more than 25 years old.[17] This means that transformation cannot rely on newbuilds alone. Retrofit strategies, shore-power installation, hotel load optimisation, hybridisation, methane slip reduction where LNG is used, digital energy management and selective fuel-flexible conversions will be essential to reduce emissions and extend the useful life of existing assets.

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, digital service providers and ports. Demonstration in cruise can produce replicable European solutions for fuel-flexible engines, fuel cells, energy storage, onboard energy management, high-voltage shore interfaces, cyber-secure ship-shore data systems and human-centred automation, which then transfer to other ship types.[18]

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. 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,

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[16] Ibid, 41.
[17] EMSA, *2025 European Maritime Safety Report*, 85
[18] Ibid, 84–85.

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[19]. A strong cruise technology roadmap can help protect 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.

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.[20]
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.[21]
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.[22]
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.[23]
Air quality and ECAs	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.[24]

[19] European Commission, *EU Industrial Maritime Strategy*, 2025

[20] Regulation (EU) 2021/1119 (European Climate Law), *OJ* L 243, 9.7.2021, arts. 2 and 4, as amended in 2026 to set a binding 90% net reduction by 2040; see Council of the European Union, "2040 climate target: Council gives final green light," press release, 5 March 2026.

[21] 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.

[22] Regulation (EU) 2023/1804 (AFIR), *OJ* L 234, 22.9.2023, art. 9.

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

[24] 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.

Driver	Implication for cruise RD&I and deployment
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.[25]
Industrial competitiveness	Europe's cruise-build 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.[26]

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.[27]
Heterogeneous vessels and itineraries	Large contemporary vessels, luxury vessels and expedition ships have different space, range, port, safety and passenger-experience constraints.[28]
Patchy port and grid readiness	Shore-power capability, grid capacity, renewable procurement, berth allocation and connection procedures vary strongly across cruise ports.[29]
Fuel uncertainty	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	Alternative fuels, batteries, fuel cells, carbon capture, high-voltage OPS and autonomous functions require harmonized safety cases for passenger-carrying service.
Cyber and data risk	Digitalization expands the attack surface across navigation, machinery, hotel systems, passenger services, suppliers and port interfaces.
Capital intensity	Cruise newbuilds and major retrofits are high-cost, long-lived investments. Financing requires confidence in regulations, fuels, infrastructure and future market access.
Social license	Concentrated passenger arrivals, local pollution, underwater noise, congestion and waste management affect community acceptance and destination access.[30]

[25] Norwegian Maritime Authority, "Zero-Emission Requirements for the World Heritage Fjords Adopted" (Haugesund: NMA, 22 April 2025).
[26] European Commission, *EU Industrial Maritime Strategy* (Brussels: European Commission, 2025), 3; and Waterborne Technology Platform, *Waterborne Technology Leadership* (Brussels: Waterborne TP, 2025), 7, drawing on Mario Draghi, *The Future of European Competitiveness* (European Commission, 2024).
[27] Waterborne Technology Platform, *Strategic Research and Innovation Agenda for the Partnership on Zero-Emission Waterborne Transport*, version 1.2 (Brussels: Waterborne TP, 2021), 47.
[28] Cruise Lines International Association, *State of the Cruise Industry Report 2025* (Washington, DC: CLIA, 2025), 29, 32–33.
[29] European Commission, *EU Ports Strategy* (2025), citing ESPO, *EcoPorts Insights 2025* (62% of surveyed ports offer OPS at one or more berths; high-voltage supply scarce).
[30] destination measures at note 6 and the Venice/Cannes/Barcelona measures.

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 is absent, fuel supply is uncertified, or destination authorities have not accepted the operating model. Each roadmap action should therefore be tested against the following deployment questions:

- 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 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 to 2035, 2040, and 2050

Capability area	2035 early deployment	2040 scale-up	2050 full transformation
Energy and emissions[31]	Zero-emission-at-berth capability in principal European cruise ports; shore-power ready retrofits; 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.[32]	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 alternative-fuel supply; near-zero local emissions in sensitive areas; explicit design management of machinery-space, safety, passenger-capacity and passenger-value trade-offs.	Zero-emission cruise operations over full itineraries; lifecycle-optimized energy systems; Elimination of local pollutants, underwater noise, waste and water impacts; exploratory assessment of bidirectional ship-port energy interfaces and high-density energy sources where safety, regulation and public acceptance allow.

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

[32] 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, 22 April 2025).

