Technology Roadmap

Resilient, Competitive and Sustainable Maritime Technology Sector

Contents

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.[1] The term denotes shipyards and marine equipment companies together.[2] 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.[3] Marine 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, consulting and aftersales support.[4]

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.

Europe's maritime manufacturing base consists of some 300 shipyards and 28,000 maritime equipment manufacturers.[5] Small and medium-sized enterprises form the largest part of this base and account for the majority of component and subsystem supply.[6] 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.

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, offshore installation vessels, inland waterway retrofits 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.[7] Preserving a critical mass of commercial shipbuilding sustains naval shipbuilding, given the strong dual-use interlinkages and cross-fertilisation between them.[8] Ship repair, maintenance, conversion, retrofitting and recycling capabilities are critical for advancing the safety, decarbonisation and circularity of waterborne transport.[9]

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[1] 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.
[2] 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.
[3] BALance Technology Consulting, *European Shipbuilding Supply Chain Statistics: A Report for SEA Europe* (Bremen: BALance Technology Consulting, June 2025), 8.
[4] OECD, *Analysis of the Marine Equipment Industry*, C/WP6(2022)15/FINAL, 8, box 3.1.
[5] European Commission, *EU Industrial Maritime Strategy*, COM(2026) 111 final, 2n7.
[6] Waterborne Technology Platform, *Waterborne Technology Leadership: Towards a Competitive, Resilient and Sustainable Waterborne Sector* (Brussels: Waterborne TP, January 2026), 5.
[7] European Commission, *EU Industrial Maritime Strategy*, COM(2026) 111 final, 2.
[8] Ibid.
[9] Ibid.

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.[10] German analysis quantifies the effect: one job in the shipbuilding industry generates a total of ten jobs across the associated value chains.[11]

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,[12] and approximately 70% to 80% of the final output value of ship production is generated through the upstream supply chain.[13] European companies supply almost half of the world's maritime equipment and have played a leading role in designing and developing most of the global fleet's power systems.[14] **The shipyard is therefore an assembler and integrator that assumes responsibility for systems it does not manufacture.**

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.[15] 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.[16] Coordination capability is the binding constraint on yard throughput.

Outsourcing has deepened and value added has thinned. Purchasing values now account for between 65% and 90% of total production values across European yards.[17] In EU-27 shipbuilding, value added represents 26.24% of production value, with non-marine equipment purchases accounting for a further 25.00%.[18] 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.[19] 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.[20]

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. 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.[21] Ship

[10] Ibid.
[11] OECD, *Analysis of the Marine Equipment Industry*, C/WP6(2022)15/FINAL, 3.
[12] Ibid., 4.
[13] Ibid., 5.
[14] Waterborne Technology Platform, *Waterborne Technology Leadership*, 5.
[15] OECD, *Analysis of the Marine Equipment Industry*, C/WP6(2022)15/FINAL, 5.
[16] Ibid., 21.
[17] BALance Technology Consulting, *European Shipbuilding Supply Chain Statistics*, 13.
[18] Ibid., 21, fig. 15.
[19] Ibid., 12.
[20] Ibid.
[21] European Commission, *EU Industrial Maritime Strategy*, COM(2026) 111 final, 3n12.

recycling is the terminal segment of the same value chain, with over 16,000 ships projected to be recycled globally over the next decade.[22]

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.[23]

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*.

Europe is the world's largest supplier of marine equipment, including services, ahead of Korea, China and Japan.[24] In marine diesel engines, the largest trade segment in marine 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.[25] **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.[26] 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.[27]

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.[28] European industry has lost ground to China in strategic segments including ferries and offshore wind installation vessels, while leadership in underwater vessels and in maritime and port equipment is increasingly challenged.[29] Europe's global market share in large ferries above 5,000 GT fell to around 15% in 2020–2024,

[22] Ibid., 6.
[23] BALance Technology Consulting, *European Shipbuilding Supply Chain Statistics*, 18.
[24] OECD, *Analysis of the Marine Equipment Industry*, C/WP6(2022)15/FINAL, 3.
[25] Ibid., 10.
[26] European Commission, *EU Industrial Maritime Strategy*, COM(2026) 111 final, 2–3.
[27] Ibid., 3.
[28] Ibid.
[29] Ibid.

