WATERBORNE TECHNOLOGY ROADMAP

Competitive, resilient and sustainable maritime technology sector

September 2026

MARITIME TECHNOLOGY ROADMAP

01 DESCRIPTION OF THE SECTOR

The maritime technology sector is the industrial base that designs, builds, equips, repairs,maintains, converts, retrofits and recycles vessels, offshore platforms and integrated maritime systems — shipyards and maritime equipment companies together. Europe's manufacturing base comprises some 300 shipyards and 28,000 equipment manufacturers, predominantly SMEs. This roadmap extends the perimeter to software, automation and digital platform providers, and treats port terminal equipment and underwater and unmanned vehicle technologies as supplied capabilities, deployed in the Port Ecosystems and Blue Economy roadmaps. It covers the commercial value chain including its dual-use dimension; naval platform programmes are out of scope, but the shared industrial capabilities, supply chains, skills and facilities that underpin both are within it. The sector is the delivery mechanism for every other roadmap in this series: where European capacity is absent, decarbonisation is imported rather than delivered.

PRODUCTION VALUE
114.6 bn €
across the chain: €50.4 bn shipbuilding, boatbuilding and repair, €40.5 bn first-tier and €23.7 bn second-tier suppliers

DIRECT EMPLOYMENT
343 m FTE
218,501 in yards and repair plus 124,916 at first-tier suppliers, across 49,660 enterprises; one yard job carries ten in the chain

ALT-FUEL ORDERBOOK
44 %
of the 2022 global orderbook is alternative-fuel capable, against 14% in 2017 — each point a European equipment market

PRICE DIFFERENTIAL
30–40 %
below European yard prices offered by Asian competitors; Korea has announced USD 1.8 bn for next-generation shipbuilding

STRATEGIC ROLE — FOUR FUNCTIONS

Delivery of every roadmap
Short sea electrification, ferry batteries, cruise energy architectures, oceangoing energy-efficiency and equipment, offshore installation vessels, inland retrofits, port equipment and blue economy platforms all depend on European capacity to design, certify, manufacture and integrate

European sovereignty
Vessels and systems for energy independence,food supply, border protection, defence, military mobility, critical infrastructure protection, ocean observation and Arctic navigation; commercial mass sustains naval capability

Regional employment multiplier
Yards and their supply chains concentrate skilled manufacturing in peripheral areas, islands and outermost regions; German analysis puts the multiplier at ten jobs in the value chain for every job in shipbuilding

Technology-leadership opportunity
Up to 364 electrifiable ferries by 2030 and an industry ambition of 10,000 sustainable, digitalised vessels built in Europe by 2035; offshore renewables, underwater technologies and defence investment widen the demand base

VALUE CHAIN BY TIER — PRODUCTION VALUE AND JOBS

	Value €bn	jobs
Yards, boats, repair	50.4	219
First-tier suppliers	40.5	125
Second-tier suppliers	23.7	N/A
Value added in yards	26.2	% OF PV

Figure 1: Value creation sits upstream of the yard. Equipment and materials are 55–60% of the cost of a ship and the supply chain generates 70–80% of final output value. Purchasing is 65–90% of production value across European yards, and grew faster than production value over 2010–2022 — a declining value-added share.

ASSET TAXONOMY — CATEGORIES WITHIN CLASSES A AND B

Project-based	Low-volume, high-complexity output; capital assets with 25–30 year lives built in series of one to a few units
Wide supplier pyramid	Yards contract directly with 1,000–2,500 companies, against fewer than 500 platform suppliers in automotive and aerospace
Assembly complexity	Up to 550,000 parts in a research vessel and 900,000 in a cruise ship;coordination is the binding constraint on throughput
External certification	Class and flag approval gates every new energy carrier, material and autonomous function, adding fixed lead time to each cycle
Retrofit and recycling	A distinct production line: two-thirds of 12,000 inland vessels retrofitted by 2050;16,000+ ships to be recycled globally this decade
Geographic concentration	The six largest EU-27 shipbuilding countries hold over 80% of purchase value, and almost 90% in 2022

02 POLICY DRIVERS AND CONSTRAINTS

2.1 POLICY, REGULATORY AND MARKET DRIVERS

EU Industrial Maritime Strategy.
Six pillars led by Build, Equip and Repair: an Industrial Maritime Value Chains Alliance in 2026, a Shipyards of the Future flagship call, simplified permitting and EU preference conditions — the first instruments addressing manufacturing capacity directly.

Fit for 55 maritime instruments.
ETS coverage rising to 100% of verified emissions from 2026, FuelEU Maritime tightening GHG intensity from −2% in 2025 to −80% in 2050, and AFIR shore-side requirements convert climate policy into dated equipment specifications.

Marine Equipment Directive.
Directive 2014/90/EU sets uniform conformity assessment and the wheelmark for equipment on EU ships, with electronic tags under Reg. (EU) 2018/608 as a trace ability instrument; its annually updated standards define every certification pathway here.

EU Ports Strategy.
Ports are the interface where onboard energy systems meet shore infrastructure. Charging, shore power, multi-fuel bunkering and battery swapping cannot be specified at design stage without a matching port investment sequence — and port equipment is itself a key European market.

IMO efficiency instruments and recycling.
EEDI, EEXI and CII target equipment design directly and have driven energy-saving technology investment ahead of any fuel transition; strengthened Hong Kong Convention alignment and EU recycling capacity decide where residual vessel value is captured.

Fuel transition and optionality.
LNG-capable ordering dominates with growing attention to methanol, hydrogen and ammonia; battery and battery-diesel propulsion is taken up in ferries, tugs and offshore units. Optionality, not fuel choice, is the property the market is buying.

Digital equipment and sovereignty.
Nearly two-thirds of ships carry digital equipment for efficiency, navigation and security, and rising complexity drives demand for model-based engineering, AI design tools and digital validation environments — with European control of design platforms and system integration at stake.

Safe deployment and insurability.
Operators, yards, financiers, insurers and authorities need credible evidence that innovative systems are equally safe. Common validation methods and reusable safety evidence cut first-of-a-kind risk, approval time and insurance uncertainty as batteries, alternative fuels and autonomy scale.

2.3 STRUCTURAL CONSTRAINTS

Price and support differential.
Asian prices 30–40% below European yards, with USD 1.8 bn announced by Korea against up to €530 m under the Co-programmed Partnership for 2021–2027 and some €3.3 bn private investment. The gap is structural and research funding alone cannot close it.

Value-added erosion.
Value added is 26.24% of production value and purchasing 65–90%, growing faster than production. Each increment of outsourcing transfers margin and technical knowledge to the supplier tier; where that tier is not European, the transfer leaves the Union.

Supply-chain capacity.
No accepted classification identifies maritime equipment in official statistics, so multi-tier dependency cannot be governed because it cannot be measured. Korea already sources over 25% of ship machinery abroad — domestic content erodes fast in an outsourced model.

Certification lead time.
Simulation-based certification is not yet accepted and no type-approval framework exists for standardised platforms, so approval duration is added to development duration rather than run in parallel —displacing European first-mover advantage to market entry.

IP leakage and counterfeiting.
Counterfeit and pirated spare parts may reach 20% of the global market, a grey market of some €1 bn, with at least 50% of exhaust gas cleaning turnover reported counterfeited. Article 5ter of the Paris Convention obstructs enforcement and incidents are attributed to the original maker.

Digital maturity and integration gap.
Most digital technologies in design and construction remain at low maturity, and digital engineering platforms ensuring continuity between design, production and lifecycle are unevenly adopted. Configuration and interface management increasingly drive schedule, cost and performance.

Test infrastructure and safety validation.
Shared European facilities for testing, hardware-in-the-loop and virtual commissioning are limited; full-scale evidence for new fuels, batteries and integrated systems is scarce, and safety cases are repeated project by project rather than reused.

Skills, concentration and cyclicality.
Automation, software, energy systems, cyber-resilience and integration competences are contested in a labour market wider than maritime. Concentration narrows the resilience base and cyclicality deters the long-horizon capital that modernisation requires.

03 TARGET CAPABILITIES

CURRENT STATE-OF-PLAY

Battery-electric propulsion is the most mature zero-emission solution and is deployable today on short-range, high-cycle operations; methanol-capable engines are entering the market ahead of hydrogen and ammonia propulsion and fuel cells, whose deployment depends on safety systems, bunkering readiness and regulatory acceptance. Energy-saving technologies, exhaust after treatment and hybrid architectures are installed at scale. Industrial capability is unevenly distributed across the same value chain: European yards lead in complex, high added-value vessels and European suppliers hold roughly half the world equipment market, yet digital shipyard architectures, robotics and modular production lines are deployed only at pilot scale.Mature technologies require industrial-scale validation; earlier-stage technologies require targeted research, risk reduction and regulatory preparation.

2035

INDUSTRIAL UPGRADE

Core shipyard processes digitalised; robotics and flexible automation scaled into wider production, assembly and outfitting; first modular construction lines across leading European yards

Digital engineering environments support multidisciplinary design, automated compliance checking and change-impact assessment; first large-scale hardware-in-the-loop and virtual commissioning environments

Advanced materials and circular design in new vessel classes; energy-efficiency and abatement deployed fleet-wide; battery-electric mainstream on short, high-cycle routes; 20% of yard energy renewable

Three deployability conditions: virtual certification accepted by at least two class societies, multi-tier supply chain resilience monitoring operational, and cybersecurity certification agreed with post-quantum cryptography under way

2040

SCALED MANUFACTURING

Large-scale production of zero-emission vessels and propulsion systems on automated yards with modular assembly; productivity up and costs down 30% against current levels

Digital twins integrated across design, production and maintenance for mainstream vessel classes; advanced robotics, predictive automation and real-time quality control widely adopted

Resilient component manufacturing clusters in key European regions; AI-supported engineering, generative design and engineering copilots mainstream; 50% of yard energy renewable

Industrial scaling depends on regulatory scaling: type-approval for standardised platforms, dual-use certification pathways and AI-assisted compliance verification. Without series certification there is no series production

2050

GLOBAL LEADERSHIP

Fully digital, highly automated shipyards producing zero-emission and autonomous assets at high volume; zero-emission yards with 90–100% renewable energy become standard

Fully circular material flows across construction, operation and end-of-life, with complete lifecycle digital continuity from design through recycling

Secure, sovereign and cyber-resilient supply chain architectures; AI-enabled design, production, maintenance and recycling fully integrated across an SME and research ecosystem

The export unit is no longer the vessel but the industrial ecosystem — designs, production methods, propulsion systems, digital platforms, certification frameworks and lifecycle services, sold together

04 TECHNOLOGY PATHWAYS

OPERATIONAL OBJECTIVES — SEVEN PATHWAYS

4.1 Green maritime technologies and integrated propulsion	Modular, fuel-agile zero-emission propulsion deployed across all vessel segments —validated once per vessel family, reconfigurable across variants, integrated with port and energy infrastructure and viable across the lifecycle including retrofit.
4.2 Digital shipyards, advanced manufacturing and robotics	A digitally orchestrated, distributed industrial ecosystem rather than one mega-yard: platform-based production reusing designs, software and certification artefacts across vessel families, serving newbuild, retrofit, repair and recovery alike.
4.3 Materials innovation, circularity and lifecycle optimisation	Material systems, structural interfaces and coatings qualified once and reused across vessel families, with embedded sensing, structural-health monitoring and digital material passports recovering value at end of life.
4.4 Digital, cyber-secure and interoperable systems	European control over software architectures, common data models and lifecycle digital threads. Vessels as software-defined platforms with secure update, cryptographic verification and operation under degraded conditions.
4.5 High-performance autonomy, sensing and integration	Certified, design-integrated autonomy packages reusable across vessel variants rather than bespoke retrofits, extending toward cognitive systems that combine AI, sensing and human expertise. Autonomy is a design characteristic, not a manning policy.
4.6 Workforce transformation and skills	A skilled, adaptable and augmented workforce. Europe's answer to demographic decline is capability augmentation through AI-enabled engineering, decision support and human-centred automation, not workforce expansion alone.
4.7 Standards, certification and regulatory pathways	Coherent, exportable frameworks certifying complex, first-of-a-kind and software-defined systems on timescales that preserve first-mover advantage, with goal-based approaches and reusable assurance cases replacing sequential approval.

05 ENABLERS AND DEPLOYMENT

5.1 Industrial-scale integration.
Digital shipyard architectures, modular platforms and standardised interfaces, robotics adapted to low-volume high-complexity work, and facilities for propulsion integration, virtual commissioning and hardware-in-the-loop testing.

5.2 Reusable approval.
Early class and flag involvement as standard, simulation-based certification, type approval of modular systems, reusable evidence across vessel families, regulatory sandboxes and shared test facilities accessible to SMEs.

5.3 Resilient supply chains.
Multi-tier mapping of critical dependencies, qualification of alternative European suppliers, protection of data and integration knowledge, and common data models with secure edge and cloud infrastructure.

5.4 Operational validation.
Representative test areas, resilient positioning and communications, remote operation infrastructure and human-factors validation covering sensor fusion, communication loss,cyber incidents and safe fallback modes.

5.5 Skills transformation.
Industrial training tied directly to digital shipyards and demonstrators, common European competence frameworks, AI-assisted tools that augment scarce skills, and retention of tacit integration knowledge.

5.6 Investment and lead markets.
Support bridging demonstration to first industrial deployment: first-of-a-kind integration, facility modernisation, retrofit programmes, certification costs, lifecycle financing and public procurement as a lead market.

