Technology Roadmap

Competitive, resilient and sustainable blue economy

Contents

1. Description of the Sector

1.1 Definition and scope

The Blue Economy broardly comprises economic activities that depend on, operate in, or supply goods and services to oceans, seas, coasts and inland waters. The European Commission delineates it through marine-based activities undertaken in the ocean, sea and coastal areas, and marine-related activities that supply or process their outputs.[1] Its established sectors include marine living and non-living resources, marine renewable energy, port activities, shipbuilding and repair, maritime transport, and coastal tourism.[2]

Within the Waterborne Technology Platform, this broad economy-wide definition is implemented through nine complementary Technology Roadmaps. Cruise, Ferries, Inland Waterway Transport, Oceangoing, and Short Sea Shipping address the pricipal transport vessel segments. The Port Ecosystem Roadmap addresses port systems and interfaces. The Offshore Vessels Roadmap addresses specialised offshore installation, construction, service and support vessels. The Maritime Technology Roadmap addresses the common industrial and technological base, including shipbuilding, equipment, materials, propulsion and generic digital technologies. For the purpose of the present roadmap, the Blue Economy covers the specialised waterborne, floating, and underwater technologies, assets and operational systems that enable the sustainable production, observation, use, restoration and protection of marine, coastal, inland and aquatic resources and environments, beyond the primary transport funtions addressed in the other roadmaps. Its core scope comprises fisheries and aquaculture systems and craft, ocean observation and environmenal monitoring, underwater autonomy, sensing, communication and intervention, multi-use infrastructure, marine biotechnology-enabling systems, sustainable recreational boating and specialised tourism craft, coastal and aquatic resilience, and the monitoring, maintenance and protection of underwater and other blue economy assets. Inland waters are integral to this scope. Rivers, canals, lakes and lagoons, together with their navigation channels, locks, weirs, dams, bridges, dikes and digital systems, form part of the same waterborne infrastructure base as coastal and offshore assets, both on surface and underwater. Freshwater and seawater constitute a single hydrological system, and water security is therefore a precondition for a resilient Blue Economy.

Elements addressed in other roadmaps are refenced where necessary, to describe the complete blue economy system, but their technology pathways are not elaborated here.[3]

1.2 Strategic role in the European waterborne ecosystem

The Blue Economy is a structural component of the European economy and a growing instrument of its strategic autonomy. In the Waterborne context, its strategic role lies in enabling economic, scientific, environmental and security-related activities on, beneath and in close interaction with water. The European Ocean Pact provides the overarching policy framework, aligning ocean, coastal and inland-water policy around a competitive and sustainable Blue Economy, maritime security, healthy ecosystems, and marine knowledge and investment.[4] Blue economy assets deliver renewable energy, freshwater, food, and ecosystem services, support ocean observation, marine

[1]European Commission and Joint Research Centre, The EU Blue Economy Report 2025 (Luxembourg: Publications Office of the European Union, 2025), 9.
[2]European Commission and Joint Research Centre, EU Blue Economy Report 2025, 10.
[3] Inland Navigation Europe (INE), Consultation Input to the Blue Economy Technology Roadmap (Brussels: INE, 2026), section on the definition and scope of the Blue Economy. The three-layer delineation — infrastructure, technology and equipment, and fleet — is proposed by INE. On the delineation of the blue economy as a segment of the waterborne sector, see Waterborne Technology Platform, Waterborne Technology Leadership (Brussels: Waterborne Technology Platform, 2026), 24.
[4]European Commission, The European Ocean Pact, COM(2025) 281 final (Brussels, 5 June 2025), 2.

research and climate adaptation, and contribute to the monitoring and protection of critical infrastructure.

The sector follows an ecosystem logic. Specialised vessels and boats, autonomous surface and underwater systems, floating and fixed infrastructure, mission equipment, digital platforms and environmental data services operate as connected components rather than as standalone assets. Their performance depends on shared energy, data, communication, logistics and regulatory interfaces. Ports provide essential logistics, energy, maintenance and data nodes and are treated in detail in the ports roadmap. Offshore installation and service fleets enable many Blue Economy activities and are treated in the Offshore Roadmap. Common propulsion, materials, shipbuilding, automation and equipment technologies are developed in the Marine Technology Roadmap. The present Roadmap concentrates on the Blue Economy applications, mission requirements and system integration that connect these capabilities.

1.3 Asset Classification of the Blue Economy

The technology-intensive base of this Roadmap is organised into **four asset classes:** vessels and boats; underwater systems; equipment and payloads; and infrastructure. The classification is functional and application oriented. It identifies the assets required for Blue Economy missions while distinguishing between core scope and interfaces with the other Waterborne Roadmaps. Assets are included here where their defining requirements arise from fisheries and aquaculture, marine science and observation, environmental stewardship, multi-use infrastructure, recreation and specialised tourism, aquatic resilience, or underwater inspection, intervention and protection. Transport vessels, port systems, offshore construction, service fleets and common marine technologies are identified for completeness but their technology development is elaborated in the corresponding roadmaps.

Vessels and boats:

- **Fisheries and aquaculture craft** include the fishing fleet, the most numerous vessel type flagged in Member States, at **2,540 vessels**, for which coastal, pot-fishing and hydrogen-powered zero-emission concepts have been developed under Union-funded work,[5] together with aquaculture service, well-boat, feed-supply and harvest craft.[6]
- **Offshore service and support vessels** comprise dredgers and tugs, the second most numerous type at **2,007 vessels**,[7] alongside cable-laying, stone-dumping, heavy-lift installation and shallow-water support craft.
- **Recreational and tourism craft** constitute a distinct industrial base of over **6 million boats** served by more than 10,000 marinas, in which Union manufacturing and refit capacity is globally competitive.[8]
- **Research, monitoring and specialised craft** cover survey, aids-to-navigation, environmental-monitoring and inland-waterway service vessels.

Underwater systems

- **Mobile platforms** range from remotely operated and autonomous vehicles, including hybrid architectures that operate either tethered from a support vessel or fully autonomously, to gliders, seabed crawlers and large-displacement autonomous vehicles.

[5] European Commission: Directorate-General for Maritime Affairs and Fisheries, Study on the Fishing Fleet Capacity and the Energy Transition (Luxembourg: Publications Office of the European Union, 2025), 356, 359–360.
[6] Aquaculture service-vessel and installation categories are indicative and drawn from sector practice; no Union-level source disaggregates them. [Source TBC].
[7] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 43.
[8] European Boating Industry, Manifesto for a Sustainable Boating Industry (Brussels: European Boating Industry, 2026), 2.

