WATERBORNE

WATERBORNE TECHNOLOGY ROADMAP

Competitive, resilient and sustainable blue economy

September 2026

BLUE ECONOMY TECHNOLOGY ROADMAP

01 DESCRIPTION OF THE SECTOR

The Blue Economy comprises economic activities that depend on, operate in, or supply oceans, seas, coasts and inland waters. Within the Waterborne Technology Platform this broad definition is implemented through nine roadmaps; the present one covers the specialised waterborne, floating and underwater technologies that enable sustainable production, observation, use, restoration and protection of aquatic resources — beyond the transport functions addressed elsewhere. Its core scope is specialised vessels, sustainable boating and tourism craft, multi-use infrastructure, coastal and aquatic resilience, and the monitoring and protection of underwater assets. Inland waters are integral: rivers, canals and lakes with their locks, weirs, dams and digital systems form one infrastructure base with coastal and offshore assets, and freshwater and seawater are a single hydrological system.

GROSS VALUE ADDED
250.7bn € 1.7% of the EU-27 economy
on €890.6 bn turnover; GVA€263 bn estimated for 2023

DIRECT EMPLOYMENT
4.82m people
above 6 m and €350 bn GVA once indirect and induced effects are included

GROWTH ON 2021
+33%
on €188 bn in 2021, and 23% above the 2019 pre-pandemic level

CLIMATE EXPOSURE
72k people hit by coastal flooding yearly
damages could reach €137–814 bn a year by 2100

ASSET TAXONOMY — CATEGORIES WITHIN CLASSES A, B, C AND D

A	Fisheries & aquaculture	Fishing vessels; service, well-boat, feed-supply and harvest craft
A	Offshore service	Dredgers and tugs; cable-laying, stone-dumping and heavy-lift vessels
A	Recreational & tourism	Charter and passenger craft; marinas and leisure harbours
B	Mobile platforms	ROVs, AUVs and hybrids; gliders; seabed crawlers
B	Sensing & comms	Early-warning barriers; positioning, C2 and AI layers
B	Mission management	Orchestration, multi-vehicle coordination and fleet control

ASSET TAXONOMY — CATEGORIES WITHIN CLASSES A, B, C AND D

A · Vessels and boats
2,540 EU-flagged fishing vessels; 2,007 dredgers and tugs; over 6 million recreational boats served by 10,000+ marinas, mostly SME or municipal; survey, monitoring and inland-service craft

B · Underwater systems
ROVs, AUVs, gliders and seabed crawlers; acoustic and fibre-optic early-warning barriers; trenchers and intervention tooling; seabed docking and charging; mission-orchestration layers

C · Equipment and payloads
Interchangeable mission modules; sonar, hyperspectral and distributed sensing; fuel cells, high-density batteries and hybrid DC micro-grids; aquaculture cage, feed and harvest systems

D · Infrastructure
Fixed and floating energy installations, multi-use platforms, cables and pipelines; ports, marinas and coastal defences; the class I–VII inland network; and a digital layer of twins, RIS and sensor networks binding them

GVA AND EMPLOYMENT BY ESTABLISHED SECTOR

Coastal tourism	82.0	2 560
Maritime transport	61.7	390
Marine living resources	37.9	1 090
Port activities	33.0	420
Shipbuilding & repair	19.9	312
Marine non-living res.	10.6	15
Marine renewable energy	5.3	15

Figure 1: Coastal tourism alone is 53% of employment and 33% of GVA; Germany, France, Italy and Spaintogether 60% of GVA. Marine renewable energy is the smallest established sector but the fastest-growing, and the main near-term driver of vessel demand.

OFFSHORE WIND — AMBITION AND DELIVERY GAP (GW)

2023	18.9
2024	21.2
2030 likely	-73
2030 target	111
2050 target	317

Figure 2: Europe installed 2.6 GW in 2024 and 2 GW in 2025 — the lowest annual addition since 2016 —against an original 2030 ambition of about 140 GW. Permitting, grid and supply-chain constraints define the deployment challenge. Some 122 GW is nonetheless expected over 2026–2035, and the January 2026 Hamburg Declaration commits nine North Sea states to 300 GW by 2050.

02 POLICY DRIVERS AND CONSTRAINTS

2.1. POLICY AND MARKET DRIVERS

Ocean governance and competitiveness.
The European Ocean Pact is the first single reference framework across all ocean policy areas, naming renewable energy, blue biotechnology, underwater robotics and ocean observationas priority fields and maritime security as an underlying condition.

Decarbonisation and the energy transition.
The Climate Law sets −55% by 2030, a binding −90% by 2040 and neutrality by 2050; FuelEU Maritime, ETS extension and AFIR convert these into procurement and retrofit demand for newbuilds and major retrofits.

Offshore renewable energy and multi-usedeployment.
111 GW by 2030 and 317 GW by 2050 require specialised vessels, floating and multi-purpose infrastructure, autonomous inspection, environmental intelligence and shared energy and logistics interfaces.

Water resilience and climate adaptation.
The Water Resilience Strategy and the adaptation framework require infrastructure managing flood risk, freshwater supply and estuarine salinisation across the land–sea and freshwater–seawater interfaces.

Security, preparedness and dual use.
Subsea cables carry 99% of intercontinental internet traffic; military mobility, NIS2 and the Preparedness Union Strategy impose dual-use requirements on coastal and inland infrastructure and on the systems that monitor and repair it.

Underwater robotics and subsea situational awareness.
The Maritime Security Strategy and Cable Security Action Plan require persistent monitoring only autonomous vehicles can deliver at scale; market sources put AUV and robotics growth at 7.8% to over 16% CAGR.

Spatial planning, boating and bankability.
The MSP Directive drives multi-use scenarios; the Biodiversity Strategy and Nature Restoration Law require nature-positive design from inception; the Recreational Craft and Concession Directives drive boating decarbonisation; and credible risk evidence underpins investment, insurance and permitting.

2.2 CONSTRAINTS AND BOTTLENECKS

Fragmented governance.
Offshore energy, transport, water management, environmental protection and digital services are planned in separate silos across national, regional and sectoral authorities, raising coordination costs and slowing permitting.

Single-purpose assets and the multiplier gap.
Most offshore, coastal and inland infrastructure serves one purpose; awareness of the multiplier effect of multi-purpose investment is low, so assets are under-used and co-benefits foregone.

Infrastructure and energy interface gaps.
Charging, fuel supply, docking and maintenance remain fragmented across ports, marinas, islands and offshore sites; power-sharing is not designed for and certification for multi-use energy distribution does not exist.

Missing interface standards.
Umbilicals,connectors, protocols and mission modules are proprietary per vessel and mission, so autonomous docking and charging cannot scale and modular reusable platforms cannot emerge.

Weak surface–underwater integration.
No standardised protocols exist for multi-vehicle coordination, swarm planning or cross-manufacturer cooperation, preventing the step from individual systems to coordinated fleets and integrated architectures.

Regulatory barriers and cyber-physical exposure.
Approval pathways for autonomous vessels, novel fuels and unmanned underwater systems are unharmonised; fragmented environmental datablocks adaptive operations; and rising connectivity enlarges the attack surface on assets exposed to hybrid threats.

SME capacity, finance, basin heterogeneity and skills.
Most operators are SMEs facing a €60–70 bnEU financing gap; solutions rarely transfer between basins; and deployment depends on crews and inspectors yet to be trained.

BLUE ECONOMY TECHNOLOGY ROADMAP

03 TARGET CAPABILITIES

CURRENT STATE-OF-PLAY

Blue-economy vessels, infrastructure and subsea systems are today largely single-purpose, fossil-fuelled and weakly interconnected. Vessels serve narrow mission profiles with substantial crew; infrastructure is asset-specific and depends on manual inspection; underwater operations are limited by endurance, fragmented data and cost; and regulation was designed for crewed, sector-bound operations. Marine renewable energy is the growth exception, but its €5.3 bn GVA in 2022 remains small relative to its deployment trajectory — which is the measure of the industrial build-out required.