DEPLOYMENT SEQUENCE — FROM INDUSTRIAL VALIDATION TO EXPORTABLE ECOSYSTEM

To 2030 VALIDATE
Industrial validation of digital shipyard systems, modular architectures, alternative energy integration, vessel–port interfaces, virtual certification, lifecycle data systems and supply-chain mapping

2030–2035 DEMONSTRATE
Integrated demonstrators across representative vessel families and yard environments, reusable certification packages, validated remote and autonomous operations, expanded retrofit and circularity programmes

2035–2040 SCALE
Modular production, robotics, digital twins, zero-emission integration and interoperable data architectures scaled across European yards and supplier clusters, with shipyard decarbonisation solutions

2040–2050 CONSOLIDATE
A fully digital, circular, cyber-resilient and globally competitive manufacturing ecosystem exporting complete vessel, technology, production, certification and lifecycle-service packages

06 EXPECTED IMPACTS

INDUSTRIAL COMPETITIVENESS

2035 Digital engineering and virtual commissioning reduce design rework and shorten industrial validation

2040 Modular production, robotics and reusable certification cut lead times and costs while raising quality and productivity

2050 European yards competitive at volume, exporting complete industrial ecosystems rather than hulls

CLIMATE AND ENVIRONMENT

2035 Zero- and low-emission propulsion and energy-efficiency technologies deployed across newbuild and retrofit

2040 Fuel-agile architectures, modular retrofits and circular design reduce emissions, waste and premature asset replacement

2050 Circular material flows and reduced dependence on selected critical raw materials

RESILIENCE AND SOVEREIGNTY

2035 Multi-tier supply chains mapped and monitored; cybersecurity certification frameworks agreed

2040 Stronger European control over critical technologies, software, data, repair, retrofit and recycling capacity

2050 Secure, sovereign supply-chain architectures sustaining production under disruption

FLEET TRANSFORMATION

2035 First-of-a-kind projects give way to repeatable newbuild and retrofit solutions

2040 Lower energy and maintenance costs, reduced downtime and flexibility to adapt vessels to future fuels

2050 Integrated vessel-port-energy solutions deployed across relevant vessel segments

SAFETY AND WORKFORCE

2035 Common test protocols and reusable safety cases make approval of battery, alternative-fuel and software-defined systems more predictable

2040 Robotics and AI tools reduce exposure to hazardous tasks and shift employment to higher-skilled integration roles

2050 Continuous assurance and continuous learning embedded across the industrial base

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ROADMAP POSITIONING WITHIN THE WATERBORNE TECHNOLOGY LEADERSHIP FRAMEWORK

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

The roadmap on the maritime technology sector is closely interlinked with the following dedicated Technology Roadmaps: port ecosystems, inland waterway transport, short sea shipping, ferries, cruise, ocean-going shipping, offshore vessels and blue economy.

1 Waterborne Technology Platform, Waterborne Technology Leadership: Towards a Competitive, Resilient and Sustainable Waterborne Sector – A Co-programmed Partnership under Framework Programme 10, 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 maritime technology sector comprises the industrial base that designs, builds, equips, repairs, maintains, converts, retrofits and recycles vessels, offshore vessels and platforms, and integrated maritime systems.[3] The term denotes shipyards and maritime equipment companies together.[4] Its statistical perimeter covers, shipbuilding, naval shipbuilding, boatbuilding, repair and conversion of ships and boats, and the building of offshore vessels and platforms, together with first-tier and second-tier maritime suppliers.[5] Maritime equipment within this perimeter comprises systems, components and materials incorporated in a vessel or related by function to its operation, together with the technical services of engineering, design, safety technologies and services, consulting and aftersales support.[6] Areas such as multidisciplinary engineering environments, lifecycle configuration management, design authority, system-of-systems integration, internal combustion engines, gas turbines and integrated power-generation systems are part of the maritime technology ecosystem.

A shipyard is an industrial facility engaged in the construction, repair or conversion of vessels. Its activities include structural fabrication, outfitting, the installation and integration of equipment and systems, as well as the testing and delivery of fully operational vessels.

This roadmap extends the perimeter in two respects. Software, automation and digital platform providers are treated as members of the sector, on the ground that Chapter 4 identifies software architectures, common data models and lifecycle digital threads as core industrial capabilities. Port terminal equipment is treated as a supplied technology in this roadmap and as a deployed asset in the Port Ecosystems roadmap. Underwater and unmanned vehicle technologies are treated as a supplied capability of the maritime technology sector in this roadmap and as a deployed blue economy asset in the Blue Economy roadmap.[7]

Europe's maritime manufacturing base consists of some 300 shipyards and 28,000 maritime equipment manufacturers.[8] Small and medium-sized enterprises form the largest part of this base and account for the majority of component and subsystem supply.[9] This Technology Roadmap covers the commercial maritime manufacturing value chain, including its dual-use dimension. Naval and defence-specific platform programmes are outside its scope, but the shared industrial capabilities, supply chains, skills and facilities that underpin both civil and naval construction are within it.

3 European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the EU Industrial Maritime Strategy, COM(2026) 111 final (Brussels, 4 March 2026), 2.
4 OECD, Analysis of the Marine Equipment Industry and Its Challenges, C/WP6(2022)15/FINAL (Paris: OECD Council Working Party on Shipbuilding, 19 January 2023), 15.
5 BALance Technology Consulting, European Shipbuilding Supply Chain Statistics: A Report for SEA Europe (Bremen: BALance Technology Consulting, June 2025), 8.
6 OECD, Analysis of the Marine Equipment Industry, C/WP6(2022)15/FINAL, 8, box 3.1.
7 Waterborne Technology Platform, Strategic Research Agenda for the European Waterborne Sector, consolidated version 5.0 (Brussels: Waterborne TP, June 2025), 12. On the sector's leadership in the underwater domain, see also European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 3.
8 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 2n7.
9 Waterborne Technology Platform, Waterborne Technology Leadership, 5.

1.2. STRATEGIC ROLE IN THE EUROPEAN WATERBORNE ECOSYSTEM

The maritime technology sector is the delivery mechanism for every other roadmap in this series. Short sea electrification, ferry battery systems, cruise energy architectures, oceangoing energy-efficiency and equipment, offshore installation vessels, inland waterway retrofits, port equipment and blue economy platforms are all conditional on European industrial capacity to design, certify, manufacture and integrate the relevant systems. Where that capacity is absent, decarbonisation is imported rather than delivered.

The maritime manufacturing sector is strategic for European sovereignty. It provides the ability to build and maintain the vessels, equipment, platforms and technologies required for energy independence, climate resilience, food supply, border protection, defence, critical infrastructure protection, military mobility, ocean observation and Arctic navigation.[10] Preserving a critical mass of commercial shipbuilding sustains naval shipbuilding, given the strong dual-use interlinkages and cross-fertilisation between them.[11] Ship repair, maintenance, conversion, retrofitting and recycling capabilities are critical for advancing the safety, decarbonisation and circularity of waterborne transport.[12]

The sector anchors regional industrial employment with a high multiplier. Shipyards and their supply chains concentrate skilled manufacturing jobs in peripheral areas, islands and outermost regions, where alternative industrial employment is limited.[13] German analysis quantifies the effect: one job in the shipbuilding industry generates a total of ten jobs across the associated value chains.[14]

1.3. INDUSTRIAL STRUCTURE

The sector operates on a project-based, low-volume, high-complexity production model. Vessels are capital assets with service lives of twenty-five to thirty years, built in series of one to a few units, against customer-specific specifications and classification requirements. Production cycles are long, order books are cyclical, and yard capacity utilisation is exposed to demand shocks in the segments served.

Value creation sits predominantly upstream of the yard. Equipment and materials account for between 55% and 60% of the total cost of a ship, varying by type and size,[15] and approximately 70% to 80% of the final output value of ship production is generated through the upstream supply chain.[16] European companies supply almost half of the world's maritime equipment and play a leading role in designing and developing most of the global fleet's power systems.[17]

The supplier base is pyramidal and unusually wide. Where automotive and aerospace manufacturers concentrate on platform suppliers numbering fewer than 500 at that level, shipyards contract directly with a far larger population, generating purchasing databases of between 1,000 and 2,500 companies depending on company size and ship type.[18] Assembly complexity is correspondingly high: a complex research vessel is built from up to 550,000 parts and a cruise ship from up to 900,000.[19] Coordination capability is the binding constraint on yard throughput.

10 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 2.
11 Ibid.
12 Ibid.
13 Ibid.
14 OECD, Analysis of the Marine Equipment Industry, C/WP6(2022)15/FINAL, 3.
15 Ibid., 4.
16 Ibid., 5.
17 Waterborne Technology Platform, Waterborne Technology Leadership, 5.
18 OECD, Analysis of the Marine Equipment Industry, C/WP6(2022)15/FINAL, 5.
19 Ibid., 21.

Outsourcing has deepened and value added has thinned. Purchasing values now account for between 65% and 90% of total production values across European yards.[20] In EU-27 shipbuilding, value added represents 26.24% of production value, with non-marine equipment purchases accounting for a further 25.00%.[21] Between 2010 and 2022 the average annual growth rate of EU-27 purchasing values, at 3.8%, exceeded that of production values, at 3.5%, indicating a declining value-added share in EU-27 shipbuilding.[22] The supplier base is also geographically concentrated: the six largest EU-27 shipbuilding countries accounted for more than 80% of total purchase value over the period and for almost 90% in 2022.[23]

Certification is external and sequential. Class and flag approval gates the deployment of any new energy carrier, material or autonomous function, and adds a fixed lead time to every innovation cycle irrespective of technology readiness.

Retrofit and conversion constitute a distinct production line with its own economics. As an example, two-thirds of the current fleet of 12,000 inland navigation vessels operating on European waterways are estimated to undergo retrofitting between 2020 and 2050, while one-third will be new constructions, corresponding to approximately 140 new vessels per year.[24] Ship recycling is the terminal segment of the same value chain, with over 16,000 ships projected to be recycled globally over the next decade.[25]

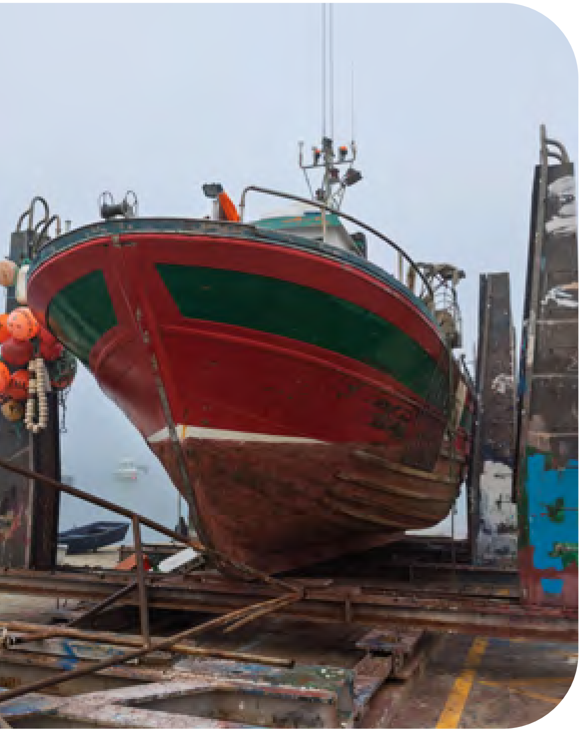
1.4. SECTOR BASELINE AND MARKET POSITION

The EU-27 shipbuilding value chain generated an annual average production value of EUR 50,385 million in shipbuilding, boatbuilding and ship repair over 2018-2022, employing 218,501 full-time equivalents across 24,917 enterprises. First-tier maritime suppliers added a production value of EUR 40,545 million, with 124,916 employees across 24,743 enterprises, and second-tier suppliers a total domestic production value of EUR 23,695 million.[26]

Indicator	EU-27
Production value – shipbuilding, boatbuilding, repair (EUR m)	50,385
Production value – first-tier maritime suppliers (EUR m)	40,545
Production value – second-tier maritime suppliers (EUR m)	23,695
Employment – shipbuilding, boatbuilding, repair (FTE)	218,501
Employment – first-tier maritime suppliers (FTE)	124,916
Enterprises – shipbuilding, boatbuilding, repair	24,917
Enterprises – first-tier maritime suppliers	24,743

Table 1: The European shipbuilding value chain, annual average 2018-2022
Source: BALance Technology Consulting, European Shipbuilding Supply Chain Statistics, 18, 21-22. SEA Europe membership comprises 17 countries including Norway, the United Kingdom and Türkiye.

20 BALance Technology Consulting, European Shipbuilding Supply Chain Statistics, 13.
21 Ibid., 21, fig. 15.
22 Ibid., 12.
23 Ibid.
24 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 3n12.
25 Ibid., 6.
26 BALance Technology Consulting, European Shipbuilding Supply Chain Statistics, 18.