- **Fixed elements** comprise acoustic and fibre-optic early-warning sensor barriers, underwater communication and positioning networks, and seabed docking and charging stations.
- **Intervention tooling** covers seabed preparation and cable-protection equipment — jetting and mechanical trenchers, ploughs and jet sleds, boulder-clearance grapples and mattress-installation frames — together with survey, inspection, maintenance and repair, and decommissioning systems.
- **Underwater robotics and ocean observation** are identified in the European Ocean Pact as priority technology fields, and the domain is inherently dual-use, serving both commercial offshore operations and the protection of critical subsea infrastructure.[9]
- **Equipment and payloads are the value-bearing components of most blue-economy assets**, and are frequently modern even where the hull or structure carrying them is not. They comprise interchangeable mission modules for inspection, sampling, intervention and logistics; sensing payloads including multibeam and side-scan sonar, hyperspectral, acoustic and distributed sensing; and energy and propulsion systems including fuel cells, high-density batteries, hybrid direct-current micro-grids, alternative-fuel systems and shore-power interfaces. Modularity at payload level is the principal means by which a single platform serves multiple missions over its lifetime.[10]

Infrastructure

- **Offshore infrastructure** comprises fixed and floating energy installations, multi-use platforms and hubs, and the submarine cable and pipeline network. [11]
- **Coastal infrastructure** comprises seaports and their onshore power supply and alternative-fuel bunkering facilities, marinas, flood and coastal defences, and nature-based and eco-engineered structures. [12]
- **Inland-waterway infrastructure** comprises the class I–VII navigable network with its locks, weirs, dams, bridges, dikes and navigation channels. [13]
- **The digital layer** comprises digital twins, river information services, interoperable data platforms and persistent sensor networks, and binds the other three categories into a single operable system. At least 44 ports across 15 Member States have implemented onshore power supply, with 352 berths equipped, which illustrates both the direction of travel and the scale of the remaining build-out.[14]

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[9]European Commission, European Ocean Pact, 10.
[10] Inland Navigation Europe (INE), *Consultation Input to the Blue Economy Technology Roadmap* (Brussels: INE, 2026), section on the definition and scope of the Blue Economy. The three-layer delineation — infrastructure, technology and equipment, and fleet — is proposed by INE. On equipment as the value-bearing component of waterborne assets, see also Waterborne Technology Platform, *Strategic Research Agenda (SRA)*, v5.0, 10.
[11] Inland Navigation Europe (INE), *Consultation Input to the Blue Economy Technology Roadmap* (Brussels: INE, 2026), section on infrastructure scope. On offshore energy installations and the submarine cable and pipeline network, see European Commission, *European Ocean Pact*, 2, 10.
[12] Inland Navigation Europe (INE), *Consultation Input to the Blue Economy Technology Roadmap*, section on infrastructure scope. On seaport onshore power supply and alternative-fuel bunkering obligations, see Regulation (EU) 2023/1804 (AFIR), OJ L 234, 22.9.2023, Art. 9–11.
[13] Inland Navigation Europe (INE), *Consultation Input to the Blue Economy Technology Roadmap*, section on inland waterway infrastructure. The class I–VII classification of navigable inland waterways, and the associated locks, weirs, dams, bridges, dikes and navigation channels, are set out therein
[14]European Commission and Joint Research Centre, EU Blue Economy Report 2025, 41–42.

Asset class	Category	Principal assets
A. Vessels and boats	Fisheries and aquaculture	Fishing vessels (2,540 EU-flagged); coastal, pot-fishing and hydrogen/methanol/electric zero-emission concepts; aquaculture service, well-boat, feed-supply and harvest craft
	Offshore service and support	Dredgers and tugs (2,007 EU-flagged); cable-laying, stone-dumping, heavy-lift installation and ultra-shallow support vessels
	Recreational and tourism	Over 6 million recreational boats; charter and passenger craft; served by over 10,000 marinas
	Research and specialised	Survey, environmental-monitoring, aids-to-navigation and inland-waterway service craft
B. Underwater systems	Mobile platforms	ROVs, AUVs and hybrid ROV/AUV vehicles; gliders; seabed crawlers; large-displacement autonomous vehicles
	Sensing and communication	Acoustic and fibre-optic early-warning barriers; underwater communication, positioning and monitoring networks; command-and-control and AI analysis layers
	Intervention and tooling	Jetting and mechanical trenchers; ploughs and jet sleds; boulder-clearance grapples; mattress-installation frames; IMR and decommissioning systems
	Support and residency	Seabed docking and charging stations; launch-and-recovery systems; resident-vehicle garages
C. Equipment and payloads	Mission modules	Interchangeable inspection, sampling, intervention and logistics modules
	Sensing payloads	Multibeam and side-scan sonar; hyperspectral, acoustic and distributed sensing; cameras and telemetry
	Energy and propulsion	Fuel cells; high-density batteries; hybrid DC micro-grids; alternative-fuel systems; shore-power interfaces
	Aquaculture equipment	Cages and net systems; feed and harvest systems; recirculating systems [source TBC]
D. Infrastructure	Offshore	Fixed and floating energy installations; multi-use platforms and hubs; submarine cables and pipelines
	Coastal	Seaports with OPS and alternative-fuel bunkering; marinas; flood and coastal defences; nature-based structures
	Inland waterway	Class I–VII navigable network; locks, weirs, dams, bridges, dikes and channels
	Digital layer	Digital twins; river information services; interoperable data platforms; persistent sensor networks

Table 1:Asset Classification of the Blue Economy

Vessel counts: EU Blue Economy Report 2025, p. 43 (EU-flagged fleet, Q2 2024). Recreational figures: European Boating Industry Manifesto, p. 2. Aquaculture equipment and service-craft categories are indicative pending a Union-level source.

1.4 Operational profile

Blue economy operations differ from conventional maritime transport in their diversity of mission and operating environment. Activities range from aquaculture, marine science and environmental monitoring to offshore energy servicing, dredging, carbon capture and storage logistics, tourism, and infrastructure inspection and protection, on seas and inland waters alike.[15] Missions are frequently short-duration, repetitive, hazardous or remote, and they are performed across the full range of

[15] Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0 (Brussels: Waterborne Technology Platform, June 2025), 11. The blue economy sectors enabled by the waterborne sector are identified therein as fisheries, aquaculture, renewable offshore energy and critical infrastructure at sea, in rivers and underwater.