2035

DEMONSTRATION AND EARLY DEPLOYMENT

Validated zero-emission and hybrid-electric vessels in aquaculture, offshore service, dredging, marine science and tourism; repairability and composite recovery standard in boatbuilding

Modular architectures with interchangeable mission modules demonstrated; remote and assisted operation validated in controlled environments

Digitally connected port microgrids and alternative-fuel bunkering hubs on TEN-T corridors; multi-purpose and nature-positive infrastructure piloted; common hazard taxonomy, HAZID methods and shared incident learning in place

Integrated surface-underwater demonstrators with mission orchestration, secure links and early Digital Ocean Twins; regulatory sandboxes support large-scale testing

2040

SCALE-UP AND SYSTEM INTEGRATION

Zero-emission vessels operating routinely in coastal, offshore and inland waters, with charging and fuel infrastructure across all strategic basins

Long-endurance autonomous underwater systems with AI mission planning and autonomous docking and charging reach maturity

Operational multi-use offshore DC microgrids coordinating wind, storage, vessel charging, aquaculture and subsea infrastructure, certified by class

Manufacturer-independent protocols for synchronised multi-vehicle missions, with distributed planning and failure tolerance; multi-hazard digital twins and coordinated emergency response across waterborne and shore-side assets

2050

FULL TRANSFORMATION

Standardised autonomous multi-mission platforms operating continuously within integrated ecosystems, on a circular shipbuilding base with digital material passports

Fully autonomous subsea networks with seabed charging and AI coordination, delivering near-zero unplanned downtime of critical infrastructure

Infrastructure operating as an intelligent, climate-resilient component of Europe's energy, water, flood-defence, transport and digital systems

A mature integrated underwater domain: resident systems, Digital Ocean Twins, secure communication backbones and mission orchestration platforms, with European leadership reflected in IMO and ISO standards

04 TECHNOLOGY PATHWAYS

OPERATIONAL OBJECTIVES — FIVE PATHWAYS

4.1 Zero-emission, modular and multi-mission vessels	Vessels for aquaculture, tourism, dredging, marking, research and small offshore logistics that support multiple missions over their lifetime, operate with minimal crew and adapt through modular energy, payload and automation interfaces.
4.1 Resilient, sustainable and interconnected infrastructure	The shift from isolated, asset-specific assets to digitally interconnected, secure, dual-use and nature-positive systems supporting multi-use operations across the land-sea and freshwater-seawater interfaces.
4.3 Advanced under water autonomy, sensing and intervention	Long-endurance, intelligent and interoperable underwater systems operating with minimal human oversight as part of coordinated surface-underwater-shore ecosystems, delivering high-quality data and reliable intervention.
4.4 Human-centred solutions, skills and workforce	A workforce able to operate zero-emission, autonomous and digitally integrated systems safely, through advanced training, ergonomic design and safe human-machine teaming across interconnected operational environments.
4.5 Regulatory frameworks, standards and governance	Harmonised European frameworks enabling deployment of autonomous vessels, underwater systems, floating infrastructure and digital platforms across all sea and river basins, including surface-underwater-shore interfaces.

05 ENABLERS AND DEPLOYMENT

AI and machine learning.
Mission planning, multi-asset coordination, anomaly detection, predictive maintenance and decision support —the principal means of reducing crew need and downtime. Trusted-AI frameworks required for safety-critical use.

Digital twins and data architectures.
Lifecycle optimisation, infrastructure health monitoring and mission rehearsal, dependent on interoperable standards and data governance across siloed sectors — without which twins stay isolated applications.

Propulsion and energy storage.
Fuel cells, high-density batteries, hybrid DC micro-grids, alternative fuels and seabed or inductive charging, with sizing matched to diverse duty cycles and offshore and inland bunkering deployed in step with vessels.

Autonomy and connectivity.
Autonomous navigation, sensor fusion, resilient SATCOM, 5G and acoustic-optical links; secure underwater command-and-control and standardised power, data and docking interfaces.

Advanced materials and sensing.
Lightweight composites, circular and recycled materials, eco-engineered structures and functionalised membranes; hyperspectral, acoustic and distributed sensing with design for repairability and recovery.

Energy and refuelling infrastructure.
Offshore charging, alternative-fuel bunkering and interoperable onshore power, extended to inland and coastal nodes, not only major seaports.

Regulation, standards and safety validation.
Sandboxes, objective-oriented legislation and adaptive certification, with shared testing environments and reusable risk evidence accessible to SMEs.

Cross-sector coordination.
Energy, aquaculture, tourism, transport, environment and digital services planned as one system, unlocking the multi-purpose multiplier.

Investment and risk-sharing.
PPPs, blended finance and the SustainableTransport Investment Plan against a€60–70 bn SME gap, with leasing and pooled procurement models.

Skills and safety validation.
Harmonised competency frameworks, competence centres and validated XR training, with shared testing environments and reusable risk evidence accessible to SMEs.

DEPLOYMENT PATHWAY — FROM LABORATORY VALIDATION TO MARKET NORM

Phase 1 · 2025–2030
Component testing, reference architectures, regulatory engagement and first pilot demonstrators

Phase 2 · 2030–2050
Integrated demonstrators at sea and on inland waters, regulatory approval, first commercial pilots with SME operators

Phase 3 · 2035–2040
Market launch, supply-chain development and scaling across European sea and river basins

Phase 4 · 2040–2050 MARKET NORM
Standardised, autonomous, zero-emission blue-economy operations as the European norm

06 EXPECTED IMPACTS

ENVIRONMENTAL

2035 Demonstrated zero-emission and hybrid solutions; expanded autonomous environmental monitoring; nature-positive infrastructure pilots

2040 Wider deployment of low- and zero-emission vessels and infrastructure; integrated monitoring and predictive environmental management

2050 Climate-neutral and circular assets; continuous ecosystem monitoring and climate-resilient infrastructure

TECHNOLOGY AND OPERATIONS

2035 Integrated surface–underwater demonstrators; early multi-asset coordination; autonomous inspection and docking/charging pilots

2040 Routine coordinated multi-vehicle operations; interoperable surface–underwater–shore systems; predictive maintenance at scale

2050 Persistent autonomous subsea networks integrated with vessels, infrastructure and shore-based systems

ECONOMIC AND INDUSTRIAL

2035 New markets for modular vessels, underwater robotics, sensing, energy and digital services

2040 Scaling of European shipyard, equipment manufacturing, system integration and underwater technology value chains

2050 European global leadership in integrated blue-economy and underwater technologies

SAFETY AND RESILIENCE

2035 Common risk methodologies and representative-scale validation

2040 Integrated multi-hazard monitoring, coordinated emergency response and reduced downtime

2050 Resilience-by-design and continuous assurance across interconnected blue-economy systems

SKILLS AND WORKFORCE

2035 New competencies and XR-based training for autonomous and digitally integrated operations

2040 Harmonised competence frameworks and workforce mobility

2050 Continuous pan-European skills development and adaptation to evolving technologies

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ROADMAP POSITIONING WITHIN THE WATERBORNE TECHNOLOGY LEADERSHIP FRAMEWORK

This roadmap operationalises the Technology Leadership[1] framework for Blue Economy. It translates the overarching objectives, including competitiveness, resilience, sustainability, zero-emission operations[2], digitalisation, safety and security, human-centred innovation, standards, skills and deployment at scale, into the specific conditions of the Blue Economy. It reflects the Technology Leadership document's ecosystem approach, linking shipowners, shipyards, equipment manufacturers, ports, energy, infrastructure and service providers, classification societies, financial institutions, authorities, research organisations and logistics users into a coordinated deployment pathway.