Capability area	2035 early deployment	2040 scale-up	2050 full transformation
Ship-port-destination integration[33]	Deployment packages for homeports and frequent call ports covering OPS, passenger flows, waste, provisioning, local transport and emergency response.	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.
Safety, security and resilience[34]	Harmonised safety baselines for batteries, methanol and other low-flashpoint fuels, OPS and cyber-secure ship-shore interfaces; joint drills with ports and responders.	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.	Continuous safety and cyber assurance; robust degraded modes; human-centred automation; high resilience to cyber incidents, extreme weather, port disruption and emergency events.
Digital and lifecycle systems[35]	Operational digital twins for energy, emissions, maintenance and voyage optimisation; secure data exchange; digital commissioning for complex systems.	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.	System-of-systems digital integration across vessel, port, energy and destination; machine-verifiable compliance and lifecycle optimisation embedded in operations.

[33] Waterborne TP, *Waterborne Technology Leadership*, 2026, 18 (smart integration of vessels, ports and waterways), 21–23 (Port Ecosystems vision, priorities and development trajectories).
[34] 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.
[35] 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[36]	Training for 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.

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.

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 reduction of total energy demand, zero-emission-at-berth capability, efficient hotel and thermal systems, safe integration of sustainable alternative fuels, verified energy-saving devices and lifecycle adaptability without compromising safety, stability, passenger space or passenger experience.

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 in controlled use cases; use LNG pathways only with credible methane-slip reduction and lifecycle accounting (TRL 6-9). Verify hull, propulsor, rudder, coating, air-lubrication, wind-assist and operational ESDs under real cruise duty cycles (TRL 5-9).
2040: scale-up and system integration	Scale integrated AC/DC electrical architectures and advanced energy intelligence coordinating engines, batteries, fuel cells, shore power, heat recovery, HVAC and hotel services (TRL 6-8). Demonstrate and certify multi-MW fuel-cell modules for hotel power and zero-emission operating windows in ports, fjords and sensitive areas (TRL 6-8). Mature safe methanol, ethanol, hydrogen-based and other sustainable-fuel systems for

[36] 7. 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.

	cruise applications, including detection, ventilation, aftertreatment and emergency-response interfaces (TRL 6-9). Demonstrate onboard carbon capture, methane oxidation and port-side handling where lifecycle value is proven (TRL 5-8). Develop design methods that explicitly balance machinery space, fuel volume, stability, safety, passenger capacity and passenger value (TRL 5-8). Advance winterised energy systems for Arctic and high-latitude cruise operations (TRL 5-8).
2050: full transformation	Deploy modular, retrofit-ready multi-energy cruise platforms with plug-and-play energy bays for future energy converters, batteries and fuel systems where technically and commercially justified (TRL 7-9). Embed lifecycle energy optimisation across propulsion, hotel, thermal and auxiliary loads, supported by renewable electricity and sustainable-fuel integration at itinerary level (TRL 8-9). Develop energy-collecting and heat-harvesting vessel concepts, including photovoltaic surfaces, solar glazing, 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). Maintain exploratory RD&I on advanced high-density energy sources, including nuclear or other options, limited to feasibility, marinisation, safety, regulatory readiness, public acceptance and cruise-specific integration constraints (TRL 2-5).

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; machinery-space and passenger-space trade-offs; validated ESD savings; lifecycle assessment of carbon capture and methane-slip solutions; port-side handling interfaces; Arctic and low-temperature impacts on fuels, batteries, sensors and materials; bidirectional ship-port energy models; and exploratory marinisation, safety and acceptance questions for advanced high-density energy sources.

4.2 Intelligent safety, security and resilience as foundational enablers

Objective: Ensure that decarbonisation and digitalisation strengthen, rather than complicate, passenger-ship safety. 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.

Target capability:

Horizon	Priority actions
2035: early deployment	Establish harmonised safety concepts for methanol, batteries, fuel cells, OPS, charging, sustainable alternative-fuel bunkering and onboard thermal systems in passenger service (TRL 6-9). Deploy detection, ventilation, isolation, fire suppression and safe shutdown concepts for new energy systems (TRL 6-8). Use simulation environments for full-vessel integration, commissioning validation and crew familiarisation (TRL 5-8). Introduce human-centred alarm management to reduce alarm fatigue and improve bridge and engine-room decision-making (TRL 5-8). Implement cybersecurity-by-design for navigation, machinery, hotel systems, passenger-facing systems and ship-shore interfaces (TRL 6-9).
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 (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).

Key research gaps: Priorities include sustainable alternative-fuel emergency response for passenger vessels; battery thermal-event mitigation; safety assessment of fuel cells, carbon capture and high-voltage OPS; validation and certification of AI-enabled safety functions; safe degraded-mode operation under cyber, communication or positioning disruption; predictive reliability data for components and subsystems; dynamic evacuation and crowd-modelling methods; robotic emergency response; polar rescue-time assumptions; 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 cruise 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.