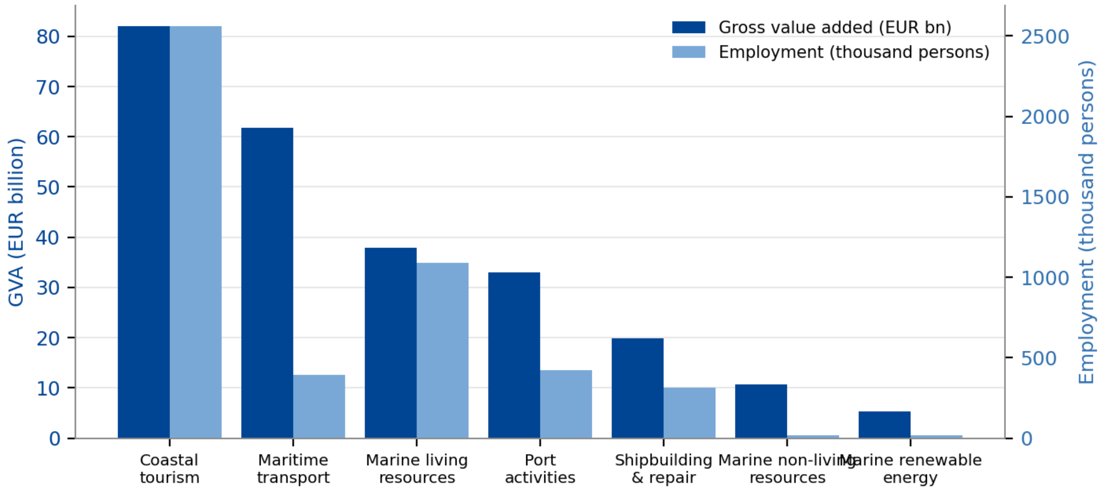
European conditions, from ice-affected northern waters to the enclosed Mediterranean and the class I–VII inland waterway network.[16]

These characteristics create strong potential for modular and multi-mission vessels, remote and autonomous operation, and digitally integrated infrastructure. They also expose the sector to specific constraints: fragmented governance across the many authorities responsible for waterborne assets; low awareness of the multiplier value of multi-purpose infrastructure;[17] and the dependence of most activities on specialised vessels, fixed infrastructure and subsea systems that are today largely single-purpose, fossil-fuelled and weakly interconnected.[18]

1.5 Sector baseline and market characteristics

The established sectors of the EU Blue Economy generated EUR 250.7 billion in gross value added (GVA) and EUR 890.6 billion in turnover in 2022, and directly employed 4.82 million people.[19] Direct GVA represented 1.7 % of the EU-27 economy, a 33 % increase on the EUR 188 billion recorded in 2021 and 23 % above the 2019 pre-pandemic level of EUR 203 billion.[20] Preliminary estimates place 2023 GVA at EUR 263 billion and employment at 4.89 million; once indirect and induced effects along the value chains are included, GVA exceeds EUR 350 billion and employment exceeds 6 million.[21] These figures cover the seven sectors for which comparable Union-level data exist, and therefore understate the full scope of the Blue Economy addressed by this Roadmap.

Figure 1. EU Blue Economy: gross value added and employment by established sector, 2022



Source: European Commission and Joint Research Centre, The EU Blue Economy Report 2025, Table 3, p. 13 (2022 data).

Economic weight is unevenly distributed across sectors and Member States. Coastal tourism alone accounted for 53 % of employment and 33 % of GVA in 2022, while the four largest Member States

[16] On the diversity of European coastal and sea-basin conditions, including the lower wave energy of the enclosed Mediterranean basin and the storm regimes of the Atlantic and North Sea coasts, see European Commission and Joint Research Centre, EU Blue Economy Report 2025, 64. On the class I–VII inland waterway network, see Inland Navigation Europe (INE), Consultation Input to the Blue Economy Technology Roadmap, section on inland waterway infrastructure.

[17] Inland Navigation Europe (INE), Consultation Input to the Blue Economy Technology Roadmap (Brussels: INE, 2026), section on drivers and constraints. The fragmentation of governance across the authorities responsible for waterborne assets, and the limited awareness of the multiplier effect of multi-purpose infrastructure, are identified therein.

[18] Waterborne Technology Platform, Waterborne Technology Leadership, 24–25; Inland Navigation Europe (INE), Consultation Input to the Blue Economy Technology Roadmap, section on the current state of waterborne assets.

[19] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 7 (Table 1).

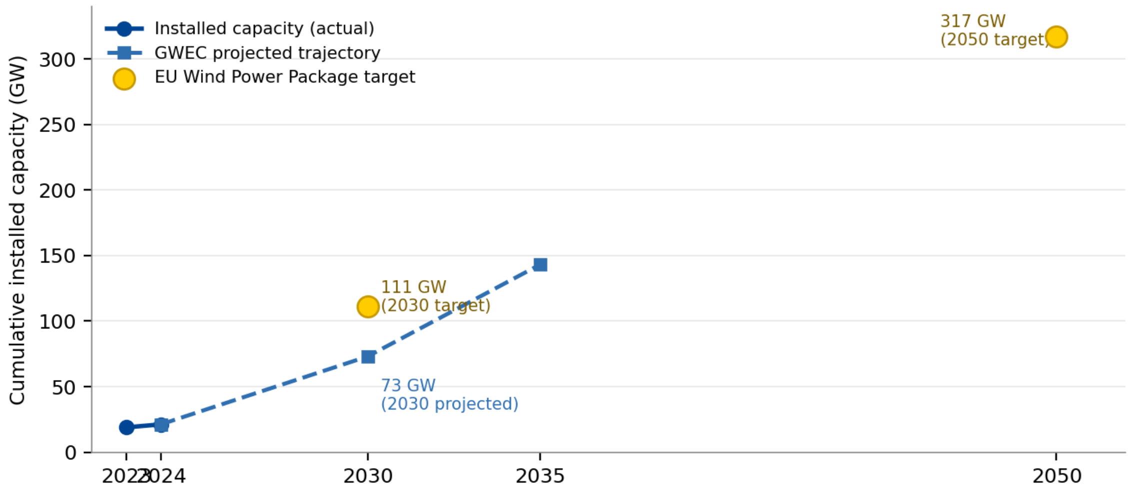
[20] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 10.

[21] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 11.

(Germany, France, Italy and Spain) together generated 60 % of GVA and 52 % of employment.[22] The sector's relative importance is greatest in island and archipelagic economies: its share of national employment ranges from 13.7 % in Greece to 0.4 % in Austria, and its share of national GVA from 7.3 % in Croatia to 0.2 % in Austria and Luxembourg.[23]

Marine renewable energy is the fastest-growing established sector and the principal near-term driver of demand for blue-economy vessels and infrastructure. EU cumulative offshore wind capacity reached 18.9 GW at the end of 2023 and 21.2 GW at the end of 2024, and the EU Wind Power Package targets 111 GW by 2030 and 317 GW by 2050.[24] Delivery has fallen behind ambition: Europe installed 2.6 GW in 2024 and 2 GW in 2025, its lowest annual addition since 2016, and is now expected to reach approximately 73 GW by 2030 against an original policy ambition of around 140 GW.[25] The resulting gap between targets and timely delivery, driven by permitting, grid and supply-chain constraints, defines the deployment challenge for the vessels, infrastructure and subsea systems addressed in this Roadmap. Some 122 GW of offshore wind is nonetheless expected in Europe over 2026–2035, and the January 2026 Hamburg Declaration commits nine North Sea states to 300 GW by 2050.[26]

Figure 2. EU offshore wind: installed capacity, projected trajectory and 2030/2050 targets



Sources: EU Blue Economy Report 2025, p. 30; GWEC, Global Offshore Wind Report 2026, pp. 62, 77.