The roadmap on Blue Economy is closely interlinked with the following dedicated Technology Roadmaps: maritime technology sector, inland waterway transport and port ecosystems.

1 Waterborne Technology Platform, Waterborne Technology Leadership: Towards a Competitive, Resilient and Sustainable Waterborne Sector – A Co-programmed Partnership under Framework Programme 10, January 2026.

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

1. DESCRIPTION OF THE SECTOR

1. DESCRIPTION OF THE SECTOR

1.1 DEFINITION AND SCOPE

The Blue Economy broadly 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.[3] Its established sectors include marine living and non-living resources, marine renewable energy, port activities, shipbuilding and repair, maritime transport, and coastal tourism.[4]

Within the Waterborne Technology Platform, this broad economy-wide definition is implemented through nine complementary Technology Roadmaps. Inland Waterway Transport, Short Sea Shipping, Ferries, Cruise and Ocean-going shipping address the principal 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 functions addressed in the other roadmaps. Its core scope comprises specialised vessels, e.g. fisheries and aquaculture vessels, sustainable recreational boating and specialised tourism craft, multi-use infrastructure, 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 referenced where necessary, to describe the complete blue economy system, but their technology pathways are not elaborated here.[5]

3 European Commission and Joint Research Centre, The EU Blue Economy Report 2025 (Luxembourg: Publications Office of the European Union, 2025), 9.
4 European Commission and Joint Research Centre, EU Blue Economy Report 2025, 10.
5 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.

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.[6] Blue economy assets deliver renewable energy, freshwater, food, and ecosystem services, support ocean observation, marine research and climate adaptation, and contribute to the monitoring and protection of critical infrastructure.

Sustainable aquaculture and aquatic food production constitute one of the strategic mission domains of the European Blue Economy. Alongside offshore renewable energy, ocean observation and environmental monitoring, and the protection of critical underwater infrastructure, aquaculture is expected to drive demand for autonomous systems, environmental intelligence, digital platforms, resilient infrastructure and low-emission vessels across European coastal and inland waters. This role is increasingly reflected in European policy[7], which identifies sustainable aquaculture as a contributor to food security, resilience, innovation and strategic autonomy, and as a growing component of a sustainable European food system.

Recreational boating is an interconnected ecosystem covering boatbuilding, equipment manufacturing, repair and refit, marinas, charter services, nautical tourism and associated services. Recreational marine companies are direct and indirect suppliers of propulsion systems, equipment, materials, digital technologies, maintenance and infrastructure solutions to aquaculture, environmental monitoring, coastal services and other blue economy activities.

Infrastructure serving both coastal and inland environments must accommodate salinity gradients, freshwater-seawater interfaces, ecological transitions that affect material compatibility, and operational procedures. Ports, lock systems, marinas, and charging nodes operate under distinct ownership and governance structures (national authorities, municipalities, private operators) requiring integrated but decentralised control architectures. Climate resilience and adaptation requirements differ fundamentally across sea-level-rise-vulnerable coastal zones versus flood-risk-vulnerable inland corridors.

The underwater domain is a strategic European capability integrating robotics, sensing, communication, subsea infrastructure, mission orchestration, critical infrastructure protection and ocean data services, resulting in European Excellence in the Underwater Domain.

6 European Commission, The European Ocean Pact, COM(2025) 281 final (Brussels, 5 June 2025), 2.

7 European Commission, Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture for the Period 2021 to 2030, COM(2021) 236 final (Brussels, 12 May 2021); European Commission, "Aquaculture Guidelines," Oceans and Fisheries, accessed September 17, 2026, https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/aquaculture/aquaculture-guidelines_en.

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, emergency resources and regulatory interfaces. Ports provide essential logistics, energy, maintenance and data nodes and are treated in detail in the Technology Roadmap Port Ecosystems. 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 Maritime 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 interrelated asset classes: vessels and boats; underwater systems; equipment and payloads; and infrastructure. The classification is functional and application oriented. Equipment, payloads and digital capabilities may operate across several asset classes, while digital layer provides the principal integration mechanism between them. 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.

A. Vessels and boats:

- **Fisheries and aquaculture craft** includes 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,[8] together with aquaculture service, well-boat, feed-supply and harvest craft.[9]
- **Offshore service and support vessels** comprise dredgers and tugs, the second most numerous type at **2,007 vessels**,[10] alongside cable-laying, stone-dumping, heavy-lift installation and shallow-water support craft. More recent Clarksons Research data cited by ES|ECSA indicate 1,567 offshore vessels and a further 549 dredgers as of January 2026, suggesting a broadly comparable fleet size, although the underlying classifications differ.[11]
- **Recreational and tourism craft** constitute a distinct industrial base of over 6.5 million boats, many with a lifespan exceeding 40-50 years, served by more than 10,000 marinas, in which European Union manufacturing and refit capacity is globally competitive.[12] This requires specifically solutions applicable to boats already in use.
- **Research, monitoring and specialised** craft cover survey, aids-to-navigation, environmental-monitoring and inland-waterway service vessels.

8 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.
9 European Commission, Staff Working Document on the Energy Transition of the EU Fisheries and Aquaculture Sector — Aquaculture Factsheets, SWD(2024) 280 final (Brussels, 13 December 2024), https://aquaculture.ec.europa.eu/system/files/2024-12/SWD_2024_Energy%20Transition.PDF; S. Thermes, R. Van Anrooy, A. Gudmundsson, and D. Davy, Classification and Definition of Fishing Vessel Types, 2nd ed. (Rome: FAO Fisheries and Aquaculture Technical Paper No. 267, 2023), figs. 54–56.
10 European Commission and Joint Research Centre, EU Blue Economy Report 2025, 43.
11 European Shipowners (ES|ECSA), The Economic Value of European Shipping (2026 update) (Brussels: ES|ECSA, 2026), citing Clarksons Research, data as of January 2026.
12 European Boating Industry, Manifesto for a Sustainable Boating Industry (Brussels: European Boating Industry, 2026), 2.

B. 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.
- **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.[13]

C. Equipment and payloads

- **Equipment and payloads** comprise the mission-specific and value-bearing components deployed across vessels, underwater systems and infrastructure. They include interchangeable mission modules for inspection, sampling, intervention and logistics; sensing payloads including multibeam and side-scan sonar, hyperspectral, acoustic and distributed sensing; energy and propulsion systems including fuel cells, high-density batteries, hybrid direct-current micro-grids, and sustainable alternative-fuel systems; and specialised equipment for applications such as aquaculture. They may be upgraded or replaced independently of the hull, vehicle or structure on which they are deployed, making modularity at payload level a principal means of extending asset capability and enabling multi- mission operation over its lifetime.[14]
- **Their integration** increasingly depends on standardised mechanical, electrical, power, communication and data interfaces, allowing equipment and payloads to operate across different platforms and supporting interoperable surface-underwater-infrastructure systems.

D. Infrastructure

- **Offshore infrastructure** comprises fixed and floating energy installations, multi-use platforms and hubs, and the submarine cable and pipeline network.[15]
- **Coastal infrastructure** comprises seaports and their onshore power supply and sustainable alternative-fuel bunkering facilities, marinas, flood and coastal defences, and nature-based and eco-engineered structures.[16]
- **Inland-waterway infrastructure** comprises the class I-VII navigable network with its locks, weirs, dams, bridges, dikes and navigation channels. [17]
- **The digital layer** comprises digital twins, river information services, interoperable data platforms, persistent sensor networks and associated communication and data architectures. It is represented here under infrastructure because parts of this layer constitute persistent shared digital infrastructure. Funtionally, however, it is a cross-cutting integration layer spanning all four asset classes, connecting vessels and boats, underwater systems, equipment and payloads, and physical infrastructure into interoperable operational ecosystems. Its enabling technologies and deployment requirements are therefore further addressed in Section 5.1.
- **Underwater infrastructure** comprises subsea sensor and observation networks, resident subsea installations, underwater communication backbones, subsea energy distribution and charging systems, and protected cable and pipleline corridors. It provides the presistent seabed and water-column infrastructure required for monitoring, communcation, energy supply, inspection and intervention.