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). Establish secure ship-shore data exchange, remote diagnostics, software-update procedures and digital commissioning for first-of-a-kind systems (TRL 5-9). Develop emissions and pollutant 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).
2040: scale-up and system integration	Develop a lifecycle data thread linking design, production, suppliers, commissioning, operation, class, retrofit, maintenance and compliance (TRL 5-8). Scale machine-verifiable reporting for emissions, 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).

Key research gaps: Research should address data standards for multi-supplier cruise systems; cyber-secure interoperability; 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; 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).

Key research gaps: Priority topics include human factors in highly automated cruise operations; 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, low-pollution, low-noise and digitally advanced cruise operations through harmonised regulation, standards, certification, 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, other 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 (TRL 5-8).
2040: scale-up and system integration	Develop mature certification pathways for fuel cells, alternative fuel systems, onboard carbon capture, advanced batteries, AI-enabled safety functions, supervised automation and cyber-secure ship-shore interfaces (TRL 5-8). Use regulatory sandboxes and corridor demonstrations for technologies with high potential but incomplete approval pathways (TRL 5-8). 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).

Key research gaps: Research should support harmonised ESD verification methods; certification of AI systems that evolve over time; approval pathways for fuel cells, hydrogen-based fuels, onboard carbon capture, robotics and supervised automation; standards for bidirectional ship-port energy interfaces; machine-readable compliance and fuel-passport systems; lifecycle carbon and circularity accounting; 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

The RD&I priorities in Section 4 will only translate into operational impact if deployment conditions are aligned across vessels, shipyards, ports, energy providers, regulators, destinations and the workforce. Cruise deployment is particularly sensitive to itinerary structure: the environmental performance of a voyage can be limited by one port without adequate shore power, one weak-grid island, one destination with access restrictions, or one unresolved safety approval. The following enablers should therefore be treated as part of every demonstration and deployment project.

5.1 Itinerary-based deployment packages

Each cruise deployment project should be defined as an itinerary 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 and financing model. For homeport itineraries, airport-port connectivity and passenger flow management 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, high voltage shore power systems, frequency conversion where needed, safe connection procedures, renewable power procurement, pricing models, energy storage where valuable, and compatible onboard electrical and thermal systems. Shore power projects should be combined with hotel load optimisation, HVAC efficiency, heat recovery, thermal storage, smart cabin control and integrated energy management. 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, not isolated bunkering opportunities. Ports, suppliers and cruise lines should develop harmonised procedures for sustainable methanol, certified bio- and synthetic methane, hydrogen-based fuels and other sustainable fuels, including lifecycle emissions documentation, emergency response, crew training and port authority approval. Where LNG remains in use, methane slip reduction and lifecycle accounting should be deployment conditions. Onboard carbon capture, if deployed, requires compatible port side handling, storage, transport and accounting systems. Exploratory work on advanced high density energy sources, including nuclear or other options, should remain limited to feasibility, safety, regulatory readiness, public acceptance and cruise specific integration studies until approval pathways become credible.

5.4 Financing, industrial capacity and procurement

Deployment requires funding instruments that reduce first-of-a-kind risk and reward lifecycle performance rather than only capital expenditure. Priorities include shore power retrofits, fuel flexible newbuilds, retrofit ready machinery and tank layouts, digital production tools, safety validation, class approval, port grid reinforcement, renewable power procurement and training infrastructure. Procurement should include verified energy performance guarantees, maintainability requirements, data sharing obligations, cybersecurity requirements and upgrade pathways. Public-private financing should recognise that zero-emission cruise produces benefits across vessels, ports, destinations, local air quality, industrial capability and tourism acceptance, while costs are distributed across different actors.

5.5 Standards, certification and regulatory readiness

The sector needs harmonised 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 and selected automated functions. Regulatory sandboxes and corridor demonstrations should be used where technologies are promising but approval pathways are not mature. Standards should also cover interface management, configuration control and lifecycle data exchange, because cruise vessels integrate large numbers of suppliers and safety critical systems.

5.6 Data governance, interoperability and lifecycle integration

Digital deployment must avoid fragmented supplier systems that are difficult to maintain, secure or upgrade. The roadmap requires interoperable data architectures, secure ship-shore connectivity, data quality rules, digital twin credibility methods, lifecycle asset identifiers, clear ownership of operational data, cybersecurity controls and privacy safeguards for passenger related information. Lifecycle data should link design, production, commissioning, operation, maintenance, class approval and retrofit planning, allowing operational lessons to improve future cruise designs and reducing first-of-a-kind integration risk.

5.7 Workforce and change management

Training must be integrated into demonstration and deployment projects from the start. Crew, hotel personnel, shore teams, port staff, emergency responders, shipyard and equipment engineers 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 for seafarers and hotel service personnel, IMO-aligned processes where relevant, simulation, XR, joint drills and lessons learned from operational data. Human centred change management should also address workload, alarm fatigue, ethical AI use, fatigue and wellbeing monitoring, and the transition toward hybrid marine-hospitality-digital roles.