The sector is also exposed to climate pressure that shapes its infrastructure requirements. Coastal flooding already affects approximately 72,000 people in the EU each year, and, absent additional protection, associated annual damages could reach between EUR 137 billion and EUR 814 billion by 2100.[27] Resilient, adaptive and nature-positive infrastructure is therefore a baseline requirement rather than an option.

1.6 The Blue Economy as a technology-leadership opportunity

The Blue Economy is a natural deployment environment for European technology leadership. Its vessels, infrastructure and subsea systems operate predominantly in European waters and along European coasts and inland corridors, where European shipyards, equipment manufacturers, automation and digital providers, classification societies, ports and waterway authorities can

[22] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 7, 12.
[23] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 13.
[24] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 30.
[25] GWEC, Global Offshore Wind Report 2026 (Brussels: Global Wind Energy Council, 2026), 62.
[26] GWEC, Global Offshore Wind Report 2026, 77.
[27] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 7.

demonstrate and scale replicable solutions.[28] Demonstration in blue-economy applications can generate European capability in modular zero-emission vessels, multi-purpose and nature-positive infrastructure, autonomous underwater systems, and secure ship-to-shore and asset-to-grid data architectures.[29]

This capability is a condition of strategic autonomy. Anchoring the design, construction and operation of blue-economy assets in the European value chain strengthens industrial competitiveness, security of supply, and the Union's capacity to protect its critical maritime and inland-water infrastructure.[30] The chapters that follow derive the drivers, target capabilities, technological pathways, enablers and impacts from this objective.

[28] Waterborne Technology Platform, Waterborne Technology Leadership, 5. The European waterborne ecosystem is described therein as comprising shipowners, shipbuilders, equipment manufacturers, ports, classification societies, infrastructure and service providers, blue economy actors, and universities and research institutes.
[29] Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0, 11; Waterborne Technology Platform, Waterborne Technology Leadership, 24.
[30] Waterborne Technology Platform, Waterborne Technology Leadership, 5, on the waterborne sector as fundamental to Europe's sovereignty and to its resilience in trade, safety, security, defence and energy supply; European Commission, European Ocean Pact, 2, 17; European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final (Brussels, 2026).

2. Drivers and Constraints

2.1 Policy and market drivers

Five policy and market drivers define the technology agenda of the Blue Economy.

- **Ocean governance and competitiveness.** The European Ocean Pact provides, for the first time, a single reference framework across all ocean policy areas, with the sustainable Blue Economy and its competitiveness as a central objective. It identifies renewable energy, blue biotechnology, underwater robotics and ocean observation as priority technology fields.[31] It also establishes maritime security and defence as an underlying condition for the sector, linking industrial capability to the protection of critical maritime infrastructure.[32]
- **Decarbonisation and the energy transition.** Binding Union climate legislation drives demand for zero-emission vessels, alternative fuels and offshore renewable energy. The European Climate Law establishes a 2030 target of at least a 55 % net reduction in greenhouse gas emissions relative to 1990, a binding 2040 milestone of a 90 % net reduction, and climate neutrality by 2050.[33] Blue-economy newbuilds and major retrofits must be compatible with this trajectory. FuelEU Maritime, the extension of the EU Emissions Trading System to shipping, and the Alternative Fuels Infrastructure Regulation set a compliance trajectory to 2050.[34] These instruments convert climate obligations into procurement and retrofit demand.
- **Offshore renewable energy and multi-use deployment.** The EU Wind Power Package targets 111 GW of offshore wind by 2030 and 317 GW by 2050.[33] Delivery has lagged, with 2 GW installed in 2025 — the lowest annual addition since 2016 — and Europe now expected to reach approximately 73 GW by 2030.[34] Closing this gap requires the specialised vessels, floating and multi-purpose infrastructure, and subsea inspection systems. Offshore renewable energy, creates demand for multi-use infrastructure, autonomous inspection, environmental intelligence, underwater intervention and shared energy and logistics interfaces.
- **Water resilience and climate adaptation.** Water is a strategic asset under growing pressure from extreme events, progressive climate change and hybrid threats. The European Water Resilience Strategy and the Union's climate-adaptation framework require infrastructure that manages flood risk, freshwater supply and the salinisation of estuaries across the land–sea and freshwater–seawater interfaces.[35] Adaptation and resilience are therefore design objectives for waterborne infrastructure rather than downstream considerations.
- **Security, preparedness and dual use.** The protection of critical maritime and inland-water infrastructure has become a Union priority. Subsea cables carry 99 % of intercontinental internet traffic, while offshore energy assets and inland locks and bridges present concentrated points of vulnerability.[36] The military mobility framework, the NIS2 Directive and the Preparedness Union

[31]European Commission, European Ocean Pact, 10; Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0 (Brussels: Waterborne Technology Platform, June 2025), 7–8.
[32]European Commission, European Ocean Pact, 17. On the dual-use dimension of transport infrastructure, see also European Commission, Proposal for a Regulation establishing a framework of measures to facilitate the transport of military equipment, goods and personnel across the Union, COM(2025) 847 final (Brussels, 19 November 2025).
[33]European Commission and Joint Research Centre, EU Blue Economy Report 2025, 30. See also ibid., 28–29, on the composition of the marine renewable energy sector.
[34]GWEC, Global Offshore Wind Report 2026 (Brussels: Global Wind Energy Council, 2026), 62; on the 2026–2035 European pipeline and the Hamburg Declaration, see ibid., 77.
[35]European Commission, European Water Resilience Strategy (Brussels, 2025), COM number [TBC]. On the exposure of coastal populations and the projected cost of coastal flooding, see European Commission and Joint Research Centre, EU Blue Economy Report 2025, 7, 63.
[36]European Commission, European Ocean Pact, 2.

Strategy impose dual-use requirements on inland-waterway and coastal infrastructure and on the systems that monitor, protect and rapidly repair it.[37]

2.2 Constraints and bottlenecks

- **Fragmented governance.** Responsibility for waterborne assets is dispersed across many national, regional and sectoral authorities. Offshore energy, transport, water management, environmental protection and digital services are planned and operated in separate silos. This fragmentation raises coordination costs, slows permitting, and prevents the integrated planning that multi-purpose infrastructure requires.[38]
- **Single-purpose infrastructure and the multiplier gap.** Most offshore, coastal and inland-water infrastructure is designed for a single purpose. Awareness of the multiplier effect of multi-purpose investment remains low, and coordinated cross-sectoral management is the exception rather than the rule. As a result, assets are under-used, adaptation is costly, and cross-sectoral co-benefits are foregone.[39]
- **Infrastructure and energy interface gaps.** Charging, alternative-fuel supply, communications, docking and maintenance facilities remain fragmented across ports, marinas, islands and offshore and inland locations, limiting wider deployment of zero-emission and autonomous systems. Although the Alternative Fuels Infrastructure Regulation sets minimum requirements, investment in supporting energy and refuelling infrastructure continues to lag demand, keeping many zero-emission vessel concepts at the demonstration stage.[40]
- **Regulatory barriers.** Approval pathways for autonomous vessels, novel fuels and unmanned underwater systems are not harmonised across jurisdictions. Certification frameworks were developed for crewed, single-purpose and short-duration operations. Regulatory uncertainty fragments the market and deters the investment needed to move from pilots to fleets.[41]
- **SME capacity and financing.** The majority of blue-economy operators are small and medium-sized enterprises with limited capacity to absorb research and innovation costs. Blue-economy SMEs face a Union financing gap estimated at EUR 60 to 70 billion.[42] Scalable, modular and cost-effective solutions, supported by blended finance and risk-sharing instruments, are therefore prerequisites for uptake.