13 European Commission, European Ocean Pact, 10.

14 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.

15 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.

16 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.

17 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

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. Small local marinas, yacht harbours and leisure harbours across coastal and inland waters. Most marinas are SMEs or municipally operated facilities.
	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
	Mission and fleet management	Mission orchestration systems; underwater management systems; multi-vehicle coordination systems; autonomous mission planning engines; fleet monitoring and control systems; collaborative autonomy services.

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.

Asset class	Category	Principal assets
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; sustainable alternative-fuel systems; shore-power interfaces
	Aquaculture equipment	Cages and net systems; feed and harvest systems; recirculating systems
D. Infrastructure	Offshore	Fixed and floating energy installations; multi-use platforms and hubs; submarine cables and pipelines
	Coastal	Seaports with OPS and sustainable 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
	Underwater infrastructure	Subsea sensor networks; seabed infrastructure and observations; critical subsea infrastructure monitoring systems; resident subsea infrastructure; underwater communication backbones; subsea energy distribution and charging networks; protected cable and pipeline corridors.

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.

The four asset classes are not standalone categories. Blue economy operations increasingly depend on their integration into connected surface-underwater-shore systems, linking vessels, autonomous systems, equipment and payloads, fixed infrastructure, communication networks and digital mission control platforms.

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.[18] Missions are frequently short-duration, repetitive, hazardous or remote, and they are performed across the full range of European conditions, from ice-affected northern waters to the enclosed Mediterranean and the class I-VII inland waterway network.[19]

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;[20] 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.[21]

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.[22] 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.[23]

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.[24] 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.

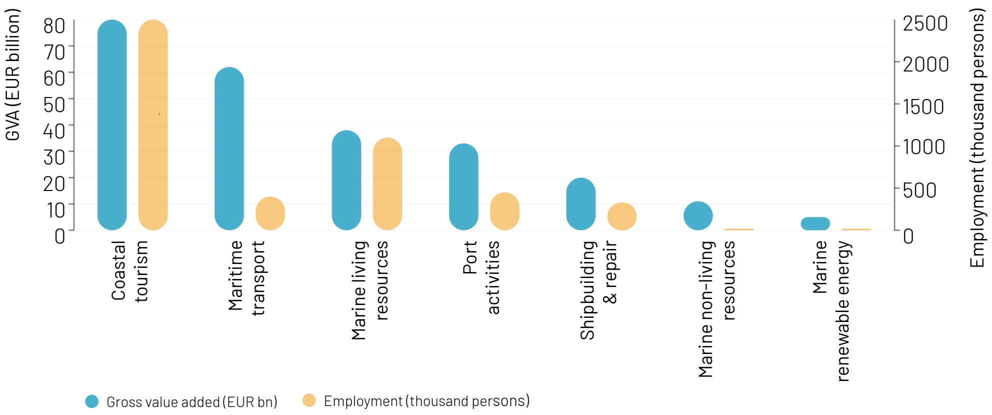


Figure 1: EU Blue Economy: gross value added and employment by established sector, 2022
Source: European Commission and Joint Research Centre, The EU Blue Economy Report 2025, Table 3, p. 13 (2022 data).

18 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.

19 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.

20 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.

21 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.

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

23 Ibid., 10.

24 Ibid., 11.

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 (Germany, France, Italy and Spain) together generated 60 % of GVA and 52 % of employment.[25] 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.[26]

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.[27] 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.[28] 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.[29]

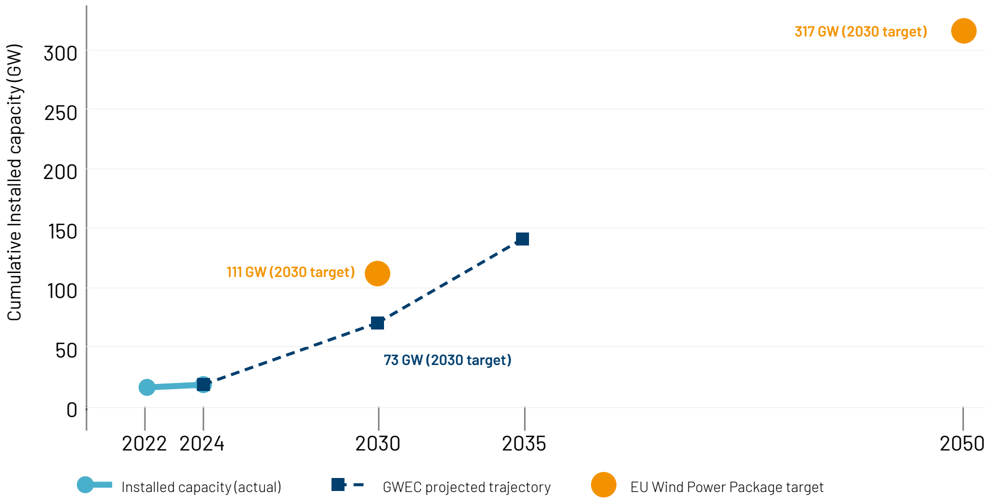


Figure 2: EU Offshore wind: installed capacity, projected trajectory and 2030/2050 targets
Source: EU Blue Economy Report 2025, p. 30; GWEC, Global Offshore Wind Report 2026, pp. 62, 77.

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.[30] Resilient, adaptive and nature-positive infrastructure is therefore a baseline requirement rather than an option.

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

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 demonstrate and scale replicable solutions.[31] Demonstration in blue-economy applications can generate European capability in modular zero-emission vessels, multi-purpose and nature-positive infrastructure, integrating robotics, sensing, communication, subsea infrastructure, mission orchestration, critical infrastructure protection, ocean data services, autonomous underwater systems, and secure ship-to-shore and asset-to-grid data architectures.[32]

This capability is a condition of strategic autonomy, resilience and sovereignty. Anchoring the design, construction and operation of blue-economy assets in the European value chain strengthens industrial competitiveness, security of supply, and the European Union's capacity to protect its critical maritime and inland-water infrastructure.[33] Furthermore, the roadmap offers a pathway to European excellence in growing markets, like the strong potential in AUVs and underwater robotics, where market sources indicated a Compound Annual Growth Rate ranging from approximately 7.8% to over 16% depending on scope and geography. The chapters that follow derive the drivers, target capabilities, technological pathways, enablers and impacts from this objective.

31 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.

32 Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0, 11; Waterborne Technology Platform, Waterborne Technology Leadership, 24.

33 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. DRIVERS AND CONSTRAINTS

2.1 POLICY AND MARKET DRIVERS

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.[34] It also establishes maritime security and defence as an underlying condition for the sector, linking industrial capability to the protection of critical maritime infrastructure.[35] Furthermore, the Industrial Maritime Strategy includes certain blue economy domains, including the potential for dual-use purposes and the related competitiveness of the European maritime technology sector.
- **Decarbonisation and the energy transition.** Binding European Union climate legislation drives demand for zero-emission vessels, sustainable alternative fuels and offshore renewable energy. The European Climate Law establishes a 2030 target of at least 55 % net reduction in greenhouse gas emissions relative to 1990, a binding 2040 milestone of a 90 % net reduction, and climate neutrality by 2050. 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. These instruments convert climate obligations into procurement and retrofit demand.
- **Digitalisation, automation and data-driven logistics**. Ecosystem performance increasingly depends on interoperable digital systems, digital twins, AI-enabled planning, zero-emission and automated equipment and trusted data exchange with vessels, authorities and hinterland networks. Digitalisation is therefore a competitiveness driver, but also a condition for resilience, safety, energy optimisation and multimodal integration.
- **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.[36] 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.[37] 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.[38] Adaptation and resilience are therefore design objectives for waterborne infrastructure rather than downstream considerations.