Europe is the world's largest supplier of maritime equipment, including services, ahead of Korea, China and Japan.[27] In maritime diesel engines, the largest trade segment in maritime equipment, the EU recorded net exports of USD 12.9 billion over 2019–2020, and it also leads the global export market for marine turbines, propellers and blades.[28] **Europe also retains global leadership in the most technologically sophisticated ship types.** These include cruise ships, naval vessels, icebreakers, research vessels, submarine cable vessels, offshore wind support vessels, floating and converter platforms, yachts and recreational craft, together with clean propulsion systems and advanced equipment.[29] With 97% of the world's fleet of cruise ships built in Europe, cruise production sustains the complex shipbuilding capabilities on which other strategically significant segments depend.[30]

Market position in merchant shipbuilding has eroded. European shipyards have lost global market share over recent decades in a distorted international market affected by state-driven investment in third countries, non-market practices, and labour and energy cost differentials.[31] European industry has lost ground to China in strategic segments including offshore wind installation vessels, while leadership in underwater vessels and in maritime and port equipment is increasingly challenged.[32] Europe's global market share in large ferries above 5,000 GT fell to around 15% in 2020–2024, from 60% in 2010; its share of deliveries to the domestic EU market stood at 38% over the same period, averaging three ships per year.[33]

The sector's exposure to demand shocks is asymmetric across subsectors. EU-27 shipbuilding production value declined by 4.6% in 2020, while boatbuilding production rose by 20.37% in the same year, partially offsetting the aggregate loss.[34]

The competitive gap is priced and funded. Asian competitors offer prices 30% to 40% below those of European shipyards.[35] South Korea has announced a record investment of USD 1.8 billion to strengthen its leadership in next-generation shipbuilding.[36] By comparison, up to EUR 530 million has been made available under Horizon Europe for the transition towards zero-emission waterborne transport through the Co-programmed Partnership for the period 2021–2027, complemented by approximately EUR 3.3 billion in private investment.[37]

27 OECD, Analysis of the Marine Equipment Industry, C/WP6(2022)15/FINAL, 3.
28 Ibid., 10.
29 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 2–3.
30 Ibid., 3.
31 Ibid.
32 Ibid.
33 Ibid., 3n11.
34 BALance Technology Consulting, European Shipbuilding Supply Chain Statistics, 10.
35 Waterborne Technology Platform, Waterborne Technology Leadership, 7.
36 Ibid.
37 Ibid.

1.5. MARITIME TECHNOLOGY AS A TECHNOLOGY-LEADERSHIP OPPORTUNITY

Demand for European maritime technology is expanding in the segments where European industry is strongest. Decarbonisation, digitalisation, the expected expansion of offshore renewables deployment, the emergence of new blue economy growth markets such as underwater and ocean observation technologies, military mobility and rising defence investment together provide the demand base for strengthening Europe's maritime manufacturing capacity.[38] The number of electrifiable ferries is estimated to rise to as many as 364 by 2030, subject to battery energy density improvement and onshore power deployment rates.[39] European industry has set the ambition of building 10,000 sustainable and digitalised vessels in Europe by 2035.[40]

The twin transition is already visible in the order book and in the installed fleet. Alternative-fuel-capable vessels rose from 14% of the global orderbook in 2017 to 44% in 2022.[41] More than 5,000 vessels carried significant energy-saving technologies by late 2022, against approximately 3,000 in 2017, and 24% of world tonnage was fitted with at least one such technology.[42] Each of these figures represents a European equipment market.

The blue economy provides diversified demand that mitigates the cyclical nature of the shipbuilding market and strengthens long-term industrial stability.[43] Underwater and unmanned vehicle technologies, in which the European sector is a technology leader, are essential to the security and resilience of submarine cables and other critical infrastructure.[44] The sector's ambition is to navigate and operate autonomously below the surface to monitor, survey and protect the underwater domain by 2040, and to achieve seamless data interchange above and below the surface by 2050.[45]

Converting this demand into European manufacturing output requires industrial modernisation rather than incremental improvement. By 2030 the European industry needs to advance towards smart and clean maritime manufacturing, leveraging digitalisation, advanced robotics, artificial intelligence, modularity, energy-efficiency and circularity in industrial processes.[46] This is the condition for making maritime manufacturing in Europe more resilient and cost-efficient, mitigating labour shortages, enhancing productivity and expanding the operational capacity of industrial facilities.[47]

38 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 3n12.
39 Ibid.
40 SEA Europe, Setting Sail to Build in Europe 10,000 Sustainable and Digitalised Vessels by 2035 (Brussels: SEA Europe, 2024), cited in European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 3.
41 OECD, Analysis of the Marine Equipment Industry, C/WP6(2022)15/FINAL, 23.
42 Ibid.
43 Waterborne Technology Platform, Waterborne Technology Leadership, 6.
44 Ibid.
45 Waterborne Technology Platform, Strategic Research Agenda, v5.0, 12.
46 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 4.
47 Ibid.

2. DRIVERS AND CONSTRAINTS

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2.1 POLICY AND REGULATORY DRIVERS

The maritime technology sector is regulated indirectly. Demand-side instruments addressed to shipowners and ports determine which equipment must be specified; supply-side instruments determine where that equipment is manufactured. Both sets of instruments are now in force, and they do not yet act with equal strength.

Instrument	Provisions relevant to the maritime technology sector
EU Industrial Maritime Strategy	The Strategy sets a vision and course of action under six pillars, the first of which is Build, Equip and Repair.[48] It launches an EU Industrial Maritime Value Chains Alliance in 2026, rolls out a Shipyards of the Future research and innovation flagship call under the Horizon Europe 2026-27 Work Programme, and applies the proposed Industrial Accelerator Act to simplify permitting for maritime manufacturing facilities.[49] It further proposes targeted non-price requirements in selected strategic public procurement segments and EU preference conditions in the European Competitiveness Fund proposal under the Multiannual Financial Framework 2028–2034.[50] These are the first EU instruments to address maritime manufacturing capacity directly rather than through vessel operators.
EU Ports Strategy	The Ports Strategy positions ports as gateways for trade, logistics, energy, security, military mobility and innovation clusters.[51] For the maritime technology sector, ports are the physical interface at which onboard energy systems meet shore infrastructure. Charging, shore power, multi-fuel bunkering and battery-swapping cannot be specified at vessel design stage without a corresponding port investment sequence. Furthermore, port equipment is a key market for European maritime equipment manufacturers. Port readiness constrains the deployable envelope of every propulsion technology in Chapter 4.
Sustainable Transport Investment Plan	The Plan responds to the need to unlock investment and scale up renewable and low-carbon fuels for aviation and waterborne transport.[52] It establishes an investment logic for fuels rather than for the equipment that consumes them. The corresponding technological backbone equipment investment gap (engines, storage, aftertreatment, power electronics and integration) is not yet closed by a comparable instrument. Fuel availability and equipment availability must be scheduled together.

48 Ibid., 2.
49 Ibid., 4.
50 Ibid., 5.
51 European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the EU Ports Strategy, COM(2026) 112 final (Brussels, 4 March 2026), 1.
52 European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Sustainable Transport Investment Plan, COM(2025) 664 final (Brussels, 5 November 2025), 1.

Instrument	Provisions relevant to the maritime technology sector
Fit for 55 maritime instruments	The EU Emissions Trading System now covers maritime transport, with shipping companies surrendering allowances for 40% of verified emissions in 2024, 70% in 2025 and 100% from 2026.[53] Fuel EU Maritime sets a declining limit on the greenhouse gas intensity of energy used on board, from a 2% reduction in 2025 to 80% in 2050, and obliges containerships and passenger ships at berth to use onshore power supply or zero-emission technology.[54] The Alternative Fuels Infrastructure Regulation sets the corresponding shore-side electricity and refuelling requirements.[55] Together these instruments convert climate policy into a dated equipment specification for onshore power connections, batteries, fuel-flexible engines, emission aftertreatment and onboard monitoring.
Marine Equipment Directive	Directive 2014/90/EU establishes uniform conformity assessment and the wheel mark for marine equipment placed on board EU ships.[56] Implementing Regulation (EU) 2018/608 lays down technical criteria for electronic tags for marine equipment, providing a traceability instrument against counterfeiting.[57] The Directive is the principal Union instrument governing the sector's own product. Its scope and its annually updated testing standards define the certification pathway for every equipment innovation in this roadmap.
Ship recycling and circularity framework	The Commission will work to strengthen the Hong Kong Convention on Ship Recycling and to align international rules with the EU Ship Recycling Regulation and will explore expanding domestic EU ship recycling capacity.[58] Recycling closes the material loop on which the circularity pathway depends. It also determines whether the residual value of European-built vessels is captured inside or outside the Union. Circularity is therefore an industrial policy and environmental question.
IMO efficiency instruments	The Energy Efficiency Design Index and the Energy Efficiency Existing Ship Index are technical standards assessing the theoretical efficiency of newbuild and existing vessels on the basis of design and equipment; the Carbon Intensity Indicator measures the carbon intensity of ships in operation.[59] These instruments target equipment design directly. They have driven investment in energy-saving technologies ahead of any fuel transition. They also set the global baseline against which European equipment competes.

53 Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system, OJ L 130, 16.5.2023, 134–202, art. 3ga.
54 Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC, OJ L 234, 22.9.2023, 48–100, arts. 4 and 6.
55 Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU, OJ L 234, 22.9.2023, 1–47.
56 Directive 2014/90/EU of the European Parliament and of the Council of 23 July 2014 on marine equipment and repealing Council Directive 96/98/EC, OJ L 257, 28.8.2014, 146–185, arts. 5 and 9.
57 Commission Implementing Regulation (EU) 2018/608 of 19 April 2018 laying down technical criteria for electronic tags for marine equipment, OJ L 101, 20.4.2018, 64–67.
58 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 6.
59 OECD, Analysis of the Marine Equipment Industry, C/WP6(2022)15/FINAL, 22.

Instrument	Provisions relevant to the maritime technology sector
European technological sovereignty	The growing need for European technological sovereignty in complex maritime systems, including design platforms, digital engineering environments, propulsion technologies and system integration capabilities. At the same time, the increasing complexity of vessels is driving demand for model-based engineering, AI-supported design tools, engineering copilots and advance digital validation environments.
Decarbonisation of industries	The decarbonisation of shipyards and manufacturing operations is becoming a strategic objective and acts as a catalyst for innovation over the coming decades
Safe deployment, insurability and predictable regulatory acceptance	Operators, yards, suppliers, financiers, insurers and authorities need credible evidence that innovative systems achieve equivalent or improved safety. Common validation methods and reusable safety evidence can reduce first-of-a-kind risk, approval time and insurance uncertainty, thereby accelerating investment and market uptake. Demand for validated safety systems will grow as batteries, sustainable alternative fuels, high-voltage systems, autonomy and remote operation scale.

Table 2: Policy and regulatory instruments shaping the maritime technology sector
Sources: as footnoted in the right-hand column.

2.2. TECHNOLOGY AND MARKET DRIVERS

Fuel transition has already moved the order book. Alternative-fuel-capable vessels accounted for 44% of the 2022 orderbook, against 14% in 2017, with LNG-capable ordering dominant and increasing attention to methanol, hydrogen and ammonia, alongside a trend toward optionality.[60] Battery propulsion and battery–diesel combinations have been taken up in smaller and coastal vessels, notably ferries, tugs and offshore units.[61] Optionality, rather than fuel choice, is the property the market is buying.

Energy-saving technologies are the near-term equipment market. More than 5,000 vessels carried significant energy-saving technologies by late 2022, against approximately 3,000 in 2017, and 24% of world tonnage was fitted with at least one such technology, rising to 33% of containership tonnage.[62] Approximately 4,700 vessels representing around 360 million gross tonnes are fitted with sulphur oxide scrubbers. Onboard carbon capture remains at pilot stage and is not currently commercially or technologically viable, with high costs and low capture rates.

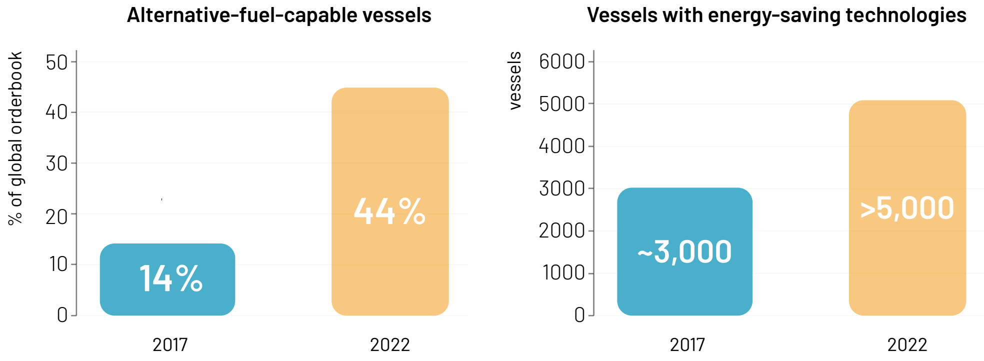

Figure 1: Uptake of alternative fuels and energy-saving technologies in the world fleet
Source: OECD, Analysis of the Marine Equipment Industry and Its Challenges, C/WP6(2022)15/FINAL, 23, drawing on Clarkson's World Fleet Register.

Digital equipment is already installed but shallowly integrated. Nearly two-thirds of ships use digital equipment for efficiency enhancement, commercial performance, navigation and maritime security.[63] Patent activity confirms the shift toward a technology-intensive industry: applications filed under the Patent Cooperation Treaty for marine-equipment technologies rose from around 300 per year in the early 2000s to 700 per year in 2010 and 1,200 per year in 2017, declining thereafter.[64] The leading applicants over 2011–2020 are shipbuilding groups located in Japan, Korea and China, alongside German industrial firms.[65] Europe's equipment leadership is not matched by a proportionate share of registered maritime intellectual property.

The retrofit, conversion and recycling pipeline described in sections 1.3 and 1.5 constitutes a demand stream that is independent of newbuild ordering. It is served by different facilities, different skills and different financing structures. Its scale is fixed by the age profile of the existing fleet rather than by market sentiment.