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[37] Directive (EU) 2022/2555 (NIS2), OJ L 333, 27.12.2022; European Commission, Proposal for a Regulation establishing a framework of measures to facilitate the transport of military equipment, goods and personnel across the Union, COM(2025) 847 final (Brussels, 19 November 2025); European Commission, Preparedness Union Strategy (Brussels, 2025) [COM number TBC]. On ports as critical infrastructure subject to cybersecurity obligations, see European Commission and Joint Research Centre, EU Blue Economy Report 2025, 42.

[38] Inland Navigation Europe (INE), Consultation Input to the Blue Economy Technology Roadmap (Brussels: INE, 2026), section on drivers and constraints, identifying the dispersion of responsibility for waterborne assets across national, regional and sectoral authorities as a structural constraint.

[39] Inland Navigation Europe (INE), Consultation Input to the Blue Economy Technology Roadmap, section on drivers and constraints, on the limited awareness of the multiplier effect of multi-purpose infrastructure and on the prevailing silo approach. On multi-use infrastructure as the alternative model, see Waterborne Technology Platform, Waterborne Technology Leadership (Brussels: Waterborne Technology Platform, 2026), 25.

[40] Regulation (EU) 2023/1804 (AFIR), OJ L 234, 22.9.2023, arts. 9–11, setting minimum requirements for shore-side electricity supply and alternative-fuel infrastructure at TEN-T ports. On the uneven distribution of deployment — 44 ports across 15 Member States with 352 berths equipped with onshore power supply — see European Commission and Joint Research Centre, EU Blue Economy Report 2025, 41–42.

[41] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on the need for new regulations and standards for floating infrastructure, multi-use platforms, autonomous underwater systems and digital interoperability, and on fragmented regulation as a barrier to technologies operating across national boundaries and sectoral domains.

[42] European Commission, European Ocean Pact, 6.

- **Sea- and river-basin heterogeneity.** The Baltic, North Sea, Atlantic, Mediterranean and Black Sea basins and the class I–VII inland waterway network differ in regulatory regime, environmental conditions and infrastructure maturity. A single technical solution rarely transfers unchanged between basins. Roadmap solutions must therefore be adaptable to divergent hydrological, hydro-morphological and market conditions.[43]

2.3 Implications for roadmap design

The drivers and constraints converge on a clear roadmap logic. Demand from decarbonisation, offshore energy, water resilience and security is strong and legally established, while deployment is held back by fragmented governance, single-purpose assets, infrastructure gaps, regulatory uncertainty and limited SME finance. The Roadmap responds by organising its technological response into five pathways — vessels, infrastructure, underwater systems, workforce, and regulation — and by treating multi-purpose design, cross-sectoral coordination and the integration of inland waters as horizontal requirements across all five. The EU Industrial Maritime Strategy, the EU Ports Strategy and the Sustainable Transport Investment Plan connect this response to European industrial, port and investment capacity.[44] The pathways are aligned with the missions of the waterborne sector set out in the Strategic Research Agenda.[45]

[43]OECD, Policy Pathways Beyond the Shoreline: Enhancing Resilience and Innovation in Island Economies, OECD Rural Studies (Paris: OECD Publishing, 2026), [page TBC]. On the divergence of Blue Economy contribution across Member States, see European Commission and Joint Research Centre, EU Blue Economy Report 2025, 13.
[44]European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final (Brussels, 2026); European Commission, EU Ports Strategy, COM(2026) 112 final (Brussels, 2026); European Commission, Sustainable Transport Investment Plan, COM(2025) 664 final (Brussels, 2025).
[45]Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0, 7–8.

3. Target Capabilities

The target capabilities are derived from the mission and vision of the Waterborne Strategic Research Agenda and the Waterborne Technology Leadership document, and are expressed across the 2035, 2040 and 2050 horizons.[46] Each horizon states the capability the European Blue Economy must possess, expressed in technology-readiness-level (TRL) terms, to remain competitive and to meet Union climate, resilience and security objectives.

3.1 Current state of play

Blue-economy vessels, infrastructure and subsea systems are today largely single-purpose, fossil-fuelled and weakly interconnected. Vessels are designed for narrow mission profiles and require substantial onboard crew, including for repetitive and hazardous tasks. Infrastructure is asset-specific and depends on periodic manual inspection. Underwater operations are constrained by limited endurance, fragmented data systems and high cost. Regulatory frameworks were designed for crewed, short-duration and sector-bound operations, and alternative-fuel and charging infrastructure is unevenly distributed.[47] Marine renewable energy is the exception in growth terms, but its GVA of EUR 5.3 billion in 2022 remains small relative to its deployment trajectory, underlining the scale of the industrial build-out required.[48]

3.2 By 2035 — demonstration and early deployment

By 2035, validated zero-emission and hybrid-electric vessels operate in representative blue-economy segments — aquaculture, offshore service, dredging, marine science and coastal tourism — at TRL 6–7. Modular vessel architectures with interchangeable mission modules are demonstrated, and remote and assisted operation is validated in controlled environments. Digitally connected, resilient port microgrids and alternative-fuel bunkering hubs are established on major TEN-T corridors, alongside demonstrator fleets of autonomous underwater and surface systems for inspection and monitoring at TRL 5–7. Multi-purpose and nature-positive infrastructure concepts, including floating platforms serving offshore and inland-water functions, are demonstrated at pilot scale, and regulatory sandboxes support large-scale testing.[49]

3.3 By 2040 — scale-up and system integration

By 2040, zero-emission vessels operate routinely in coastal, offshore and inland-water environments at TRL 8–9, supported by operational charging and alternative-fuel infrastructure across all strategic European sea and river basins. Autonomous underwater systems with long endurance, AI-enabled mission planning and autonomous docking and charging reach TRL 7–8, and coordinated multi-vehicle operations are integrated into infrastructure monitoring and maintenance workflows. Modular, multi-use infrastructure is deployed as part of coordinated waterborne energy and logistics ecosystems, interoperable digital platforms enable real-time coordination between assets, vessels, ports and grids, and harmonised EU standards enter into force.[50]

[46] Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0, 7–8.
[47] Waterborne Technology Platform, Waterborne Technology Leadership, 24–25.
[48] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 12.
[49] The 2035 capability set is derived from the missions of the waterborne sector in Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0, 7–8, 11, and from the blue economy milestones in Waterborne Technology Platform, Waterborne Technology Leadership, 26.
[50] Waterborne Technology Platform, Waterborne Technology Leadership, 26, on integrated offshore systems and mature digital operations by 2040.