34 European Commission, European Ocean Pact, 10; Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0 (Brussels: Waterborne Technology Platform, June 2025), 7–8.

35 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).

36 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.

37 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.

38 European Commission, European Water Resilience Strategy (Brussels, 2025), 280 final (Brussels, 4 June 2025). 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.

- **EU Biodiversity Strategy & Nature Restoration Law.** The EU Biodiversity Strategy for 2030 and the proposed Nature Restoration Law establish binding targets for aquatic and marine ecosystems, requiring ecosystem-positive impact. Blue economy infrastructure must be designed as "nature-positive" from inception.[40]
- **Fisheries Sustainability & Aquaculture Transition Policy.** The EU Common Fisheries Policy, FAO Guidelines for Responsible Fisheries and OECD Recommendations imply that fishing fleet decarbonisation is inseparable from operational sustainability. Zero-emission fishing vessels with integrated environmental monitoring become compliance tools.[41]
- **Multi-Use Maritime Spatial Planning & Cumulative Impact Assessment.** The EU Maritime Spatial Planning Directive drives technology to support multi-use operational scenarios (offshore wind + aquaculture + submarine cables + marine research + military mobility), designed to co-exist and coordinate.
- **Drivers for boating.** The Recreational Craft Directive, AIFR, the Concession Directive and tourism-related infrastructure planning are key drivers for decarbonisation of the European boating industry.[42]
- **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.[43] The military mobility framework, the NIS2 Directive and the Preparedness Union Strategy impose dual-use requirements on inland-waterway and coastal infrastructure and on the systems that monitor, protect and rapidly repair it.[44]
- **Underwater robotics and subsea situational awareness.** The convergence of offshore energy expansion, subsea cable proliferation and hybrid threats to critical maritime infrastructure is generating structural demand for autonomous underwater systems across civil, dual-use and defence-adjacent applications. The European Ocean Pact identifies underwater robotics as a priority technology field. The revised EU Maritime Security Strategy and the Cable Security Action Plan require persistent subsea monitoring and rapid-response inspection capabilities that only autonomous and semi-autonomous vehicles can deliver at scale. On the civil side, offshore wind inspection and maintenance, subsea cable monitoring and environmental ocean observation are accelerating commercial adoption of ROV and AUV systems. These converging demand signals, regulatory, operational and security-driven, establish underwater robotics as a technology field with compounding public and private investment across the Blue Economy.
- **Bankability, insurability, permitting confidence and societal acceptance.** Blue economy projects often deploy novel technologies in exposed environments with limited incident data and complex interfaces between operators, communities and public authorities. Credible risk evidence, resilient design and tested emergency arrangements reduce uncertainty for investors and insurers, support faster permitting, informed public perception, and strengthen local acceptance.

40 European Commission, Communication on an EU Biodiversity Strategy for 2030 — Bringing Nature Back into our Lives, COM(2020) 380 final (Brussels, 20 May 2020), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380; Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on Nature Restoration and amending Regulation (EU) 2022/869, OJ L, 2024/1991, 29.7.2024, in force since 18 August 2024, art. 5 (marine ecosystems), https://eur-lex.europa.eu/eli/reg/2024/1991/oj.

41 Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, OJ L 354, 28.12.2013, pp. 22–61, https://eur-lex.europa.eu/eli/reg/2013/1380/oj; FAO, Code of Conduct for Responsible Fisheries (Rome: FAO, 1995), art. 9 (Aquaculture Development), https://www.fao.org/4/v9878e/v9878e00.htm; OECD, OECD Review of Fisheries 2025 (Paris: OECD Publishing, 2025), https://www.oecd.org/en/publications/2025/02/oecd-review-of-fisheries-2025_d308ff48.html.

42 Directive 2013/53/EU of the European Parliament and of the Council of 20 November 2013 on Recreational Craft and Personal Watercraft, OJ L 354, 28.12.2013, pp. 90–131, https://eur-lex.europa.eu/eli/dir/2013/53/oj; Regulation (EU) 2023/1804 (Alternative Fuels Infrastructure Regulation), OJ L 234, 22.9.2023, https://eur-lex.europa.eu/eli/reg/2023/1804/oj; Directive 2014/23/EU of the European Parliament and of the Council of 26 February 2014 on the Award of Concession Contracts, OJ L 94, 28.3.2014, pp. 1–64, https://eur-lex.europa.eu/eli/dir/2014/23/oj.

43 European Commission, European Ocean Pact, 2.

44 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),JOIN (2025) 130 final (Brussels, 26 March 2025). On ports as critical infrastructure subject to cybersecurity obligations, see European Commission and Joint Research Centre, EU Blue Economy Report 2025, 42.

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.[45]
- **Fragmented underwater power & communication standards.** Underwater systems (ROVs, AUVs, gliders, seabed sensors) require proprietary umbilicals, power connectors and protocols per vessel and mission. Each mission needs custom integration, autonomous docking and charging cannot scale, and in addition the supply chain is fragmented. Modular reusable platforms cannot emerge.
- **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.[46]
- **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 (AFIR) sets minimum requirements, investment in supporting energy and refuelling infrastructure continues to lag demand, keeping many zero-emission vessel concepts at the demonstration stage.[47] Offshore wind, floating aquaculture, subsea cables and vehicle charging require coordinated DC microgrid management and dynamic power allocation. Current infrastructure is not designed for power-sharing, and certification for multi-use energy distribution does not exist.
- **Real-time environmental data assimilation & adaptive operations.** Fragmented data sources, non-standardised formats and absence of integrated environmental intelligence platforms prevent real-time adaptive operations. AI-enabled adaptive mission planning requires validated environmental models and historic data depth that does not yet exist for emerging operations.
- **Security and cyber-physical exposure.** Increasing automation and connectivity enlarge the cyber-attack surface of operations and energy systems. Critical infrastructure, including underwater assets, is exposed to sabotage and hybrid threats. Resilience must be designed into system architecture rather than added afterwards.
- **Modular vessel design & standardised mission module interfaces.** Each mission module (sonar, robotic arm, aquaculture equipment, sensors) requires custom mechanical, electrical, hydraulic and data integration per vessel class. Standardised interfaces are prerequisites for modular deployment at scale.

45 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.
46 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.
47 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.

- **Insufficient integration of the underwater domain with sea-surface assets,** offshore infrastructure and digital command layers. Future underwater operations require integrated surface-underwater architectures linking vessels, USVs, offshore platforms, resident subsea systems, seabed infrastructure, communication networks, mission orchestration systems and digital twins.
- **Distributed autonomous system coordination & swarm operations.** No standardised protocols exist for real-time multi-vehicle coordination, swarm mission planning and priority arbitration, failure tolerance, or cross-manufacturer cooperation. This prevents scaling from individual systems to coordinated fleets.
- **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.[48]
- **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 European Union financing gap estimated at EUR 60 to 70 billion.[49] Scalable, modular and cost-effective solutions, supported by blended finance and risk-sharing instruments, are therefore prerequisites for uptake.
- **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.[50]
- **Skills availability and workforce shortages are cross-cutting constraints.** The safe deployment of new fuels, electrification, circularity, digital systems, automation, remote and underwater operations depends on the availability of suitably trained personnel, shore operators, crews, emergency responders, inspectors and maintenance teams. Automation, remote technical support and digital decision-support tools can improve safety, reduce workload and make blue economy operations more attractive for future generations of professionals. Skills gaps may slow deployment or increase operational risk. Training systems, competence standards and certification requirements will need to evolve in parallel with innovations, while human-centered design will be necessary to ensure that digital and automated systems support rather than overburden personnel and crew.