60 Ibid., 23.
61 Ibid.
62 Ibid.
63 Ibid., 24.
64 Ibid., 30.
65 Ibid., 31, table 12.

2.3. CONSTRAINTS

Constraint	Evidence and implication
Price and support differential	Asian competitors can offer prices 30% to 40% below those of European shipyards, and competing regions sustain public research and innovation investment at levels Europe does not match.[66] South Korea has announced USD 1.8 billion for next-generation shipbuilding; consolidated figures for China's shipbuilding research investment are not publicly disclosed. The European Co-programmed Partnership has made up to EUR 530 million available for 2021–2027, complemented by approximately EUR 3.3 billion in private investment. The gap is structural and cannot be closed by research funding alone.
Value-added erosion	Value added represents 26.24% of production value in EU-27 shipbuilding, and purchasing values account for between 65% and 90% of production value across European yards.[67] Between 2010 and 2022 purchasing values grew faster than production values, indicating a declining value-added share. Each increment of outsourcing transfers margin and technical knowledge to the supplier tier. Where that tier is not European, the transfer leaves the Union.
Supply-chain capacity	The shipbuilding value chain is pyramidal, with shipyards contracting directly with between 1,000 and 2,500 companies, and no internationally accepted classification exists that would allow the maritime equipment industry to be identified in official statistics.[68] Korea already sources more than 25% of ship machinery and equipment from foreign suppliers, demonstrating how rapidly domestic content can erode in an outsourced model.[69] Multi-tier dependency cannot be governed while it cannot be measured. Statistical invisibility is therefore itself a policy constraint.
Certification and approval lead time	Class and flag approval gates the deployment of every new energy carrier, material and autonomous function. Simulation-based certification is not yet accepted for these purposes, and no type-approval framework exists for standardised vessel platforms. Certification duration is therefore added to development duration rather than run in parallel with it. This displaces European first-mover advantage to the point of market entry.

66 Waterborne Technology Platform, Waterborne Technology Leadership, 7.
67 BALance Technology Consulting, European Shipbuilding Supply Chain Statistics, 21, fig. 15; 12; 13.
68 OECD, Analysis of the Marine Equipment Industry, C/WP6(2022)15/FINAL, 5 and 7.
69 Ibid., 21.

Constraint	Evidence and implication
Intellectual property leakage and counterfeiting	The volume of counterfeited and pirated spare parts in the global market may reach as much as 20% of total spare parts, corresponding to a grey market estimated at EUR 1 billion.[70] Enforcement is obstructed by Article 5ter of the Paris Convention, under which the use on board vessels of patented devices is not treated as infringement where such vessels temporarily enter the waters of another Union country.[71] In exhaust gas cleaning systems, at least 50% of turnover is reported as counterfeited. Counterfeit equipment transfers safety risk to the vessel and reputational risk to the original manufacturer, since incidents may be attributed to the equipment maker.[72]
Digital maturity gap	Most digital technologies applied in the waterborne sector are assessed at low maturity for both the design and the construction of products.[73] The gap is not one of awareness but of validated, commercially viable deployment. High costs and limited data availability slow the demonstration of viability. Technologies proven in automotive and aerospace are transferable, but transfer requires marinisation, certification and demonstration at yard scale. Furthermore, significant progress has been made in digital shipbuilding, however the maturity and deployment of digital engineering platforms capable of ensuring continuity between design, production and lifecycle management is unequally adopted across the supply chain.
Fragmentation of configuration management	As maritime platforms become more complex and software-intensive, configuration management, interface management and system integration become increasingly important for schedule, cost and technical performance.
Limited availability of infrastructure	The limited availability of shared European infrastructure for testing, validation, Hardware-in-the-Loop activities and virtual commissioning of complex maritime systems. Similar challenges exist regarding harmonised approaches to simulation-based validation and certification.
Strategic dependencies	Strategic dependencies affect critical propulsion technologies, energy systems and related industrial value chains.

70 Ibid., 41.
71 Ibid., 42.
72 Ibid., 41.
73 Ibid., 25.

Constraint	Evidence and implication
Fragmented safety validation and approval pathways	Full-scale evidence for new fuels, batteries and integrated systems is limited. Safety cases and tests are repeated project by project and are rarely reusable. Detection, suppression and ventilation lack common performance validation. This raises costs, approval time and first-mover risk for shipyards and suppliers.
Skills and demographic constraint	Attracting and retaining qualified personnel remains a challenge, and the maritime labour sector faces persistent difficulties relating to skills shortage as well as to working conditions both on board and ashore.[74] The competences required by the pathways in Chapter 4 — automation, software, energy systems, cyber-resilience, systems integration — are contested in a labour market wider than maritime. Workforce expansion alone will not close the gap. Capability augmentation and human-centred design are conditions of deployment, not accompaniments to it.
Concentration and cyclicality	The six largest EU-27 shipbuilding countries accounted for more than 80% of purchase value over 2010–2022, rising to almost 90% in 2022, and EU-27 shipbuilding production fell 4.6% in 2020 while boatbuilding rose 20.37%.[75] Equipment manufacturers are subject to the same cyclicality as their customers, mitigated only where they also serve non-maritime downstream industries. Concentration narrows the base on which industrial resilience rests. Cyclicality deters the long-horizon capital investment that modernisation requires.

Figure 2: Structural constraints on the European maritime technology sector
Sources: as footnoted in the right-hand column.

74 European Commission, EU Industrial Maritime Strategy, COM(2026) 111 final, 21–22.

75 BALance Technology Consulting, European Shipbuilding Supply Chain Statistics, 12 and 10.

3. TARGET CAPABILITIES

3. TARGET CAPABILITIES

3.1 CURRENT STATE-OF-PLAY AND ACHIEVED DEVELOPMENTS

The target capabilities are derived from the current state of technology, regulation and industrial deployment. Battery-electric propulsion is the most mature zero-emission solution and is deployable today on short-range, high-cycle operations. Methanol-capable engines are entering the market ahead of hydrogen- and ammonia-fuelled propulsion and fuel-cell systems. Deployment of these latter technologies depends on further development of safety systems, bunkering readiness and regulatory acceptance. Energy-saving technologies, exhaust aftertreatment and hybrid architectures are installed at scale. Alternative-fuel-capable vessels already account for 44% of the orderbook, while most digital technologies applied to vessel design and construction remain at low maturity.[76]

Industrial capability is unevenly distributed across the same value chain. European yards retain world leadership in complex, high added-value vessels[77] and European suppliers hold roughly half the world equipment market,[78] yet digital shipyard architectures, robotics and modular production lines are deployed only at pilot scale. Regulation provides direction but does not by itself resolve certification duration, supply-chain capacity, intellectual property leakage, skills shortage or the price differential set out in section 2.3. Mature technologies require industrial-scale validation; earlier-stage technologies require targeted research, risk reduction and regulatory preparation.

3.2 CAPABILITY ARCHITECTURE

Target capabilities are organized in seven domains, corresponding to the research and innovation priorities of the Waterborne Technology Leadership document for a resilient, competitive and sustainable maritime technology sector.[79] Chapter 4 disaggregates each domain into technology tracks, operational objectives, dated capability statements and research gaps. The domains are stated here at the level of the industrial capability they deliver; they are not restated as pathway content.

76 OECD, Analysis of the Marine Equipment Industry, C/WP6(2022)15/FINAL, 23 and 25.
77 Waterborne Technology Platform, Strategic Research Agenda for the European Waterborne Sector, consolidated version 5.0 (Brussels: Waterborne TP, June 2025), 9.
78 Waterborne Technology Platform, Waterborne Technology Leadership, 5.
79 Ibid., 15–16.

Capability domain	Industrial capability delivered
Design and integration of modern onboard energy systems	The capability is to design, integrate, certify and lifecycle-manage complete zero-emission energy architectures, validated once per vessel family and reconfigurable across variants. Strategic value lies in integration rather than in individual fuels or components. Fuel agility, modularity and upgradeability are design principles rather than options. European ownership of the intellectual property and industrial capability for these systems is a stated condition.[80]
Digital shipyards, advanced manufacturing and robotics	The capability is to operate a digitally orchestrated, distributed industrial ecosystem in which design, engineering, production, suppliers and lifecycle services are connected through shared platforms. Production shifts from project-centric to platform-based, with designs, software, certification artefacts and system architectures reused across vessel families. The objective is series production capability without loss of first-of-a-kind capability.[81] Production costs must fall and productivity rise by 30% against current levels by 2040.[82] Shipyards must serve newbuild, retrofit, repair, conversion, dismantling and component recovery.
Materials innovation, circularity and lifecycle optimisation	The capability is to qualify material systems, structural interfaces and coatings once and reuse them across vessel families, while recovering material value at end of life.[83] Materials become active components of digitally managed systems through embedded sensing and structural-health monitoring. Digital material passports establish traceability from sourcing through recycling. The sector target is 100% recycling and upcycling of production waste and decommissioned assets.[84] Lifecycle data becomes a strategic industrial asset.
Digital, cyber-secure and interoperable systems.	The capability is to retain European control over maritime software architectures, common data models, integration interfaces and lifecycle digital threads.[85] Vessels operate as software-defined platforms with secure update, cryptographic verification and rollback capability. Operational and lifecycle data remain accessible within European industrial ecosystems. Systems remain operational under degraded conditions, including navigation-signal disruption, cyber incidents and communication loss.

80 Ibid., 15.
81 Ibid.
82 Waterborne Technology Platform, Strategic Research Agenda, v5.0, 9.
83 Waterborne Technology Platform, Waterborne Technology Leadership, 16.
84 Waterborne Technology Platform, Strategic Research Agenda, v5.0, 9.
85 Waterborne Technology Platform, Waterborne Technology Leadership, 16.

Capability domain	Industrial capability delivered
High-performance systems for autonomy, sensing and integration	The capability is to deliver certified, design-integrated autonomy packages that are reusable across vessel variants rather than bespoke retrofits.[86] Autonomy is a system-design characteristic and is distinguished from crewing levels. Sensing, communications, control, cybersecurity and lifecycle assurance are integrated at platform level. Large-scale introduction of resilient and secure autonomous operations is targeted for 2050.[87] Resilient positioning independent of any single provider is a requirement rather than a refinement.
Workforce transformation and skills	The capability is to educate, train and continuously develop a workforce able to design, build, certify, service and improve integrated maritime systems.[88] Response to demographic decline rests on augmenting human capability through artificial-intelligence-enabled engineering tools, decision support, robotics and automation. Human-centred and ergonomic design conditions the safe absorption of new industrial processes, against a zero-accident target and continuous skills development.[89] Tacit production knowledge and integration competence must be retained within Europe.
Standards, certification and regulatory pathways	The capability is to certify complex, first-of-a-kind and software-defined systems within European frameworks, on timescales that preserve first-mover advantage.[90] Goal-based and risk-based approaches, simulation-based validation and continuous digital assurance replace sequential, artefact-based approval. European certification capability is an instrument of industrial sovereignty and of export credibility. Regulatory leadership is a stated strategic objective of the sector, intended to secure European influence in global waterborne markets and to expand export opportunities.[91] Coordinated European engagement in international standards bodies is a sector-level priority.

Table 2: The Seven Capabilities Domains
Source: Derived from Waterborne TP, Waterborne Technology Leadership, 15–16, and SRA v5.0, 8–9. Disaggregated in Chapter 4.

86 Ibid.
87 Waterborne Technology Platform, Strategic Research Agenda, v5.0, 8.
88 Waterborne Technology Platform, Waterborne Technology Leadership, 16.
89 Waterborne Technology Platform, Strategic Research Agenda, v5.0, 9.
90 Waterborne Technology Platform, Waterborne Technology Leadership, 16.
91 Ibid., 15.

3.3. 2035 — INDUSTRIAL UPGRADE AND INNOVATION ACCELERATION

By 2035 the sector should have completed its industrial upgrade and entered accelerated innovation. Core shipyard processes are digitalised, robotics and flexible automation are scaled beyond established applications into a wider range of production, assembly and outfitting process, and the first modular construction lines operate across leading European yards.[92] Advanced materials and circular design principles are deployed in new vessel classes. Autonomous and smart system integration is tested in vessel designs, and modelling of ship software interoperability identifies waterborne cyber risks. Digital engineering environments support multidisciplinary design, automated compliance checking and engineering change impact assessment are operational across major European programmes. The first large scale deployment of Hardware-in-the-Loop and virtual commissioning environments for propulsion, automation and digital systems. In parallel, safety-by-design and safe-integration methodologies are standard practice throughout construction and commissioning activities.

Energy-efficiency and emission-abatement technologies are deployed across the existing fleet, and battery-electric propulsion is mainstream on short, predictable, high-cycle routes. Finally, shipyards use renewable energy for 20% of the total energy need. Training focused on digital manufacturing and sustainable engineering is executed at scale, and the first European-wide industrial partnerships emerging from research and innovation programmes are operational in critical waterborne technologies.

Three capabilities beyond the 2035 trajectory are required to make it deployable. Simulation-based and virtual certification is accepted by at least two major classification societies for selected technology areas. Multi-tier supply chain mapping and resilience monitoring is operational for critical waterborne technology supply chains. Cybersecurity certification frameworks for waterborne operational and information technology systems are agreed, with post-quantum cryptography integration under way.

3.4. 2040 - SCALED MANUFACTURING AND SYSTEM INTEGRATION

By 2040 the sector should manufacture at scale. Large-scale production of zero-emission vessels and propulsion systems is supported by automated shipyards and modular assembly.[93] Digital twins are integrated across design, production and maintenance for mainstream vessel classes. Advanced robotics, predictive automation and real-time quality control are widely adopted in shipbuilding. Resilient component manufacturing clusters are operational in key European regions. Workforce transformation is well advanced, with digital and automation skills embedded in waterborne education and on-the-job training.