3.4 By 2050 — full transformation

By 2050, standardised autonomous multi-mission platforms operate continuously as part of integrated offshore, coastal and inland-water ecosystems, supported by a circular shipbuilding and decommissioning base with digital material passports and net-zero embodied carbon. Fully autonomous subsea networks, supported by seabed charging and AI-based coordination, deliver near-zero unplanned downtime of critical infrastructure and continuous environmental monitoring. Infrastructure operates as an intelligent, climate-resilient component of Europe’s energy, water, flood-defence, transport and digital systems, and European technological leadership is reflected in globally recognised IMO and ISO standards.[51]

[51]European Commission and Joint Research Centre, EU Blue Economy Report 2025, 30.

4. Technology Pathways

The Roadmap organises its technological response into five pathways. Each pathway states an operational objective and a capability trajectory across the 2035, 2040 and 2050 horizons. The five pathways are addressed as an interconnected system: vessels, infrastructure and subsea systems share energy, digital and regulatory interfaces, and each pathway applies across offshore, coastal and inland waters.

4.1 Zero-emission, modular and multi-mission vessels

Future blue-economy operations require specialised vessels that are flexible, energy-efficient and capable of supporting a wide range of missions while safeguarding the ecosystems that sustain them.[52] Today's vessels are typically designed for narrow mission profiles and fixed operating conditions, which limits asset utilisation, raises lifecycle costs and impedes adaptation to new missions or regulations. Many still rely on fossil fuels, have limited digital integration and require substantial onboard crew. The objective of this pathway is to enable zero-emission, modular and digitally enabled vessels — for aquaculture, tourism, dredging, marking, data gathering, research and monitoring, small offshore logistics and specialised service craft on seas and inland waters — that support multiple missions over their lifetime, operate with minimal crew, and adapt through modular energy, payload and automation solutions.

Capability trajectory

By 2035 (TRL 6–7). Modular and zero-emission vessel concepts are demonstrated in representative operations. Hybrid-electric and alternative-fuel propulsion tailored to small and medium vessels reaches TRL 6–7, supported by validated sizing methodologies. Interchangeable mission modules for inspection, sampling, intervention and logistics are demonstrated on a common platform, and remote, COLREG-aware operation and operational digital twins are validated in controlled environments.

By 2040 (TRL 8–9). Zero-emission vessels operate routinely in coastal, offshore and inland-water environments. Modular concepts are deployed at fleet level with standardised interfaces and interoperable control systems, and energy-efficient hull and propulsion solutions are validated across multiple routes. Remote and semi-autonomous operation is integrated into day-to-day operations, and digital twins support fleet-level predictive maintenance and compliance reporting.

By 2050 (TRL 8–9). Standardised autonomous multi-mission vessels operate continuously as part of integrated offshore, coastal and inland-water ecosystems. Vessels are designed for full lifecycle circularity, supported by digital threads, material passports and predictive maintenance. Modular design enables rapid reconfiguration, repurposing and upgrading, maximising asset utilisation and minimising environmental impact.

4.2 Resilient, sustainable and interconnected infrastructure

Geopolitical change and climate pressure require waterborne infrastructure that is durable, adaptive, resilient, secure, dual-use and nature-positive.[53] Blue-economy activity depends on offshore, coastal and inland-water infrastructure that sustains freshwater supply, renewable energy generation, flood mitigation, transport, aquaculture, subsea connectivity and biodiversity. Most of this infrastructure is single-purpose, weakly connected to surrounding systems, and dependent on manual inspection,

[52] Waterborne Technology Platform, Waterborne Technology Leadership, 24, on leadership in the design, production, operation and maintenance of blue economy vessels.
[53] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on resilient, sustainable and interconnected infrastructure that is durable, adaptive and nature-positive.

which limits adaptability, raises lifecycle costs and leaves resilience to climate and security stresses insufficiently addressed. The objective of this pathway is the transition from isolated, asset-specific infrastructure to resilient, digitally interconnected, secure and nature-positive systems that support multi-use operations and function as part of integrated energy, logistics and data ecosystems connecting the land–sea and freshwater–seawater interfaces.

Capability trajectory

By 2035 (TRL 5–8). Modular and multi-use infrastructure concepts — floating platforms and hubs combining offshore and inland-water renewable energy, aquaculture, tourism, logistics and CCS/CCUS interfaces — are demonstrated at pilot scale. Nature-positive and hybrid solutions that integrate engineered structures with ecosystem functions are piloted, supported by evidence-based design and assessment frameworks and by flexible spatial planning for multi-use scenarios. Operational digital twins and autonomous inspection using AUVs, ROVs and surface drones are demonstrated for selected assets.

By 2040 (TRL 7–8). Modular and multi-use concepts are deployed as part of coordinated waterborne energy and logistics ecosystems, linking renewable generation, offshore storage, hydrogen production, aquaculture and logistics through shared infrastructure. Interoperable digital platforms enable real-time coordination between offshore assets, vessels, ports and onshore grids, AI-enabled monitoring and predictive maintenance become standard practice, and certification frameworks enable replication across European sea and river basins.

By 2050 (TRL 8–9). Infrastructure operates as part of fully integrated, climate-neutral and adaptive offshore, coastal and inland-water ecosystems, designed for continuous operation under extreme conditions and rapid restoration. Lifecycle management is fully digitalised through integrated digital twins and material passports, and persistent autonomous monitoring and intervention deliver near-zero unplanned downtime. Infrastructure functions as an intelligent, active component of Europe's energy, water-preservation, flood-defence, transport and digital systems.

4.3 Advanced underwater autonomy, sensing and intervention

Underwater operations increasingly depend on autonomous and remotely operated systems with long endurance, high intelligence and robust communication.[54] These capabilities are essential for offshore renewable energy, carbon capture and storage, aquaculture, defence and environmental monitoring. Underwater operations are today constrained by limited endurance, fragmented data systems and high cost, and human intervention remains necessary for many inspection and maintenance tasks in harsh or remote environments. The objective of this pathway is to deploy long-endurance, intelligent and interoperable underwater systems that operate with minimal human oversight while delivering high-quality data and reliable intervention.

Capability trajectory

By 2035. Modular AUV and ROV fleets with extended endurance are deployed for supervised multi-mission operations, supported by hybrid communication links and automated launch and recovery. Edge AI enables onboard anomaly detection and basic mission digital twins, and shared data platforms support reuse of ocean data.

By 2040. Coordinated multi-vehicle operations over extended ranges are supported by interoperable standards, secure communication and real-time digital twins. Underwater systems are routinely integrated into offshore infrastructure monitoring and maintenance workflows.

[54] European Commission, European Ocean Pact, 10.

By 2050. Fully autonomous subsea robot networks operate continuously, supported by seabed charging, AI-based mission coordination and persistent sensing, enabling near-zero unplanned downtime of critical subsea infrastructure and continuous environmental monitoring.