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.[51] The pathways are aligned with the missions of the waterborne sector set out in the Technology Leadership document. [52]

48 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.
49 European Commission, European Ocean Pact, 6
50 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.
51 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).
52 Waterborne Technology Platform, Waterborne Technology Leadership (Brussels: Waterborne Technology Platform, 2026), 24–26.

3. TARGET CAPABILITIES

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.[53] Each horizon states the capability the European Blue Economy must possess, expressed in technology-readiness-level (TRL) terms, to remain competitive and to meet European 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 sustainable alternative fuel and charging infrastructure is unevenly distributed.[54] 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.[55]

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 tourism and recreation. Compatible sustainable liquid fuels, electric propulsion in suitable applications, hybrid systems and targeted demonstration of emerging technologies for the boating industry will be deployed. Furthermore, for the boating industry, repairability, dismantling, material traceability and composite recovery will be standard practices. 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 sustainable alternative fuel bunkering hubs are established on major TEN-T corridors, alongside demonstrator fleets of autonomous underwater and surface systems for inspection and monitoring.

53 Waterborne Technology Platform, Strategic Research Agenda (SRA), v5.0 (Brussels: Waterborne Technology Platform, June 2025), 7–8; Waterborne Technology Platform, Waterborne Technology Leadership, 24–26.
54 Waterborne Technology Platform, Waterborne Technology Leadership, 24–25.
55 European Commission and Joint Research Centre, EU Blue Economy Report 2025, 12.

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.[56] Furthermore, standardised digital platforms integrate real-time environmental monitoring with operational systems for adaptive mission planning, dynamic resource allocation and coordinated multi-vehicle operations, with interoperability across data sources, platforms and infrastructure operators. Common hazard taxonomy and HAZID methods are in place across major asset classes and shared incident and near-miss learning platform established. This is further strengthened by validated fire, battery, fuel and hazardous-release safety concepts. Integrated sea-surface and underwater demonstrators validate coordinated operations between support vessels, USVs, AUVs, ROVs, seabed sensors and offshore infrastructure. Demonstrators include mission orchestration systems, underwater management systems, secure underwater communication links and early Digital Ocean Twin interfaces for inspection, monitoring and environmental observation.

Standardised electrical power supply, communication protocols, and mechanical connection interfaces enabling plug-and-play deployment of interchangeable underwater systems. This includes type-approval by classification societies enabling multi-supplier markets. Digital twins and AI-enabled traffic coordination should be in initial deployment across clusters. Autonomous vessel-traffic-coordination should be integrated with port digital platforms, integrated cybersecurity platforms should be rolled out, and adaptive and nature-based infrastructure should be demonstrated. Digital training programmes should be introduced.

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 sustainable 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 technological maturity, and coordinated multi-vehicle operations are integrated into infrastructure monitoring and maintenance workflows. Operational multi-use offshore DC microgrids coordinate wind generation, storage (batteries, hydrogen), vessel charging, aquaculture equipment and subsea infrastructure, with dynamic power allocation and autonomous load management, certified by classification societies. 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.[57]

56 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.

57 Waterborne Technology Platform, Waterborne Technology Leadership, 26, on integrated offshore systems and mature digital operations by 2040.

Standardised protocols enable coordinated operation of multiple autonomous vehicles performing synchronised missions, with real-time communication, distributed mission planning, failure tolerance and graceful degradation, manufacturer independent and cross-platform. Multi-hazard digital twins will link waterborne and shore-side assets, and coordinated detection, containment and emergency response is in place. Furthermore, climate and hybrid-threat stress testing at sea and river-basin level are common practice. Coordinated surface-underwater operations become operationally integrated into offshore energy, subsea cable monitoring, environmental observation and critical infrastructure inspection workflows. Mission orchestration systems and underwater management systems should support multi-vehicle coordination, fleet monitoring, autonomous task allocation, secure communications and predictive maintenance across surface and subsea assets.

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.[58] Resilience-by-design and continuous assurance across value chains is a key component of the Blue Economy.

Europe operates a mature, integrated underwater domain capability based on persistent autonomous subsea networks, resident systems, seabed charging, Digital Ocean Twins, secure communication backbones and mission orchestration platforms. This will support European excellence and leadership in underwater systems for the Blue Economy, offshore energy, environmental monitoring and critical infrastructure protection.

58 European Commission and Joint Research Centre, EU Blue Economy Report 2025, 30.

4. TECHNOLOGY PATHWAYS

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. Their deployment increasingly depends on interoperable physical and digital interfaces and on the coordinated operation of surface, underwater and infrastructure assets within common energy, data and operational ecosystems.

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.[59] 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. Modular architectures should support efficient integration, replacement and upgrading of mission equipment through compatible mechanical, electrical, energy, control and data interfaces. Digital systems should also support mission-specific monitoring, traceability and regulatory reporting where relevant.

Capability trajectory

By 2035 (TRL 6–7). Modular and zero-emission vessel concepts are demonstrated in representative operations. Hybrid-electric and sustainable 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, using compatible mechanical, electrical, energy and data interfaces that enable efficient module integration and reconfiguration. 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 mechanical, electrical, energy and digital 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, mission optimisation and compliance reporting.

59 Waterborne Technology Platform, Waterborne Technology Leadership, 24, on leadership in the design, production, operation and maintenance of blue economy vessels.

By 2050 (TRL 8–9). Standardised autonomous multi-mission vessels operate continuously as part of integrated offshore, coastal and inland-water ecosystems, interacting seamlessly with underwater systems, infrastructure and shore-based operational services. 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.[60] Resilience unfolds across four interconnected capacities: planning and preparation, absorption and response, recovery and adaptation, and transformation towards enhanced performance. 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, 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, data and subsea ecosystems, connecting the land-sea and freshwater-seawater interfaces. This includes coordinated interaction between fixed and floating infrastructure, surface and underwater assets, sensing and communication networks, and shore-based systems. Safety and resilience should be addressed from the design stage, taking account of dependencies between interacting assets and services.

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. Integrated production and service concepts link renewable energy, aquaculture, environmental monitoring and shared logistics or maintenance functions. 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, including initial integration of surface and underwater monitoring data.

60 Waterborne Technology Platform, Waterborne Technology Leadership, 25, on resilient, sustainable and interconnected infrastructure that is durable, adaptive and nature-positive.

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. Shared energy systems use interoperable architectures and control interfaces that enable safe coordination of generation, storage and multiple users. Interoperable digital platforms enable real-time coordination between offshore assets, vessels, ports, underwater systems and onshore grids, AI-enabled monitoring and predictive maintenance become standard practice, supported by integrated digital representations of connected surface, subsea and shore-based assets, 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 substantially reduce unplanned downtime and support rapid detection, response and restoration. Surface, underwater and shore-based assets operate as interoperable components of these infrastructure ecosystems, sharing energy, data, monitoring and operational services. 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.[61] 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. At scale, these systems should operate as part of coordinated surface-underwater-shore ecosystems, supported by capabilities that integrate mission planning, task allocation, vehicle supervision, communications, data management and interaction with infrastructure.

61 European Commission, European Ocean Pact, 10.

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. Initial mission-orchestration capabilities support vehicle monitoring, task allocation and coordinated operations between underwater systems and associated surface or shore-based assets. Interoperable power, communication and data interfaces are demonstrated for vehicles, launch-and-recovery systems and docking or charging infrastructure.

By 2040. Coordinated multi-vehicle operations over extended ranges are supported by interoperable standards, secure communication and real-time digital twins. Mission-orchestration systems enable coordinated mission planning, dynamic task allocation, fleet supervision and collaborative autonomy across heterogeneous underwater and surface systems. Autonomous docking, charging and data transfer support longer-duration and increasingly resident operations. Underwater systems are routinely integrated into offshore infrastructure monitoring and maintenance workflows, as well as environmental monitoring, aquaculture and other relevant blue economy applications.