Industrial scaling depends on regulatory scaling. Type-approval frameworks for standardised vessel platforms are operational, dual-use certification pathways are established for civil and naval technology variants, and artificial-intelligence-assisted compliance verification supports continuous software assurance. Without series certification, series production cannot be realised. European yards become price-competitive on selected standardised vessel types only where these three conditions hold simultaneously. Integrated system-engineering platforms support digital continuity from concept design to operation. AI-supported engineering, generative design and engineering copilots become mainstream industrial tools. European test, validation and commissioning infrastructures for complex waterborne systems are operational at scale. Finally, shipyards use renewable energy for 50% of the total energy need.

92 Ibid., 17.
93 Ibid.

3.5. 2050 - GLOBALLY COMPETITIVE, FULLY SUSTAINABLE AND AUTONOMOUS INDUSTRIAL ECOSYSTEM

By 2050 the European maritime technology sector is recognised as a global leader in clean propulsion, automation, materials science, offshore technologies, complex system integration, design authority and system-of-systems architecture.[94] Shipyards are fully digital and highly automated, capable of high-volume, cost-effective production of zero-emission and autonomous waterborne assets. Material flows are fully circular across vessel construction, operation and end-of-life management. Complete lifecycle digital continuity is established across vessel design, construction, operation and recycling, while zero-emission shipyards supported by advanced industrial energy management systems become standard across the sector. Secure, sovereign and cyber-resilient supply chain architectures are operationalised. Artificial-intelligence-enabled design, production, maintenance and recycling are completely integrated, sustained by a thriving innovation ecosystem of small and medium-sized enterprises, research institutions and industrial partners. Finally, shipyards use renewable energy for 90-100% of the total energy need.

The export unit in 2050 is not the vessel. It is the industrial ecosystem: vessel designs, production methodologies, propulsion and energy systems, digital platforms, certification frameworks and lifecycle services, sold together. European certification frameworks are adopted as international baselines for sustainable alternative fuels, digital systems, autonomy and dual-use maritime technologies. This is the outcome against which the pathways in Chapter 4 are calibrated.

3.6. DIFFERENTIATED CAPABILITY MODEL AND DEPLOYMENT PACKAGES

The capability trajectory is not uniform across the sector. A specialist yard delivering complex, first-of-a-kind vessels does not follow the same transition path as a builder of standardised, series-produced platforms, and a first-tier system integrator does not follow the same path as a second-tier component supplier. The roadmap therefore differentiates by production model, series length, technological complexity, capital intensity and enterprise size. These variables should guide research funding design, certification sequencing, standardisation priorities and the timing of industrial investment.

Capabilities should be translated into measurable deployment packages. Each package should specify the vessel families covered, the technology readiness level at entry and exit, the certification pathway and its expected duration, the interface standards to be reused, the supply-chain segments involved and their resilience status, the skills required and their source, and the financing model. The seven pathways in Chapter 4 provide the technical content of these packages. The enablers required to deliver them, and the impacts expected from them, are set out in Chapters 5 and 6.[95]

94 Ibid.
95 Ibid.

Capability domain	2035	2040	2050
Propulsion and integrated energy	Battery-electric mainstream on short, high-cycle routes; methanol in service; retrofit at fleet scale	Large-scale production of zero-emission vessels and propulsion systems	Global leadership in clean propulsion
Digital shipyards and robotics	Core processes digitalised; early robotics; first modular construction lines	Automated shipyards; modular assembly; +30% productivity; predictive automation	Fully digital, highly automated, high-volume production
Materials and circularity	Advanced materials and circular design in new vessel classes	Digital material passports; remanufacturing at scale	Fully circular material flows; 100% recycling and upcycling
Digital, cyber-secure, interoperable	Software interoperability modelled; cyber risks identified; cybersecurity certification agreed	Digital twins integrated across design, production and maintenance	Secure, sovereign, cyber-resilient supply chain architectures
Autonomy, sensing, integration	Autonomous and smart system integration tested in vessel designs	Design-integrated autonomy packages reusable across variants	Large-scale resilient and secure autonomous operations
Workforce and skills	Training in digital manufacturing and sustainable engineering at scale	Digital and automation skills embedded in education and on-the-job training	AI-enabled design, production, maintenance and recycling fully integrated
Standards and certification	Simulation-based certification accepted by at least two classification societies	Type-approval for standardized platforms; dual-use certification pathways	European certification frameworks adopted as international baselines

Table 3: Capability trajectory by domain and milestone year
Source: Waterborne TP, Waterborne Technology Leadership, 17; SRA v5.0, 8-9; and Chapter 4 of this roadmap. Cells state the capability, not the technology; Chapter 4 gives the technology tracks

4. TECHNOLOGY PATHWAYS

4. TECHNOLOGY PATHWAYS

The transition towards climate-neutral waterborne systems is also a transition towards new forms of industrial, digital and operational sovereignty. Europe's long-term competitiveness will increasingly depend not only on developing individual maritime technologies, but on retaining ownership of maritime system architectures, software platforms, operational data ecosystems, lifecycle services, industrial capability and certification frameworks. The leading waterborne regions of 2050 will be those capable of integrating vessels, ports, energy systems, digital infrastructure and industrial ecosystems into a coherent waterborne operating ecosystem.

This transition is constrained not only by technology maturity, but also by the availability, cost and scalability of climate-neutral energy and fuels. The future fuel mix remains uncertain, making fuel agility, modularity and upgradeability essential design principles. Realising this transformation across the value chain also depends on resilient multi-tier European supply chains for critical components, materials, software, sensors and digital technologies, and on the active participation of SMEs and cross-sector actors that are essential to innovation diffusion at scale.

This roadmap defines the RD&I priorities needed to maintain and strengthen European technology leadership across the maritime manufacturing sector — encompassing shipbuilders, equipment manufacturers, system integrators and the broader supply chain. It applies to the full diversity of the European shipbuilding industry: from builders of standardised, series-produced vessel platforms across multiple segments, to specialists in complex, first-of-a-kind vessels combining commercial and naval-grade capabilities. The technology pathways in this chapter address common industrial technologies, system architectures, manufacturing and integration capabilities that can be applied across vessel families. Vessel- or ecosystem-specific technology selection, operational requirements and deployment pathways are addressed in the corresponding sector roadmaps. The common technologies and industrial capabilities developed in this chapter also underpin specialised underwater systems. Their application-specific requirements and deployment pathways are addressed in the Blue Economy Roadmap, while this roadmap addresses the enabling capabilities in areas such as autonomy, sensing, robotics, digital engineering, energy systems and system integration.

The seven pathways below correspond directly to the RD&I priorities of the Waterborne TP's "Resilient, Competitive and Sustainable Maritime Technology Sector" pillar. They are ordered to reflect their interdependencies: propulsion is the anchor technology, digital shipyards are the industrial system through which it is delivered, digital infrastructure connects value across the lifecycle, and standards are the framework through which European solutions reach global markets.

The transition must remain human-centred. Digitalisation, automation and AI should enhance workforce capability, safety, productivity and the attractiveness of maritime careers, while enabling faster deployment and industrial uptake at scale.

4.1. NEXT-GENERATION GREEN MARITIME TECHNOLOGIES AND INTEGRATED PROPULSION SYSTEMS

Achieving zero-emission waterborne transport requires a system-level transformation of propulsion and onboard energy architectures, moving from fuel-centric ship design toward integrated, modular and software-defined onboard energy systems. No single technology is expected to provide a universal solution across all vessel types and operational profiles. The transition will rely on different combinations of technologies selected according to vessel and operational requirements. Strategic value increasingly lies not only in propulsion hardware or fuels, but in the capability to integrate propulsion, energy management, digital control, safety systems and lifecycle optimisation into scalable waterborne energy architectures.

For shipbuilders operating across diverse vessel portfolios — spanning ferries, tugs, workboats, offshore support, naval platforms and beyond — one of the imperatives is to develop zero-emission propulsion as a platform capability: validated once per vessel family, modular enough to be reconfigured across variants, and economically viable across the full lifecycle, and adaptable to the relevant operational profile. The pathway is therefore structured around technology tracks, integration requirements and fuel-agile propulsion architectures that can evolve as energy systems, infrastructure, economics and regulations mature.

The technology tracks below addresses common maritime technology and industrial capabilities. Their application and deployment for specific vessel types and operating profiles are addressed in greater detail in the relevant vessel roadmaps. Maintaining European capability in system integration must be accompanied by sufficient industrial capacity to design and manufacture critical propulsion and energy equipment, including advanced engines, turbines, high power electrical systems, power conversion technologies and associated marine energy equipment.

4.1.1. Technology tracks

Battery-electric propulsion

Battery-electric systems are the most mature and deployable zero-emission propulsion solution. They are well-suited to short-range, high-cycle operations and are expanding into medium-distance applications through modular, swappable and hybrid architectures.

Primary segments include ferries, tugs, inland waterway vessels and short sea applications. Development priorities include higher energy density, thermal management, modular battery systems, battery swapping, shore-side charging integration and lifecycle strategies for second-life use and recycling.

Hydrogen and fuel cell systems

Hydrogen fuel cells offer zero-emission propulsion with higher energy density than batteries and may address specific operational profiles where battery-electric solutions are less suitable. Research priorities include high-power-density marine fuel-cell systems, compact storage and handling solutions, vessel integration, safety frameworks, and validation of operational business cases.

Ammonia, methanol and ethanol propulsion

Ammonia, methanol and ethanol are important options for high-power, long-range applications where battery-electric systems are constrained by energy density or infrastructure. Their deployment depends on safety system maturity, fuel availability, bunkering infrastructure, integration capability, lifecycle emissions performance and regulatory acceptance.

Further research is required to translate technologies from large-bore two-stroke engines to smaller and four-stroke engines for smaller ship types. Additional research is needed on integrated emission aftertreatment, including N_2O control for ammonia combustion, SCR adaptation for sustainable alternative fuels and onboard emissions monitoring.

More broadly, maintaining European capability in advanced internal combustion engines and other high power energy conversion technologies, including gas turbines, combined cycle architectures and hybrid high power systems is important for the industrial integration of future fuels and energy systems.

Wind-powering and energy-saving technologies

Wind-powering technologies, including wind-assisted propulsion, reduce total energy demand and improve overall efficiency. These technologies are increasingly integrated with routing, weather intelligence, energy management systems and AI-supported operational optimisation. Additional energy-saving measures include advanced propeller and hull design, air lubrication, active flow control, low-friction coatings and system-level optimisation of onboard power flows.

- **Fuel-agile and integrated onboard energy systems**

  Across all propulsion tracks, the key differentiator is integrated, fuel-agile energy architecture: DC-based onboard grids, hybrid propulsion systems, power electronics, converters, energy management systems, digital twins, optimisation platforms and integrated safety systems. Early integration of ship-port-energy interfaces — charging, OPS, battery swapping and multi-fuel bunkering — into vessel design is essential, especially for large and energy-intensive vessels.

  Nuclear power and related waterborne energy technologies may also require further research and demonstration for relevant applications, subject to appropriate safety, security, regulatory and lifecycle requirements.

  Circularity must be built in from the outset through design for maintenance, repair, remanufacturing, upgrade and second-life use of batteries, power electronics and modular energy systems. This integration capability represents a strategic European industrial asset and export opportunity.

4.1.2. Operational objective

Enable the deployment and scaling of integrated, modular and fuel-agile zero-emission propulsion systems across all vessel segments, ensuring alignment with operational profiles; integration with port, energy and digital infrastructure; lifecycle cost competitiveness including retrofit pathways; European ownership of critical technologies and intellectual assets; exportability of complete propulsion and energy systems; dual-use applicability; and resilience under geopolitical and supply-chain disruption.

For dual-use applications, system integration should also take account of requirements that may differ from commercial vessel applications, including acoustic and thermal signature considerations.

Europe must retain sovereign capability in propulsion-system integration, validation, certification and lifecycle optimisation. Novel business models are required to enable deployment at scale and accelerate commercial uptake, not only individual technology value capture.

4.1.3. Target capability 2035, 2040 and 2050

2035 – Deployment phase (TRL 6–7 → 8–9)

- Battery-electric propulsion widely deployed in ferries, inland waterways and short sea corridors
- Battery-electric systems extended to medium-distance routes through modular and swappable architectures
- Hybrid propulsion systems standard across most vessel categories
- Methanol and other relevant sustainable alternative fuel engines widely deployed in retrofit and newbuilds; hydrogen fuel cells in pilot and early commercial applications
- Wind-powering technologies integrated as standard option in relevant vessel families
- Integrated onboard energy systems operational; corridor-based and modular deployment models established
- First fuel-agile vessel architectures validated for selected vessel families
- Onboard carbon capture systems relevant for selected deep-sea applications

2040 – Industrial scaling phase (TRL 8–9)

- Industrial-scale production of propulsion systems in Europe; standardised modular propulsion architectures across vessel classes
- Hydrogen systems scaled in selected high-demand segments; initial ammonia deployment in high-power vessels
- Deep integration between vessels, ports and energy systems
- Combined charging and battery-swapping infrastructures operational
- Large-scale deployment of advanced energy-efficiency systems
- Fuel-agile propulsion architectures mainstream in new vessel families and major retrofits
- Pilot implementation of nuclear-related maritime technologies and supporting systems where relevant

2050 – Consolidation and standardisation

- Zero-emission fleet across relevant vessel families; dominance of most cost-efficient technologies per segment
- Fully standardised modular propulsion architectures; fully integrated vessel-port-energy ecosystems
- European propulsion systems exported globally; software-defined and continuously optimised vessel energy systems operational
- Fuel-agile lifecycle upgrade pathways established across major vessel families

4.1.4. Key research gaps

- Hybrid propulsion optimisation and control; integration with port energy systems
- Fuel-agile propulsion architectures enabling cost-effective conversion between future energy vectors throughout the vessel lifecycle
- Cold climate and extreme condition performance
- System-level modelling of energy demand, fuel supply chains and infrastructure requirements
- Validation of advanced air lubrication, active flow control and AI-based optimisation systems
- Standardised interfaces for battery swapping and containerised energy systems
- Marinisation and reliability of high-power multi-MW systems
- Integrated fire safety and risk engineering architectures for battery electric, hydrogen, ammonia, methanol, ethanol and fuel cell systems, including multi-sensor detection, suppression, ventilation, emergency decision support and human factors. Research should also develop common full scale validation methods, digital safety twins and reusable safety cases supporting more predictable approval across vessel families and retrofits.