4.4 Human-centred solutions, skills and workforce

Offshore, coastal and underwater operations will demand new competencies in autonomy, robotics, sensing, data analysis and environmental management.[55] The objective of this pathway is to ensure that the European workforce can safely and effectively operate zero-emission, autonomous and digitally integrated systems, through advanced training, ergonomic design and safe human-machine teaming.

Capability trajectory

By 2035. Extended-reality training platforms and validated human-machine teaming concepts are available for early autonomous operations. **By 2040.** Harmonised competency standards and certified training curricula support routine deployment across Member States. **By 2050.** A pan-European skills ecosystem enables continuous learning and workforce mobility across the Blue Economy.

4.5 Regulatory frameworks, standards and governance

Accelerating innovation and deployment requires new regulations and standards for floating infrastructure, multi-use platforms, autonomous underwater systems, CCS logistics, offshore hydrogen and digital interoperability.[56] Fragmented regulation remains a major barrier for technologies that operate across national boundaries and sectoral domains. The objective of this pathway is to establish harmonised European regulatory frameworks and standards that enable the deployment of autonomous vessels, underwater systems, floating infrastructure and integrated digital platforms across all sea and river basins.

Capability trajectory

By 2035. Coordinated EU regulatory sandboxes and test sites support large-scale testing of autonomous vessels, underwater systems and multi-use infrastructure. **By 2040.** Harmonised EU standards and adaptive certification pathways are in force. **By 2050.** European leadership is reflected in global IMO and ISO standards, underpinned by interoperable digital and cybersecurity standards for integrated blue-economy systems.

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[55] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on human-centred solutions, skills and workforce transformation.

[56] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on regulatory frameworks, standards and governance.

Table 2. Summary of technology-pathway milestones

Pathway	2035 — demonstration	2040 — scale-up	2050 — transformation
4.1 Vessels	Modular, hybrid/alt-fuel vessels; remote operation validated (TRL 6–7)	Routine zero-emission fleets; fleet-level digital twins (TRL 8–9)	Autonomous multi-mission, fully circular platforms (TRL 8–9)
4.2 Infrastructure	Multi-use, nature-positive pilots; digital twins; drone inspection (TRL 5–8)	Integrated energy-logistics ecosystems; interoperable platforms (TRL 7–8)	Climate-resilient, self-monitoring infrastructure ecosystems (TRL 8–9)
4.3 Underwater systems	Extended-endurance AUV/ROV fleets; edge AI; shared data	Coordinated multi-vehicle operations; real-time digital twins	Persistent autonomous subsea networks; seabed charging
4.4 Workforce	XR training; human-machine teaming concepts	Harmonised competency standards; certified curricula	Pan-European skills ecosystem; workforce mobility
4.5 Regulation	EU regulatory sandboxes and test sites	Harmonised EU standards; adaptive certification	Leadership in IMO/ISO standards

Table 2: . Summary of technology-pathway milestones

5. Key Enablers and Deployment

5.1 Cross-cutting enabling technologies

A common set of enabling technologies underpins all five pathways.

- **Artificial intelligence and machine learning.** AI supports mission planning, anomaly detection, predictive maintenance and real-time decision support across vessels, infrastructure and subsea systems. It is the principal means of reducing crew requirements and unplanned downtime. Trusted-AI frameworks are required for safety-critical and autonomous applications.[57]
- **Digital twins and data architectures.** Digital twins support vessel lifecycle optimisation, infrastructure health monitoring and mission rehearsal. Their value depends on interoperable data standards, secure communication and clear data-governance rules across sectors that traditionally operate in silos. Without interoperability, digital twins remain isolated applications rather than system-level enablers.[58]
- **Propulsion and energy storage.** Fuel cells, high-density batteries, hybrid DC micro-grids, alternative-fuel integration and seabed or inductive charging enable zero-emission and long-endurance operation. Sizing methodologies must be matched to the diverse duty cycles of blue-economy missions. Offshore and inland charging and bunkering must be deployed in step with vessel development.[59]
- **Autonomous systems and connectivity.** Autonomous navigation, multi-vehicle coordination, sensor fusion and resilient SATCOM, 5G and acoustic-optical communication enable remote and unmanned operation. Interoperable and cyber-secure communication standards are prerequisites for multi-operator and cross-border deployment. Reliable offshore and subsea connectivity underpins remote operation and digital twins.[60]
- **Advanced materials and sensing.** Lightweight composites, circular and recycled materials, eco-engineered structures and functionalised membranes reduce environmental footprint and support circularity. Hyperspectral, acoustic and distributed sensing, combined with adaptive sensor networks, deliver the structural, environmental and security data on which the pathways depend.[61]

5.2 Enabling conditions

Technology maturity alone is insufficient. A parallel set of structural conditions must be developed to move solutions from pilots to fleets and basins.

- **Energy and refuelling infrastructure.** Offshore charging, alternative-fuel bunkering and interoperable onshore power supply must be deployed alongside vessel development, in line with the Alternative Fuels Infrastructure Regulation.[62] Absent this infrastructure, zero-emission concepts remain confined to demonstration. Deployment must extend to inland-waterway and coastal nodes, not only major seaports.

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[57] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on AI-enabled mission planning and underwater situational awareness.
[58] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on interoperable digital infrastructures enabling real-time coordination with vessels, ports and onshore grids.
[59] Waterborne Technology Platform, Waterborne Technology Leadership, 20, on the deployment of standardised charging infrastructure; Regulation (EU) 2023/1804 (AFIR), OJ L 234, 22.9.2023, Art. 9–11.
[60] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on autonomous docking and charging and on robust underwater communication.
[61] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on environmental sensing and integrated monitoring systems for structural health, environmental conditions and climate impacts.
[62] Regulation (EU) 2023/1804 (AFIR), OJ L 234, 22.9.2023.

- **Regulatory frameworks and standards.** Modular, autonomous, multi-use and nature-positive concepts challenge asset-specific, sector-bound approval practices. Regulatory sandboxes, objective-oriented legislation, adaptive certification and closer coordination between waterborne, energy, industrial and environmental authorities are required. Interoperable digital and cybersecurity standards are prerequisites for safe, scalable deployment.
- **Cross-sector coordination and governance.** Offshore and inland energy, aquaculture, tourism, transport, environmental protection and digital services must be planned and operated as interconnected systems. This requires new governance models, shared planning tools and coordination mechanisms that align investment and spatial planning across sectors and Member States. Coordinated management replaces the current silo approach and unlocks the multiplier effect of multi-purpose investment.
- **Skills and workforce readiness.** Digitally integrated, autonomous and nature-positive operations demand new competencies in digital systems management, robotics, environmental monitoring and data-driven decision-making. Harmonised competency frameworks, competence centres and validated XR-based training and certification are required, recognised across Member States to support mobility. Curricula must evolve in step with technological progress.
- **Investment and risk-sharing.** Many concepts involve high upfront capital and novel risk profiles, and blue-economy SMEs face a Union financing gap of EUR 60 to 70 billion.[63] Public-private partnerships, blended finance and coordinated investment strategies, supported by the Sustainable Transport Investment Plan, are required to de-risk early deployment and enable scaling beyond pilots.[64] The maritime industrial base and ports function as the critical nodes through which this investment is delivered.[65]