By 2050. Fully autonomous subsea robot networks operate continuously, supported by seabed charging, AI-based mission coordination and persistent sensing, and high capacity, resilient underwater communication networks combining acoustic, optical and other emerging communication technologies as appropriate. Integrated surface, underwater and shore-based systems support persistent monitoring, inspection and intervention across blue economy applications, substantially reducing unplanned downtime of critical subsea infrastructure and enabling 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.[62] The increasing integration of surface, underwater and shore-based systems will also require personnel to work effectively across interconnected digital and operational environments. 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, including training for remote supervision, multi-asset operations and complex or hazardous scenarios.

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

By 2040. Harmonised competency standards and certified training curricula support routine deployment across Member States, covering increasingly autonomous, remotely supported and digitally interconnected operations.

By 2050. A pan-European skills ecosystem enables continuous learning and workforce mobility across the Blue Economy, supporting the continuous adaptation of competences as technologies, operational roles and levels of automation evolve.

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, underwater communication and power/data interfaces, and digital interoperability.[63] 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, including interoperable interfaces between surface, underwater and shore-based systems.

Capability trajectory

By 2035. Coordinated EU regulatory sandboxes and test sites support large-scale testing of autonomous vessels, underwater systems and multi-use infrastructure, including integrated surface – underwater operations, interoperability and novel communication, charging and data interfaces.

By 2040. Harmonised EU standards and adaptive certification pathways are in force for autonomous and remotely operated systems, multi-use infrastructure and interoperable surface-underwater-shore interfaces, enabling replication across Member States and European sea and river basins.

By 2050. European leadership is reflected in global IMO and ISO standards, underpinned by interoperable digital, underwater communication and system interface, and cybersecurity standards for integrated blue-economy systems.

63 Waterborne Technology Platform, Waterborne Technology Leadership, 25, on regulatory frameworks, standards and governance.

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

Table 2: Summary of technology-pathway milestones

5. KEY ENABLERS AND DEPLOYMENT

5. KEY ENABLERS AND DEPLOYMENT

5.1. CROSS-CUTTING ENABLING TECHNOLOGIES

A common set of enabling technologies underpins all five pathways and provides the digital integration layer connecting the four asset classes identified in Section 1.3

- **Artificial intelligence and machine learning.** AI supports mission planning, multi-asset coordination, 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.[64]
- **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. Common data architectures should enable integration of operational environmental and asset condition data across surface, underwater and shore-based systems, supporting AI-enabled decision making and multi-stakeholder coordination. Without interoperability, digital twins remain isolated applications rather than system-level enablers.[65]
- **Propulsion and energy storage.** Fuel cells, high-density batteries, hybrid DC micro-grids, sustainable 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.[66] For multi-use infrastructure, shared energy systems require interoperable control architectures, power quality management and resilient coordination of generation, storage and multiple users.
- **Autonomous systems, communications and connectivity.** Autonomous navigation, multi-vehicle coordination, sensor fusion and resilient SATCOM, 5G and acoustic-optical communication enable remote and unmanned operation. Secure underwater communication and command-and-control architectures are essential for coordinated multi-vehicle operations, resident subsea systems, persistent monitoring and interaction between underwater, surface and shore-based assets. Standardised power, communication and data interfaces should support interoperability between vehicles, docking and charging systems, infrastructure and control platforms. 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.[67]
- **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. Design for circularity and repairability should also extend to subsea equipment and mission modules, supporting reuse, refurbishment and end-of-life recovery.[68]

64 Waterborne Technology Platform, Waterborne Technology Leadership, 25, on AI-enabled mission planning and underwater situational awareness.
65 Waterborne Technology Platform, Waterborne Technology Leadership, 25, on interoperable digital infrastructures enabling real-time coordination with vessels, ports and onshore grids.
86 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.
87 Waterborne Technology Platform, Waterborne Technology Leadership, 25, on autonomous docking and charging and on robust underwater communication.
68 Waterborne Technology Platform, Waterborne Technology Leadership, 25, on environmental sensing and integrated monitoring systems for structural health, environmental conditions and climate impacts.

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, sustainable alternative fuel bunkering and interoperable onshore power supply must be deployed alongside vessel development, in line with the Alternative Fuels Infrastructure Regulation.[69] Absent this infrastructure, zero-emission concepts remain confined to demonstration. Deployment must extend to inland-waterway and coastal nodes, not only major seaports.
- **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. Testing should progressively address integrated surface-underwater operations and interoperable communication, charging, power and data interfaces. 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.[70] 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.[71] The maritime industrial base and ports function as the critical nodes through which this investment is delivered.[72] Financing models should accommodate the different investment capacities and operational profiles of blue-economy SMEs, including leasing, pooled or cooperative procurement and other risk-sharing models where appropriate.
- **Safety validation and risk management.** Shared testing and validation environments, harmonised risk assessment approaches and mechanisms for learning from operational experience should support safe deployment across offshore, coastal and inland water applications. Representative evidence should support adaptive certification, permitting, insurance and emergency planning, while remaining accessible to SMEs.

69 Regulation (EU) 2023/1804 (AFIR), OJ L 234, 22.9.2023.
70 European Commission, European Ocean Pact, 6.
71 European Commission, Sustainable Transport Investment Plan, COM(2025) 664 final (Brussels, 2025).
72 European Commission, European Ocean Pact, 11.

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. [73]

Integrated demonstration environments should progressively move from validation of individual assets towards system-level deployment involving surface vessels and autonomous surface systems, underwater vehicles, resident subsea systems, sensors, communication and docking/charging infrastructure, and digital coordination platforms. The objective is to validate complete operational ecosystems for monitoring, inspection, intervention and environmental observation rather than isolated technologies.

Sea- and river-basin living labs can provide representative environments for testing multi-use configurations, interoperability, environmental performance and resilience under different regional conditions. Where relevant, demonstrations should combine operational, environmental, safety and cyber scenarios and involve operators, authorities, technology providers and emergency-response actors from an early stage.

Deployment environments should also demonstrate how environmental and asset-monitoring data can support coastal and inland-water resilience, including flood-risk management, freshwater–seawater interfaces and ecosystem monitoring.

5.4. KEY DEPLOYMENT ACTORS

- **European Commission.** Horizon Europe, the Innovation Fund, the Connecting Europe Facility, the European Competitiveness Fund 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.[74]
- **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.[75]
- **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.[76]
- **Ports, waterway and energy operators.** Ports, inland-waterway authorities and energy operators deliver the infrastructure investment and grid integration on which sustainable alternative fuels, charging and offshore energy depend, acting as the critical nodes of the system.[77]
- **Shipyards, system integrators and technology suppliers.** European shipyards, maritime equipment manufacturers and system integrators design, develop, test and translate propulsion, robotics, sensing, communication, energy and digital technologies into deployable vessels and integrated blue-economy systems. They provide design, construction, retrofit, integration, testing, launch-and-recovery integration, maintenance and lifecycle support, and are therefore central to scaling technologies from demonstrators to operational fleets and infrastructure.
- **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.[78]

73 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.

74 European Commission, European Ocean Pact, 6, 11; European Commission, Sustainable Transport Investment Plan, COM(2025) 664 final (Brussels, 2025).TP, January 2026), section "Items raised reconfirmed during the meetings", points 1–2.