Strategic conclusion

The future of waterborne propulsion will be defined by integrated, modular and software-defined energy systems. The most competitive solutions may not be those optimised for a single fuel, but those designed to adapt as technologies, markets and regulations evolve. For the European maritime technology sector, the competitive advantage lies in delivering complete, certified, lifecycle-managed propulsion systems — not just hardware — through close collaboration across fuel developers, component suppliers, shipbuilders, classification societies, ports and infrastructure providers.

4.2. DIGITAL SHIPYARDS, ADVANCED MANUFACTURING AND ROBOTICS

The transformation of the waterborne sector requires a shift from project-based shipbuilding toward industrialised, modular, platform-based and digitally integrated production systems. For European shipbuilders that have invested in standardised vessel portfolios, global production and repair networks, and series production capabilities, the RD&I challenge is to extend and deepen that industrial discipline while retaining the capability to deliver complex first-of-a-kind vessels.

The objective is not to build a single mega-shipyard, but to develop a digitally orchestrated, distributed industrial ecosystem in which design, engineering, production, suppliers, customers and lifecycle services are connected through shared digital platforms. Future digital shipyards must support newbuilds, retrofit, repair, conversion, dismantling and component recovery.

Digital engineering should also strengthen European capability in complex systems integration, including multidisciplinary systems engineering, interface management, configuration management, design authority and integration across increasingly complex vessel systems and supply chains. These capabilities are relevant to both commercial and naval vessel production, while navel specific platform requirements remain outside the scope of this roadmap. Design Authority should be recognised as a strategic industrial capability, enabling European industry to retain control of vessel architecture, system interfaces and configuration, manage design changes, and ensure the integrity of complex and software-intensive vessel programmes.

4.2.1. Digital shipbuilding value chain and industrial production

Future shipyards evolve into digitally integrated ship factories in which vessel design, engineering, manufacturing and lifecycle management are connected through shared digital platforms. Key elements include modular ship structures, standardised interfaces, supplier integration, digital configuration management, feedback from operations into production and traceability between as-designed, as-built and as-maintained vessel states.

Integrated multidisciplinary design environments and Model-Based Systems Engineering (MBSE) should support interface management, automated clash detection, engineering change-impact assessment and continuity from design to manufacturing. European capability should include European owned or European controlled multidisciplinary design software, MBSE platforms, configuration management tools and digital validation environments, reducing strategic dependency on non-European engineering platforms for the design and lifecycle management of complex waterborne systems.

Future competitiveness depends on the transition from project-centric shipbuilding towards platform-based vessel development, where designs, software components, certification artefacts and system architectures are reused across vessel families. This enables series production, reduced engineering effort, shorter lead times, higher repeatability and modularisation of complex subsystems such as cabins, HVAC, public spaces, accommodation modules and energy systems.

4.2.2. Digital twins, automation and data-driven production

Digital shipyards rely on comprehensive digital twins of vessels, production systems and supply chains. MBSE methodologies support multidisciplinary integration, interface management and configuration control across complex vessel programmes — enabling simulation, production optimisation, lifecycle data integration and virtual commissioning.

AI will increasingly augment engineering and production activities across the waterborne value chain. Future capabilities should include generative vessel design, AI-assisted systems engineering, automated compliance verification, engineering copilots and AI-supported production optimisation. Robotics and automation will support welding, cutting, assembly, high-variability outfitting, autonomous material handling and zero-defect manufacturing through AI-supported inspection and quality assurance.

Digital engineering and production environments should also support safety-by-design and the safe integration of innovative systems during construction, commissioning, maintenance and upgrade activities.

Industrial data, configuration knowledge and integration methodologies constitute strategic European industrial assets. Design-for-manufacture, design-for-retrofit and design-for-disassembly methodologies should be embedded across vessel lifecycles. The waterborne sector can draw on automotive and aerospace standards for collaboration, modular interfaces and software-intensive system integration.

4.2.3. Operational objective

Enable digitally integrated, modular and automated shipyard ecosystems capable of industrial-scale production of next-generation vessels, ensuring coordination of a distributed European value chain; industrialisation through modular structures, AI-enabled engineering and automation; integration of digital twins across lifecycle stages; reduction of construction time and cost; protection of industrial data and intellectual assets; and active integration of SMEs through open interfaces and accessible qualification pathways. This includes strengthening European capability in complex systems engineering, interface and configuration management, system integration and design authority across increasingly complex waterborne products and production networks.

4.2.4. Target capability 2035, 2040 and 2050

2035 – Digital foundations and initial modular production

- Digital shipyard architectures operational across leading European yards
- First modular production lines established for ferries, inland waterway and short sea vessel families
- Initial platform-based vessel families deployed using reusable designs, modules and certification artefacts
- Robots and cobots deployed at industrial scale in repeatable processes such as welding, cutting, and material handling, with advanced and flexible robotic solutions increasingly deployed in high-variability assembly and outfitting tasks
- First AI-enabled engineering environments operational for design, planning and quality assurance
- Integrated multidisciplinary design engineering environments increasingly support systems engineering, interface management and engineering change control in major vessel programmes

2040 – Industrial scaling and platform standardisation

- Widespread adoption of modular shipbuilding across major vessel categories
- Majority of new vessel families developed using platform-based design principles and AI-supported engineering environments
- Fully integrated digital production systems linking design, manufacturing, procurement, quality and lifecycle data
- Advanced robotics and automated quality assurance deployed across hull construction, outfitting and interiors
- Significant cost and lead-time reductions realised; European yards price-competitive on selected standardised vessel types

2050 – Ship factory ecosystem

- Highly automated digital ship factories producing zero-emission vessels at industrial scale with minimal bespoke engineering per hull
- AI-enabled engineering standard across the sector
- Fully integrated lifecycle systems unifying production, operational and maintenance data
- Global export of European shipbuilding ecosystems — combining vessel designs, production methodologies, digital platforms and lifecycle services, while protecting critical European intellectual property, integration know how and strategically important industrial capabilities.

4.2.5. Key research gaps

- Robotics for high-variability ship assembly, outfitting and interior installations, including applications on curved and complex surfaces
- AI-assisted engineering, generative design and automated compliance checking
- Digital twin integration across the full lifecycle from design to decommissioning
- Modular ship architecture standards and interface specifications scalable across vessel families
- AI-supported production planning and autonomous quality assurance in constrained shipyard environments
- Reduced-redundancy design approaches for cost optimisation in standardised platforms
- Qualification and industrialization of additive manufacturing for safety- and performance-critical maritime components
- Integrated digital engineering and systems engineering environments supporting multidisciplinary design, interface management, configuration control and change-impact assessment across complex vessel programmes

Strategic conclusion

The transformation of shipbuilding into a platform-driven, AI-enabled and digitally orchestrated industry is an industrial necessity. Reusing proven designs, software, certification evidence, standardised modules and validated production methods across multiple projects is the strongest lever for cost, speed and quality. The digital shipyard enables Europe to export not only ships, but complete industrial ecosystems combining design, production, servicing, lifecycle management and continuous improvement.

4.3 MATERIALS INNOVATION, CIRCULARITY AND LIFECYCLE OPTIMISATION

Materials become active components of digitally managed waterborne systems rather than passive structural elements. This pathway integrates advanced materials, circular lifecycle models, embedded sensing and digital monitoring. For shipbuilders and equipment manufacturers committed to long-term vessel performance and lifecycle services, materials choices made at the design stage determine maintenance costs, upgrade flexibility and residual value across a 30-year asset life.

4.3.1. Advanced materials and structural integration

Advanced materials include high-performance steels and aluminium, composites and hybrid materials, advanced coatings, 3D-printed components, hydrogen-compatible steels, cryogenic materials, ammonia-resistant containment materials and methanol-compatible coatings and seals. These apply to hull structures, outfitting, accommodation and system integration alike.

Materials must support battery and fuel-system integration, lightweight structures, fire safety, containment of new fuels, retrofit, upgrade and reconfiguration. Standardised structural interfaces for modular energy systems and structural adhesive bonding technologies support industrial-scale lightweight architectures.

Future materials should increasingly function as active components of digital waterborne systems through integrated sensing, structural-health monitoring and lifecycle intelligence capabilities. Digital material passports enable traceability from raw material sourcing through recycling and decommissioning.

4.3.2. Circularity, lifecycle optimisation and digital integration

Circularity requires a full lifecycle perspective: design for disassembly, reuse, remanufacturing and recycling of materials and systems. Lifecycle optimisation is supported by Digital Product Passports, European data spaces and simulation-based certification of materials. Materials must be developed in parallel with regulatory frameworks to enable deployment and certification.

Lifecycle integration enables new business models including performance-based contracts, upgrade services and circular value recovery. Material traceability and lifecycle monitoring data become strategic industrial knowledge assets, supporting residual value assessment, reuse and recoverability while reducing dependence on external raw material supply chains.

4.3.3. Operational objective

Enable advanced materials and circular lifecycle systems supporting next-generation vessel architectures, ensuring lightweight and high-performance materials; integration with propulsion and energy systems; deployment of circular lifecycle models; embedded sensing and data-driven lifecycle optimisation; and protection and utilisation of material-related data as a strategic industrial asset.

4.3.4. Target capability 2035, 2040 and 2050

2035 – Advanced materials deployed; initial circularity

- Advanced materials deployed in selected newbuild programmes
- Structural integration of zero-emission energy systems standard practice for selected vessel families
- Initial digital material passports piloted across selected vessel families
- First circular lifecycle models operational; design-for-disassembly embedded in new vessel programmes
- Self-monitoring material concepts and embedded sensing demonstrated in selected applications

2040 – Circular manufacturing systems and lifecycle data integration

- Circular manufacturing systems established in shipyard operations
- Standardised modular material systems enabling rapid reconfiguration and upgrade
- Full integration of structural health, maintenance records and material passports into digital twin platforms
- Simulation-based certification of materials accepted by leading classification societies

2050 – Full circularity and lifecycle optimisation

- Fully circular material flows in vessel construction, operation and end-of-life
- Complete lifecycle optimisation including residual value assessment, reuse and recovery
- Materials innovation embedded in European resilience strategy, reducing dependence on external raw material supply

4.3.5 Key research gaps

- Lightweight, recyclable and hydrogen/ammonia/methanol-compatible materials for waterborne applications
- Self-monitoring materials and embedded sensing technologies enabling continuous structural awareness and predictive maintenance
- Structural integration of modular energy systems including battery bays and fuel containment
- Advanced coatings and corrosion protection for sustainable alternative-fuel environments
- Simulation-based certification methodologies accepted by classification societies
- Lifecycle optimisation tools integrating structural health, maintenance and residual value data
- Advanced materials for marine fuel cell and battery systems, addressing performance, durability, safety and recyclability under maritime operating conditions

Strategic conclusion

Materials innovation sits at the intersection of propulsion performance, production efficiency and lifecycle economics. In a platform-based maritime industry, a qualified material system, structural interface or coating specified once and reused across vessel families generates compounding value. Europe's ability to monitor, maintain, upgrade and recover material value over a vessel lifetime is a major competitive differentiator relative to producers whose business model ends at delivery.

4.4. DIGITAL, CYBER-SECURE AND INTEROPERABLE SYSTEMS

Software and data become as strategically significant as steel and propulsion. This pathway addresses the transition towards software-defined vessels and secure, interoperable digital ecosystems, where European control over software, data, integration architectures and lifecycle digital threads determines long-term competitiveness. For European maritime technology companies, the goal is not only to deliver capable vessels and systems, but to retain the digital relationship that enables continuous improvement and lifecycle value creation.

4.4.1. Software-defined waterborne systems

Digital sovereignty is a core determinant of waterborne competitiveness, resilience and operational independence. A common European waterborne data model and standardised integration APIs should enable interoperability across vessels, ports, suppliers and lifecycle systems. Future vessels operate as software-defined platforms: continuous updates through DevOps lifecycles, decoupled hardware and software layers, secure over-the-air updates, cryptographic verification and rollback functionality.

Waterborne operating systems, middleware and orchestration layers become strategic control points. Europe should develop a shared waterborne digital infrastructure comprising common data models, trusted digital identities, secure interoperability standards, digital vessel passports and lifecycle digital threads spanning design, operation, retrofit and recycling.

4.4.2. Data sovereignty, cybersecurity and resilience

Operational, lifecycle and optimisation data generated through vessel operation must remain accessible within European industrial ecosystems to ensure sovereign capability for continuous system improvement. European control requires cloud and edge infrastructure, waterborne data spaces, trusted identity frameworks and clear data ownership and governance models embedded in commercial contracts.

Cybersecurity must include security by design, dual-use by design, continuous assurance of software systems, quantum resilience, degraded-mode capability and European-controlled digital infrastructure. Future systems must remain operational under degraded conditions, including GNSS disruption, cyber incidents, communication outages and cloud-service interruptions.