5.3 Deployment pathway

Deployment follows a phased TRL progression from laboratory validation to market norm. **Phase 1 (2025–2030, TRL 3–6):** component testing, reference-architecture development, regulatory engagement and initial pilot demonstrators. **Phase 2 (2030–2035, TRL 6–8):** integrated demonstrators at sea and on inland waters, regulatory approval and first commercial pilots with SME operators. **Phase 3 (2035–2040, TRL 8–9):** market launch, supply-chain development and scaling across European sea and river basins. **Phase 4 (2040–2050):** standardised, autonomous, zero-emission blue-economy operations as the European norm.[66]

5.4 Key deployment actors

- **European Commission:** Horizon Europe, the Innovation Fund, the Connecting Europe Facility and blue-economy investment instruments provide research, demonstration and deployment funding. The Commission also sets the regulatory and standardisation agenda through the pathways in Chapter 4.[67]

[63]European Commission, European Ocean Pact, 6.
[64]European Commission, Sustainable Transport Investment Plan, COM(2025) 664 final (Brussels, 2025).
[65]European Commission, European Ocean Pact, 11.
[66] The phasing follows the blue economy milestones for 2040 and 2050 in Waterborne Technology Platform, Waterborne Technology Leadership, 26. Technology readiness levels follow the definition in NASA, 'Technology Readiness Levels', as applied in European Commission and Joint Research Centre, EU Blue Economy Report 2025, 37.
[67] European Commission, European Ocean Pact, 6, 11; European Commission, Sustainable Transport Investment Plan, COM(2025) 664 final (Brussels, 2025).

- **EIB and national promotional banks:** These institutions provide the financing instruments — counter-guarantees, blended finance and de-risking facilities — needed to bridge the demonstration-to-deployment gap and address the SME financing gap.[68]
- **Classification societies and authorities:** Classification societies and national authorities provide type approval, safety certification and adaptive regulatory pathways for novel vessels, autonomous systems and offshore and inland infrastructure.[69]
- **Ports, waterway and energy operators:** Ports, inland-waterway authorities and energy operators deliver the infrastructure investment and grid integration on which alternative fuels, charging and offshore energy depend, acting as the critical nodes of the system.[70]
- **SME operators and blue-economy industries:** Blue-economy SMEs and industries are the early adopters, demonstration partners and market validators. Their capacity to absorb modular, scalable solutions determines the pace of deployment.[71]

6. Expected Impacts

6.1 Environmental impacts

- **Emissions reduction:** Zero-emission propulsion and alternative fuels deliver substantial greenhouse-gas reductions across the blue-economy fleet. Advanced propulsion and autonomous operation reduce underwater noise and pollution. Persistent sensor networks and AI analytics strengthen environmental-compliance monitoring.[72]
- **Nature-positive infrastructure:** Multi-purpose, nature-positive infrastructure enhances biodiversity, supports ecosystem services and improves coastal and inland-water resilience. Integrating ecological performance as a core design objective shifts infrastructure from minimising harm to delivering environmental benefit. This supports the Union's biodiversity and climate-adaptation objectives.[73]

6.2 Economic and industrial impacts

- **Industrial competitiveness:** European leadership in vessel design, autonomous systems and digital ocean infrastructure strengthens the maritime industrial base and its supply chains. Anchoring design, construction and operation in the European value chain supports strategic autonomy and security of supply. The Blue Economy, contributing over EUR 250 billion in GVA and close to 5 million jobs, provides the market scale for this build-out.[74]
- **New markets and lower costs:** Modular, energy-efficient and autonomous solutions reduce operating costs for blue-economy operators through predictive maintenance and reduced downtime. New markets emerge in offshore hydrogen, multi-use infrastructure, marine robotics

[68] European Commission, European Ocean Pact, 6, on the Union financing gap for blue-economy SMEs of EUR 60 to 70 billion.
[69] Waterborne Technology Platform, Waterborne Technology Leadership, 5, on classification societies as actors of the European waterborne ecosystem; ibid., 25, on standards, certification and regulatory pathways.
[70] European Commission, European Ocean Pact, 11; European Commission, EU Ports Strategy, COM(2026) 112 final (Brussels, 2026).
[71] European Commission, European Ocean Pact, 6, 12.
[72] Regulation (EU) 2023/1805 (FuelEU Maritime), OJ L 234, 22.9.2023; Directive (EU) 2023/959 amending Directive 2003/87/EC (EU ETS), OJ L 130, 16.5.2023. On the environmental footprint of waterborne operations, see European Commission and Joint Research Centre, EU Blue Economy Report 2025, 59.
[73] Waterborne Technology Platform, Waterborne Technology Leadership, 25, on hybrid and nature-based designs; on the cost-effectiveness of nature-based solutions for coastal protection, see European Commission and Joint Research Centre, EU Blue Economy Report 2025, 64.
[74] European Commission and Joint Research Centre, EU Blue Economy Report 2025, 7.

and digital ocean services. Modular and scalable solutions improve SME access to advanced technologies.[75]

6.3 Social and safety impacts

- **Safety and workforce:** Automation of hazardous tasks and improved human-machine teaming enhance crew safety. Workforce transformation supports high-quality employment in technology-intensive operations, provided competency frameworks and training keep pace. Inclusive, human-centred design ensures diversity and wellbeing are addressed from the outset.
- **Security and resilience:** Persistent monitoring and rapid-repair capability strengthen the protection of critical maritime and inland-water infrastructure, including subsea cables that carry 99 % of intercontinental internet traffic.[76] Resilient, dual-use infrastructure supports preparedness and military mobility. Sustainable aquaculture enabled by advanced monitoring improves food security and traceability.

6.4 Scientific and innovation impacts

- **Ocean knowledge:** Expanded AUV and ROV capabilities and AI-enabled analysis accelerate ocean science and generate new knowledge on ocean health, biodiversity and ecosystems. This evidence base supports the ocean-observation and knowledge objectives of the European Ocean Pact. Open science and FAIR data principles enable broad knowledge transfer.[77]
- **Technological leadership:** Sustained research and innovation establishes European leadership in underwater autonomy, digital ocean infrastructure and zero-emission waterborne systems. This leadership is translated into global standards through the IMO and ISO. It positions Europe as the reference market and technology provider for the global Blue Economy.[78]

[75] European Commission, European Ocean Pact, 12.
[76] European Commission, European Ocean Pact, 2.
[77] European Commission, European Ocean Pact, 10, on ocean observation and the marine knowledge agenda.
[78] Waterborne Technology Platform, Waterborne Technology Leadership, 24, on Europe as global leader in the development, operation and maintenance of advanced blue economy solutions by 2050.