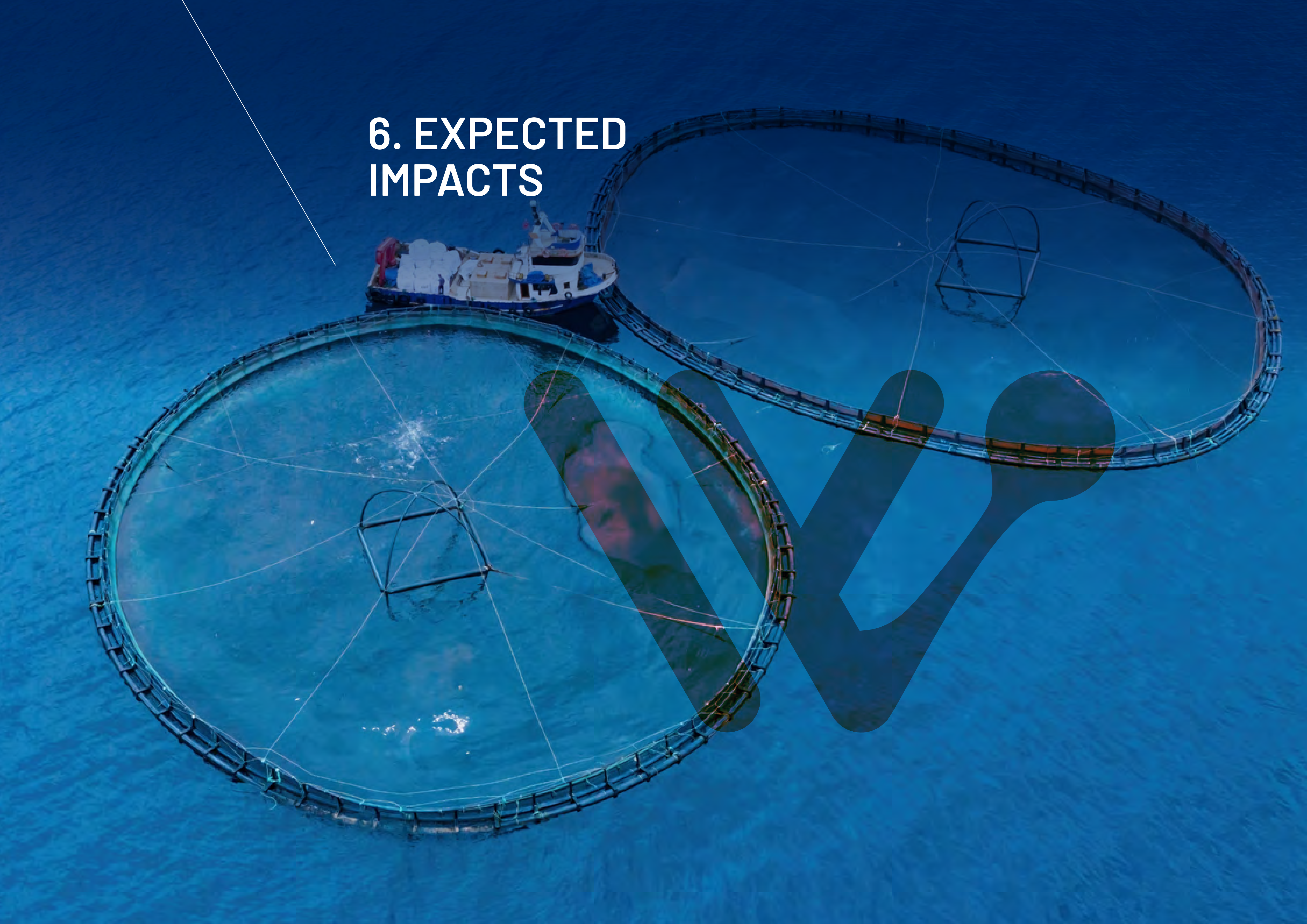
75 European Commission, European Ocean Pact, 6, on the Union financing gap for blue-economy SMEs of EUR 60 to 70 billion.

76 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.

77 European Commission, European Ocean Pact, 11; European Commission, EU Ports Strategy, COM(2026) 112 final (Brussels, 2026).

78 European Commission, European Ocean Pact, 6, 12.

6. EXPECTED IMPACTS



6. EXPECTED IMPACTS

The implementation of this roadmap is expected to generate environmental, economic, industrial, social, safety and scientific impacts across offshore, coastal and inland water applications. Because the transformation will progress from demonstration to scale-up and finally to integrated operation, impacts should be assessed across the 2035, 2040 and 2050 horizons, taking account of technological maturity, deployment scale and differences between sea and river basins.

Impact area	2035 — demonstration and early deployment	2040 – Scale-up and integration	2050 – Full transformation
Environmental	Demonstrated zero emission and hybrid solutions; expanded autonomous environmental monitoring; nature positive infrastructure pilots	Wider deployment of low-/zero-emission vessels and infrastructure; integrated environmental monitoring and predictive management	Climate neutral and circular blue economy assets; continuous ecosystem monitoring and climate resilient infrastructure
Technology and operations	Integrated surface underwater demonstrators; early multi-asset coordination; autonomous inspection and docking/charging pilots	Routine coordinated multi-vehicle operations; interoperable surface-underwater-shore systems; predictive maintenance and remote operation at scale	Persistent autonomous subsea networks integrated with vessels, infrastructure and shore-based systems
Economic and industrial	New markets for modular vessels, underwater robotics, sensing, energy and digital services	Scaling of European shipyard, equipment manufacturing and system integration and underwater technology value chains	European global leadership in integrated blue economy and underwater technologies
Safety and resilience	Common risk methodologies and representative scale validation	Integrated multi-hazard monitoring, coordinated emergency response and reduced downtime	Resilience-by-design and continuous assurance across interconnected blue economy systems
Skills and workforce	New competencies and XR-based training for autonomous and digitally integrated operations	Harmonised competence frameworks and workforce mobility	Continuous pan-European skills development and adaptation to evolving technologies

Table 3: Expected Impacts

6.1 ENVIRONMENTAL IMPACTS

- Emissions reduction: Zero-emission propulsion and sustainable 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.[79] Integrated surface, underwater and shore-based monitoring support continuous assessment of ecosystem condition, water quality and the environmental performance of blue-economy assets.
- 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 European Union's biodiversity and climate-adaptation objectives.[80] Environmental and infrastructure data should increasingly support adaptive management of coastal and inland-water systems, including flood risk, freshwater-seawater interfaces and ecosystem health.

6.2. ECONOMIC AND INDUSTRIAL IMPACTS

- Industrial competitiveness: European leadership in vessel design, autonomous systems, underwater robotics, subsea sensing and communications, system integration 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.[81] The underwater domain represents a particularly important future industrial growth area. European capability in robotics, resident subsea systems, sensing, communications, autonomous docking and charging, and integrated surface-underwater operations can support both Blue Economy growth and strategic autonomy.
- 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, underwater robotics and autonomous systems, subsea sensing and communications, multi-asset coordination systems, and digital ocean services. Modular and scalable solutions improve SME access to advanced technologies.[82]

79 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.
80 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.
81 European Commission and Joint Research Centre, EU Blue Economy Report 2025, 7.
82 European Commission, European Ocean Pact, 12.

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. Representative-scale testing, common risk-assessment approaches and validated training environments should reduce uncertainty and support safe deployment of increasingly autonomous and interconnected operations.
- 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.[83] Resilient, dual-use infrastructure supports preparedness and military mobility. Sustainable aquaculture enabled by advanced monitoring improves food security and traceability. Resilience should increasingly be assessed at system level, recognising dependencies between energy, communications, infrastructure, underwater systems and digital services. Improved detection, response and restoration capabilities reduce operational disruption and recovery time following technical, environmental or security-related incidents.

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. Persistent, interoperable observing systems combining underwater, surface and shore-based data increase spatial and temporal coverage and support reuse across research, environmental management and infrastructure monitoring. 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.[84]
- Technological leadership: Sustained research and innovation establish European leadership in underwater robotics and autonomy, sensing, communications, autonomous docking and charging, multi-asset coordination, 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.[85]

83 European Commission, European Ocean Pact, 2.
84 European Commission, European Ocean Pact, 10, on ocean observation and the marine knowledge agenda.
85 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.

WATERBORNE

WATERBORNE TP
De Meeussquare 35
1000 Brussels, Belgium

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