4.4.3. Interoperability and system integration

Standardised architectures are required to enable interoperability across suppliers, integration across vessels, ports and logistics systems, scalable upgrades, transparent multi-tier supply chains and compliance with EU critical infrastructure and cybersecurity requirements. Common interface specifications, systems engineering approaches and lifecycle configuration management should support integration across increasingly complex multi-supplier and system-of-systems environments. Software lifecycle management frameworks should support continuous regulatory-compliant updates for software-defined vessels.

4.4.4. Operational objective

Develop secure, interoperable and European-controlled digital waterborne systems, ensuring full interoperability; protection of data and intellectual assets; cyber-resilient operations; integration across waterborne ecosystems; independent European waterborne software capability; lifecycle data retained within European industrial ecosystems; and resilient waterborne digital infrastructure capable of operating under hybrid threats and contested conditions.

4.4.5. Target capability 2035, 2040 and 2050

2035 – Software-defined vessel architectures deployed

- Software-defined vessel architectures deployed in leading vessel programmes
- Initial interoperability standards agreed between major European shipbuilders and classification societies
- Waterborne data governance frameworks established; pilot waterborne digital infrastructure operational
- Cybersecurity certification frameworks for waterborne OT/IT systems agreed; post-quantum cryptography integration underway
- Multi-tier supply chain mapping and resilience monitoring operational for critical waterborne technology supply chains

2040 – Standardised digital architectures and European software stack

- Standardised digital architectures across major vessel categories
- Common European waterborne digital infrastructure operational across major waterborne ecosystems
- Fully operational European waterborne software stack — OT, IT and connectivity — reducing dependency on non-European platform providers
- Advanced cybersecurity systems, alternative Positioning, Navigation and Timing (PNT) solutions and degraded-mode operations validated across vessel families
- Secure over-the-air update capability deployed across significant portions of European-built fleets

2050 – Fully integrated digital waterborne ecosystem

- Fully integrated digital waterborne ecosystem: vessels, service networks and lifecycle platforms sharing data within European-controlled infrastructure
- Lifecycle digital threads operational from concept design through vessel recycling
- Continuous software-defined optimisation across global fleets; AI-based fleet management operational
- European waterborne operating ecosystem exported globally and adopted as industry standard

4.4.6. Key research gaps

- Waterborne software architecture: common operating systems, middleware and API standards
- European waterborne digital infrastructure, distributed waterborne cloud architectures and lifecycle digital thread architectures
- Cyber-resilient systems: degraded-mode capability, AI-based threat detection, post-quantum cryptography and alternative PNT
- Secure data sharing frameworks balancing commercial confidentiality with industrial interoperability
- Trusted AI governance and assurance for waterborne systems
- AI-based optimisation across vessel systems integrated with lifecycle and fleet management platforms
- Interoperable system architectures and interface management methods supporting integration across complex multi-supplier and system-of-systems waterborne environments

Strategic conclusion

As vessels become software-defined platforms, the competitive stakes of digital capability shift from feature differentiation to structural dependency. Companies that shape the digital architecture of a vessel — the operating system, data model, integration APIs and lifecycle digital thread — retain an ongoing relationship with that vessel and its owner. European RD&I investment should support the development, validation and scaling of European platforms, standards and governance frameworks strengthening Europe's technological capability and reducing strategic dependencies in critical waterborne digital systems.

4.5. HIGH-PERFORMANCE SYSTEMS FOR AUTONOMY, SENSING AND INTEGRATION

Autonomy, sensing and integration capabilities are increasingly specified as core requirements by shipowners and operators. The strategic challenge is to develop these capabilities not as bespoke add-ons, but as repeatable, certifiable system packages that can be integrated across vessel families at the design stage, manufactured at scale and exported globally. The next development stage extends beyond autonomy towards cognitive waterborne systems that combine AI, advanced sensing and human expertise into continuously improving operational ecosystems. These capabilities also apply to autonomous and remotely operated underwater systems, while their application-specific requirements and deployment pathways are addressed in the Blue Economy Roadmap.

4.5.1. Operational modes and autonomy development

Autonomy is a strategic capability enabling resilient waterborne operations under contested or degraded conditions. It is structured around operational modes such as Assisted Navigation, Direct Control, Operator-Assisted Operations and Constrained Autonomous Operations. Autonomy must be clearly distinguished from crewing levels: it is a system-design characteristic, not a manning policy. Autonomy systems should integrate sensing, communications, control, cybersecurity, simulation-based validation and lifecycle assurance.

4.5.2. Sensing, decision support and resilience

Advanced sensing includes radar, lidar, vision systems, sensor fusion and resilient data integration. Decision-support systems are critical for normal operations, incidents, emergency response and crisis scenarios. Remote support using XR/VR technologies supports human-centred operations. Systems must support degraded-mode operation, resilient navigation and distributed operational continuity, including multi-constellation GNSS, anti-spoofing, anti-jamming and alternative PNT approaches.

Cognitive waterborne systems should continuously learn, self-diagnose, optimise performance and support human decision-making. Capabilities include onboard AI agents, predictive mission management, intelligent maintenance planning, adaptive energy optimisation and decision-support systems that remain explainable, auditable and certifiable.

4.5.3. Exportable, design-integrated autonomy packages

The competitive value of autonomy and cognitive capability lies in delivering certified, design-integrated system packages rather than retrofitted add-ons. This requires standardised sensing and control modules, shore-side test and validation facilities, common interface specifications and platform-level certification frameworks that allow systems to be reused across vessel variants. System integration and interface management across sensing, control, communication, vessel and shore-side systems are therefore integral to the development of reusable autonomy packages.

This turns autonomy from a vessel-specific engineering exercise into a repeatable, sellable capability consistent with platform-based, series-built ship design.

4.5.4. Operational objective

Develop safe, resilient, dual-use autonomy and cognitive system packages enabling advanced waterborne operations and crisis management, that can be specified, certified, updated and reused across vessel platforms.

4.5.5. Target capability 2035, 2040 and 2050

2035 – Assisted navigation and early cognitive functions

- Assisted navigation widely deployed across European vessel families as a standard-option package
- Early remote and semi-autonomous operations validated in designated corridors
- Autonomy packages defined and qualified at platform level for at least three vessel families
- First cognitive vessel functions deployed, including AI-assisted decision support and predictive maintenance planning
- Shore-side remote operation centres and XR/VR training environments operational

2040 – Autonomous and cognitive operations in selected segments

- Autonomous operations commercially deployed in selected low-complexity, high-cycle vessel segments
- Cognitive vessel functions operational across major commercial vessel fleets
- Autonomy packages connected to fleet management, lifecycle monitoring and maintenance platforms

- Dual-use autonomous systems validated for commercial and naval/security applications
- Certification frameworks for autonomous and AI-enabled vessel functions established at IMO and EU level

2050 – Cognitive and autonomous systems widely standardised

- Autonomous and cognitive systems widely standardised across vessel categories
- Fully integrated resilient waterborne operations combining vessels, remote operation infrastructure and lifecycle support
- European autonomy and cognitive waterborne technology exported globally
- Cognitive and autonomous systems fully integrated into waterborne operations

4.5.6. Key research gaps

- Sensor fusion reliability across all weather, sea state and visibility conditions
- AI-based navigation and decision-making with explainable, auditable and certifiable outputs
- Cognitive vessel systems: onboard AI agents, predictive mission management and intelligent maintenance planning
- Resilient operations under disruption: degraded-mode performance, cyber-attack scenarios and communication loss
- Human-machine interaction and ergonomic design of remote operation interfaces
- System integration and interface management for reusable autonomy packages across sensing, control, communication, vessel and shore-side systems.

Strategic conclusion

Autonomy is evolving from a premium feature to a standard capability across multiple vessel families. The next stage extends beyond autonomy towards cognitive waterborne systems that combine AI, advanced sensing and human expertise into continuously improving operational ecosystems. The sector must invest not only in technology, but in the industrial, certification and standardisation infrastructure that makes repeatable, scalable deployment possible.

4.6. WORKFORCE TRANSFORMATION AND SKILLS

None of the preceding pathways can be deployed at scale without the people to design, build, certify, operate and continuously improve them. This pathway addresses the skills, training infrastructure, human-centred design and productivity amplification needed to ensure Europe's workforce can absorb the pace of digital, automated and zero-emission transformation.

4.6.1. Workforce transformation across shipbuilding and operations

Knowledge, skills and operational competence are strategic industrial capabilities. Europe's long-term competitiveness depends on attracting, developing and retaining highly skilled talent across engineering, digital systems, software, AI, energy systems and industrial operations. The workforce must adapt to robotics and automation, remote operations, AI-driven design and engineering, MBSE, Hardware-in-the-Loop (HIL) validation, digital commissioning and systems integration.

Europe's response to demographic decline cannot rely solely on workforce expansion. Competitiveness increasingly depends on augmenting human capability through AI-enabled engineering tools, advanced decision-support systems, robotics and automation. Human-centred and ergonomic design must ensure that workers adapt safely and confidently to new industrial processes. A safety culture in which incidents are treated as learning opportunities supports attraction and retention of talent.

4.6.2. Skills development and training systems

Europe must retain the capability to educate, train and continuously develop the workforce required for advanced waterborne systems. Training must include digital engineering and production, human-machine interaction, XR/VR, cybersecurity, data governance, alternative fuels and AI-enabled systems and complex systems integration. Collaboration between industry, academia and training providers is essential to retain tacit production knowledge and integration competence within Europe.

4.6.3. Operational objective

Develop a highly skilled, adaptable and augmented workforce capable of designing, building, certifying, servicing and continuously improving an increasingly complex integrated product portfolio, supported by AI-enabled engineering tools and human-centred automation.

4.6.4. Target capability 2035, 2040 and 2050

2035 – Training systems deployed; initial workforce augmentation

- Advanced digital training systems deployed across leading European shipyards
- MBSE, HIL validation, digital production and robotics integration competences embedded in apprenticeship and graduate programmes
- Human-centred design principles integrated into new shipyard layout and process design projects
- Initial AI-enabled engineering copilots deployed in selected design and production environments

2040 – Integrated European training and augmented engineering ecosystem

- Integrated European training ecosystem operational across major waterborne clusters
- Advanced human-machine collaboration mainstream in production and service environments
- Cross-disciplinary competence profiles established across naval architecture, systems engineering, software and data science
- AI-enabled engineering environments significantly increase engineering productivity and reduce dependency on scarce specialist resources

2050 – Fully transformed and continuously adapting workforce

- Continuous learning infrastructure embedded in waterborne companies
- AI-enabled engineering and decision-support standard across the maritime technology sector
- European waterborne competence ecosystems exported globally through training partnerships and workforce development programmes

4.6.5. Key research gaps

- Human-machine interaction for complex waterborne production and servicing environments
- Training for autonomy and cognitive vessels: competence frameworks for remote operation and AI-assisted decision-making
- AI-driven workforce transformation: tools for skill assessment, gap identification and personalised learning
- Engineering productivity amplification through AI copilots, model-based tools and automated compliance support
- Skills and competence frameworks for complex systems engineering, multidisciplinary integration and lifecycle system management

Strategic conclusion

Technology transitions are won or lost by the people implementing them. Europe must not only train more specialists but multiply the capability of its workforce through AI-enabled engineering, human-centred automation and continuous learning. As the sector shifts toward platform-based and digitally integrated production, workers must evolve from users of tools into supervisors, integrators and improvers of intelligent systems.

4.7. STANDARDS, CERTIFICATION AND REGULATORY PATHWAYS

Every pathway above depends on the speed and predictability with which new technologies can be certified and deployed. Regulation should be treated not as a constraint on innovation, but as a strategic instrument: the capability to certify complex, first-of-a-kind and software-defined systems within European frameworks shapes which technologies reach the market first, and where.

4.7.1 Regulatory frameworks and alignment

Regulatory and certification capability becomes a strategic instrument of industrial sovereignty. Effective deployment requires alignment across EU regulation, IMO frameworks, flag and port state regulations and classification societies. European certification capability should support rapid validation of first-of-a-kind systems, modular propulsion architectures, digital systems, AI-enabled functions and dual-use waterborne technologies.

4.7.2. Regulation as an enabler of innovation and competitiveness

The capability to certify complex integrated systems within European frameworks becomes a strategic competitive advantage — enabling faster deployment, lower integration risk and stronger export credibility. Regulation should enable new technologies, support competitiveness, provide first-mover advantage and enable rapid deployment of integrated solution packages through harmonised and predictable certification pathways. Goal-based and risk-based certification approaches support rapid validation of first-of-a-kind systems.

4.7.3. Virtual certification and regulatory innovation

Regulatory frameworks must support scenario-based testing, continuous regulatory adaptation, simulation-based validation prior to construction, certification methodologies for AI-enabled systems, continuous digital assurance and dual-use certification pathways. Where appropriate, virtual and digital certification should be complemented by HIL testing and representative physical validation, enabling evidence generated through simulation, laboratory testing and full-scale demonstration to be combined within a coherent assurance process. Future certification approaches should increasingly rely on digital evidence, simulation-based verification, AI-assisted compliance assessment and continuously updated assurance cases for software-defined systems. Certification evidence and assurance cases should, where technically and regulatorily appropriate, be reusable across related vessel families, modular systems and subsequent technology variants.

4.7.4. Operational objective

Develop coherent, scalable and exportable regulatory frameworks enabling European leadership in maritime certification — reducing time-to-market for new technologies, providing commercial certainty for investors, supporting reuse of validated certification evidence and shaping international standards in line with European industrial interests.

4.7.5. Target capability 2035, 2040 and 2050

2035 – Strong influence on global standards; harmonised European frameworks

- Active European influence on IMO and classification society frameworks for sustainable alternative fuels, digital systems, AI-enabled functions and autonomous vessels
- Harmonised European frameworks for goal-based and risk-based certification across EU flag states
- Simulation-based and virtual certification approaches accepted by at least two major classification societies for selected technology areas
- First digital evidence packages demonstrated for software-defined and platform-based vessel systems, including combined simulation, HIL and representative physical validation.