6. Expected Impacts

The expected impacts of the cruise roadmap should be assessed at vessel, fleet, port-call, itinerary and destination-cluster level. This is essential because cruise impacts are not determined only by average fleet performance. They depend on where the vessel calls, how long it remains at berth, whether OPS is used, how passengers move through the destination, whether the port grid is clean and reliable, and whether local environmental and social limits are respected.

6.1 Climate and environmental impacts

The roadmap will deliver measurable reductions in greenhouse gas intensity, fuel consumption, local air pollutants and underwater radiated noise from cruise operations. The most immediate impact will come from zero emission at berth operation in principal cruise ports, combined with hotel load optimisation, HVAC efficiency, heat recovery and shore power compatible thermal systems.

For city centre ports, islands, fjords, heritage destinations and protected areas, the local impact will be particularly important. Reduced NOx, SOx, particulate matter and noise will directly improve destination acceptance and public health. Over time, fuel flexible newbuilds, verified sustainable fuels, batteries, fuel cells, energy saving devices, voyage optimisation and lifecycle digital twins will reduce emissions across the full itinerary, not only at berth. By 2050, cruise will demonstrate zero-emission operation across representative voyage profiles.

6.2 Cruise competitiveness, passenger value and social acceptance

The roadmap will strengthen cruise competitiveness by making environmental performance part of the cruise value proposition. Silent arrival and departure, visible shore power use, transparent emissions information, reliable port calls, energy efficient hospitality systems and destination compatible itineraries will improve passenger perception while reducing opposition in sensitive destinations.

For operators, the impacts will include lower exposure to fuel price volatility, improved access to ports with environmental conditions, stronger compliance readiness and better itinerary reliability. For Europe, the roadmap will support the retention of high value cruise design, construction, integration, retrofit and lifecycle service capabilities.

6.3 Itinerary, port-call and destination impacts

The roadmap will improve the integration of cruise vessels with ports and destinations. Itinerary level planning will align shore power availability, grid capacity, fuel strategy, passenger and baggage flows, airport and ground transport interfaces, local mobility, waste handling, destination capacity, environmental limits and emergency response arrangements.

Expected impacts will include more reliable and environmentally compatible cruise itineraries, reduced pressure on congested city centre and heritage destinations, better management of passenger peaks, improved coordination with local transport and tourism services, and stronger acceptance of cruise activity in coastal, island, polar and environmentally sensitive regions. Cruise corridors and destination clusters will become practical deployment environments for zero emission at berth operation.

6.4 Safety, security and resilience impacts

The roadmap will strengthen cruise safety, security and operational resilience as vessels become more energy complex, digital and automated. Harmonised safety cases, cyber secure ship shore interfaces, predictive safety systems, AI-supported safety, robotic and drone based emergency support, improved emergency preparedness, human centred automation and enhanced crew training will reduce operational risk and improve response capability.

Expected impacts will include safer deployment of sustainable alternative fuels, batteries, high voltage shore connections, fuel cells, onboard carbon capture and automated systems; improved resilience under cyber incidents, port disruption, extreme weather, polar conditions, passenger health events or destination access constraints; and stronger coordination between cruise operators, shipyards, ports, classification societies, flag states, emergency responders and destination authorities.

6.5 Industrial, innovation and lifecycle impacts

The roadmap will reinforce Europe's leadership in complex cruise shipbuilding and related maritime technologies. Cruise is one of the most demanding environments for integrating propulsion, hotel systems, safety systems, digital platforms, passenger services and environmental technologies. Successful deployment will create exportable European solutions for fuel flexible engines, hybrid electric architectures, fuel cells, high voltage interfaces, digital twins, predictive maintenance, safety assurance, cyber resilience and lifecycle retrofits.

The roadmap will also strengthen repair, conversion, equipment manufacturing, class services, training, digital lifecycle services and circularity. The transition will therefore support both climate objectives and European maritime industrial competitiveness.

6.6 Workforce and organisational impacts

The roadmap will support the development of a future ready cruise workforce covering maritime operations, hotel operations, shore support, shipyards, equipment manufacturers, port interfaces and destination coordination. Expected impacts will include improved competence in sustainable alternative fuels, high voltage systems, batteries, fuel cells, automation, cyber security, digital twins, emergency response, polar operations, passenger flow management and sustainability accounting.

Recognised training qualifications, simulation, XR and remote expert support will improve preparedness for rare but high impact events. Human centred systems, transparent AI copilots and ethical workload and wellbeing monitoring will reduce cognitive load, improve decision making, preserve clear accountability and contribute to safer, more attractive and more resilient working environments.