2040 – Fully aligned regulatory systems

- Fully aligned regulatory systems across EU Member States and major European classification societies for all principal technology areas
- Type-approval frameworks for standardised vessel platforms operational, with validated evidence reusable across related variants and modular systems where appropriate
- Dual-use certification pathways established for civil and naval technology variants
- AI-assisted compliance verification and continuous software assurance frameworks operational

2050 – Global leadership in waterborne regulation

- European certification frameworks adopted as international baselines for sustainable alternative fuels, digital systems, autonomy and dual-use waterborne technologies
- Europe recognised as global leader in digital certification, simulation-based validation and certification of software-defined waterborne systems
- Regulatory leadership reinforcing export competitiveness through predictable and credible certification basis

4.7.6. Key research gaps

- Certification of new propulsion systems: sustainable alternative fuels including safety, emissions and bunkering infrastructure
- Regulation of autonomous and cognitive vessels: liability frameworks, operational design domains and minimum performance standards
- Digital interoperability and cybersecurity standards for software-defined vessels and OTA update governance
- AI-assisted compliance verification and digital certification methodologies
- Continuous software assurance frameworks for software-defined waterborne systems
- Integrated validation and certification methodologies combining simulation, HIL testing, representative physical testing and operational evidence
- Reusable certification evidence and assurance cases for modular systems, standardised vessel platforms and related vessel variants, including conditions under which evidence can be transferred without compromising safety or regulatory integrity

Strategic conclusion

Regulatory capability is an underestimated competitive asset. Maritime technology companies that shape certification frameworks reduce time-to-market and raise barriers to entry for competitors. For European shipbuilders and equipment manufacturers operating globally, the ability to navigate and influence these frameworks is not a compliance burden but a commercial capability. Coordinated European engagement in international standards bodies is therefore a sector-level strategic priority.

5. KEY ENABLERS AND DEPLOYMENT

5. KEY ENABLERS AND DEPLOYMENT

The pathways in Chapter 4 build on a strong European base: leadership in complex vessel construction and maritime equipment, mature battery-electric and hybrid solutions in selected segments, growing uptake of sustainable alternative fuel ready systems, established retrofit and repair capacity, and increasing deployment of digital tools, robotics and energy saving technologies. The remaining challenge is to move from fragmented pilots and first-of-a-kind applications to repeatable, certified and industrial-scale deployment across European yards and suppliers. This requires not only technology maturity, but also the engineering, integration, validation, safety, industrial and financing capabilities needed to move successfully from demonstration to sustained market deployment.

5.1. INDUSTRIAL-SCALE INTEGRATION AND MANUFACTURING

The principal enabler is the modernisation of European shipyards and supplier networks so that new technologies can be integrated, produced and replicated efficiently. Priority actions include digital shipyard architectures linking design, production, suppliers and lifecycle data; integrated digital engineering environments supporting multidisciplinary design, system integration, interface management and lifecycle configuration management, modular vessel platforms and standardised interfaces that allow reuse across vessel families; robotics and automation adapted to low-volume, high-complexity shipbuilding; and industrial-scale facilities for propulsion integration, virtual commissioning, hardware-in-the-loop testing, autonomous-system validation and automated quality assurance. Deployment also requires coordinated newbuild, retrofit, repair, conversion, remanufacturing and recycling capability, supported by material qualification, digital material passports and design-for-disassembly. Modernisation should also support the decarbonisation and energy efficiency of shipyard and production processes and maintain European industrial capability and resilient supply chains for critical propulsion and energy system equipment, including advanced engines, turbines, high power electrical and power conversion systems and other key marine energy technologies The focus should be on scaling technologies already demonstrated in selected yards and vessel segments, while preserving Europe's capacity to deliver complex first-of-a-kind vessels.

5.2. CERTIFICATION, STANDARDIZATION AND REUSABLE APPROVAL

Certification remains a major constraint on industrial uptake. Early involvement of classification societies and flag administrations must become standard in technology development and demonstration projects. Priority enablers include simulation-based and virtual certification; type approval of modular systems and standardised vessel platforms; reusable certification evidence across vessel families; harmonised interfaces for propulsion, energy, vessel-port connections, software, data and autonomy systems; and continuous assurance for software-defined and AI-enabled functions.

Regulatory sandboxes and representative test environments are required for sustainable alternative fuels, autonomous systems, advanced materials and digital technologies. European cooperation on maritime safety and validation should progressively provide access to shared representative and, where necessary, full-scale test facilities, common testing and performance criteria, and mechanisms for translating validated test evidence into reusable safety cases and approval packages. Such capabilities should be accessible to SMEs as well as major shipyards and equipment manufacturers. Certification pathways should also accommodate civil and dual-use variants where technologies share common architectures and components. These measures will allow certification to progress in parallel with technology development and reduce repeated engineering and approval effort.

5.3. RESILIENT EUROPEAN SUPPLY CHAINS AND DIGITAL SOVEREIGNTY

Europe must retain capability in the design, integration, production and lifecycle support of critical waterborne systems. This requires mapping multi-tier supply chains and identifying critical dependencies; qualifying alternative European suppliers for key components, software and materials; protecting industrial data, system architectures, integration knowledge and intellectual property; and establishing trusted digital environments for collaboration between yards, suppliers and SMEs. Common waterborne data models, software standards and secure edge and cloud infrastructure are required to support interoperability and lifecycle digital threads. Lifecycle configuration and data continuity should be maintained across design, construction, commissioning, operation, retrofit, repair and end-of-life activities, including where responsibility passes between different industrial actors. Trusted AI governance, secure software updates, configuration control, vulnerability management and cybersecurity assurance must apply throughout the vessel lifecycle. The objective is not complete self-sufficiency, but sufficient European control over critical technologies and the ability to maintain production, repair and upgrade capacity under disruption.

5.4. AUTONOMY, CONNECTIVITY AND OPERATIONAL VALIDATION

The deployment of autonomous and remotely operated systems requires more than onboard technology maturity. Representative test areas, resilient positioning and communications, remote operation infrastructure, human factors validation and reusable assurance frameworks are needed to demonstrate safe operation under normal and degraded conditions. Testing should cover sensor fusion, decision-making, communication loss, positioning disruption, cybersecurity incidents and safe fallback modes.
More generally, integrated technology demonstrators should include dedicated safety and resilience activities from concept design through commissioning, operation, retrofit and software update. These should include appropriate hazard identification and risk assessment, approval strategy, representative testing, crew and responder training where relevant, emergency exercises, performance monitoring and systematic capture of lessons learned.

These capabilities must be integrated with vessel design, port and shore-side systems, and certification processes from the outset.

5.5. SKILLS AND WORKFORCE TRANSFORMATION

Digital production, sustainable alternative energy systems, software defined vessels, autonomy and circular manufacturing require a workforce combining maritime engineering with robotics, software, cybersecurity, systems integration and advanced materials. Enabling actions should concentrate on industrial training linked directly to digital shipyards and demonstration programmes; upskilling the existing workforce in new energy, automation and data systems; common European competence frameworks and recognised certification; AI-assisted engineering and production tools that augment scarce skills; and retention and transfer of tacit shipbuilding and systems integration knowledge. Training associated with new technologies should also include relevant construction, commissioning, emergency response and safety competences. Digital training platforms, simulation tools and AI-enabled engineering environments should be accessible to SMEs as well as major shipyards and equipment manufacturers. Training should progress with industrial deployment rather than as a separate activity.

5.6. INVESTMENT AND MARKET DEPLOYMENT

Research funding has already supported substantial progress in zero-emission technologies and digitalisation, but industrial scaling requires investment beyond research and demonstration. Support is also needed to bridge the transition from successful technological demonstration to first industrial deployment, commercial readiness and sustained market uptake. Priority support should target first-of-a-kind vessel and system integration; modernization of production facilities; qualification and scaling of European suppliers; retrofit and conversion programmes; certification costs and reusable approval packages; and circular repair, remanufacturing and recycling capacity. Lifecycle financing models are also needed for integrated propulsion, energy, software and upgrade packages, including leasing, performance-based contracts and shared risk mechanisms. Public procurement can create lead markets for publicly produced vessel categories such as ferries, workboats, research vessels and other specialised vessels, while fleet-renewal and investment instruments can support the uptake of advanced European technologies across broader range of strategically relevant vessel segments, including offshore and ocean going vessels. Financial support should increasingly reward European value creation, supply chain resilience and retention of critical intellectual property.

5.7. DEPLOYMENT SEQUENCE

Deployment should follow a focused progression:

To 2030: complete industrial validation of digital shipyard systems, modular architectures, alternative energy integration, vessel-port interfaces, autonomy test environments, virtual certification, lifecycle data systems and supply chain mapping, including initial deployment of integrated digital engineering and lifecycle configuration-management environments and representative safety and validation capabilities.

2030–2035: deploy integrated demonstrators across representative vessel families and shipyard environments, establish reusable certification packages, validate remote and autonomous operations, and expand retrofit, remanufacturing and circularity programmes. Integrated demonstrators should systematically incorporate safety and resilience assessment, testing and lessons learned.

2035–2040: scale modular production, robotics, digital twins, zero-emission system integration, autonomous-system deployment and interoperable software and data architectures across European yards and supplier clusters, while scaling advanced system-integration capabilities, testing and validation infrastructures, lifecycle continuity and shipyard decarbonisation solutions.

2040–2050: consolidate a fully digital, circular, cyber-resilient and globally competitive European maritime manufacturing ecosystem capable of exporting complete vessel, technology, production, certification and lifecycle-service packages.

6. EXPECTED IMPACTS

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Implementation of this Roadmap will strengthen Europe's capacity to design, build, equip, retrofit, maintain and recycle the vessels and maritime systems required across the waterborne sector. Its central impact will be to convert European technological strengths into scalable industrial capability and support delivery of the other Waterborne roadmaps. Industrial competitiveness and resilience are therefore the principal expected impacts of this roadmap, supported by environmental, technological, safety, workforce and market outcomes.

6.1. CLIMATE AND ENVIRONMENTAL IMPACTS

The Roadmap will accelerate the deployment of zero- and low-emission propulsion, energy-efficiency technologies and integrated onboard energy systems. Fuel-agile architectures, modular retrofits, advanced materials, circular design and digital lifecycle management will reduce emissions, energy use, waste and premature asset replacement, while improved material efficiency, reuse, recovery and substitution will reduce dependence on selected critical raw materials.

6.2. INDUSTRIAL COMPETITIVENESS AND RESILIENCE

Digital shipyards, modular production, robotics, AI-assisted engineering and reusable certification will reduce lead times and production costs while improving quality and productivity. Integrated digital engineering environments, improved configuration and interface management, advanced system integration capabilities, hardware-in-the-loop and virtual commissioning approaches will reduce design rework, improve engineering productivity and accelerate industrial validation. Stronger European control over critical technologies, software, data, supply chains, repair, retrofit and recycling capacity will reinforce strategic autonomy and resilience. Modernisation and decarbonization of European shipyards, together with retained European manufacturing capacity and resilient supply chains of critical propulsion and energy technologies, will further support the competitiveness and resilience of the maritime manufacturing base.

Table 6: Expected Impacts

6.3. FLEET TRANSFORMATION AND MARKET UPTAKE

Standardised modules, reusable approval packages and scalable production methods will support the transition from first-of-a-kind projects to repeatable newbuild and retrofit solutions. Operators will benefit from lower energy and maintenance costs, reduced downtime and greater flexibility to adapt vessels to future fuels, technologies and regulations. Improved industrial readiness and integrated vessel-port-energy solutions will support wider deployment of zero- and low-emission technologies across relevant vessel segments.

6.4. SAFETY, DIGITALIZATION AND WORKFORCE IMPACTS

Cyber-secure software architectures, resilient positioning, automation and digital assurance will improve vessel reliability and operational safety. Common test protocols, representative validation facilities, reusable safety cases and integrated safety-validation approaches will support more predictable approval of battery, sustainable alternative fuels, autonomous and software-defined systems. Improved detection, suppression, ventilation, emergency decision support and continuous assurance will contribute to reducing the likelihood and severity of incidents and to accelerating safe market uptake. Robotics and AI-enabled tools will reduce exposure to hazardous tasks and shift employment towards higher-skilled roles in systems integration, software, automation, alternative energy and lifecycle services. These impacts extend across the wider waterborne industrial value chain, including shared civil and naval industrial capabilities where relevant.

6.5. INNOVATION AND EUROPEAN LEADERSHIP

Closer links between research, industrial demonstration, certification and deployment will shorten time to market and improve SME participation. Shared validation capability, reusable certification evidence and advanced digital engineering will improve the transfer of successful R&I results into industrial deployment. European leadership in international standards and certification will strengthen export opportunities and support global uptake of European waterborne technologies. Leadership in waterborne system integration, Digital Authority, digital engineering, lifecycle continuity and safety validation will further strengthen Europe's position as a supplier of integrated waterborne technology solutions and complex first-of-a-kind vessel programmes.

6.6. CONTRIBUTION TO THE WATERBORNE ROADMAP PORTFOLIO

This Roadmap provides the industrial foundation for the wider Waterborne portfolio by delivering the shipbuilding, equipment, software, materials, production, integration, validation and certification capabilities required across all waterborne segments. It enables the industrialization, deployment, retrofit, lifecycle support and scaling of the technologies and systems addressed in the other Waterborne roadmaps.

WATERBORNE

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