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.[30]

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.[31] **The competitive gap is priced and funded.** Asian competitors offer prices 30% to 40% below those of European shipyards.[32] South Korea has announced a record investment of USD 1.8 billion to strengthen its leadership in next-generation shipbuilding.[33] 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.[34]

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.[35] 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.[36] European industry has set the ambition of building 10,000 sustainable and digitalised vessels in Europe by 2035.[37]

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.[38] 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.[39] 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.[40] 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.[41]

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.[42] This is the condition for making maritime manufacturing in Europe more resilient and

[30] Ibid., 3n11.
[31] BALance Technology Consulting, *European Shipbuilding Supply Chain Statistics*, 10.
[32] Waterborne Technology Platform, *Waterborne Technology Leadership*, 7.
[33] Ibid.
[34] Ibid.
[35] European Commission, *EU Industrial Maritime Strategy*, COM(2026) 111 final, 3n12.
[36] Ibid.
[37] 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.
[38] OECD, *Analysis of the Marine Equipment Industry*, C/WP6(2022)15/FINAL, 23.
[39] Ibid.
[40] Waterborne Technology Platform, *Waterborne Technology Leadership*, 6.
[41] Ibid.
[42] European Commission, *EU Industrial Maritime Strategy*, COM(2026) 111 final, 4.

cost-efficient, mitigating labour shortages, enhancing productivity and expanding the operational capacity of industrial facilities.[43]

2. Drivers and Constraints

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.[44] 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.[45] 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.[46] 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.[47] 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. Port readiness therefore 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.[48] 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.

[43] Ibid.
[44] Ibid., 2.
[45] Ibid., 4.
[46] Ibid., 5.
[47] 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.
[48] 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.[49] FuelEU 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.[50] The Alternative Fuels Infrastructure Regulation sets the corresponding shore-side electricity and refuelling requirements.[51] 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.[52] Implementing Regulation (EU) 2018/608 lays down technical criteria for electronic tags for marine equipment, providing a traceability instrument against counterfeiting.[53] 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.[54] 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 question before it is an environmental one.
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.[55] 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.

Table 2: Policy and regulatory instruments shaping the maritime technology sector

Sources: as footnoted in the right-hand column.

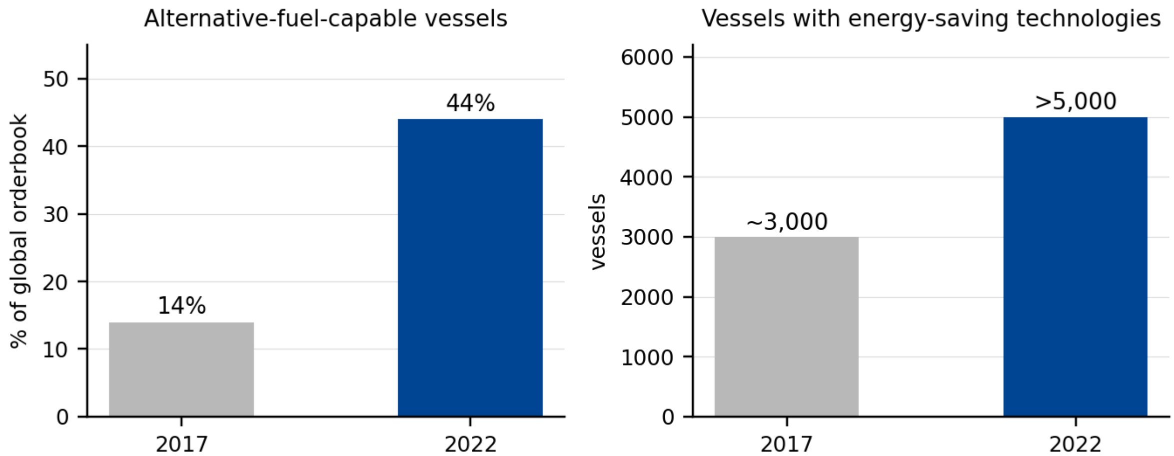
[49] Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system, OJ L 130, 16.5.2023, 134–202, art. 3ga.
[50] 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.
[51] 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.
[52] 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.
[53] 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.
[54] European Commission, *EU Industrial Maritime Strategy*, COM(2026) 111 final, 6.
[55] OECD, *Analysis of the Marine Equipment Industry*, C/WP6(2022)15/FINAL, 22.

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.[56] Battery propulsion and battery–diesel combinations have been taken up in smaller and coastal vessels, notably ferries, tugs and offshore units.[57] 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.[58] 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 2. 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 Clarksons 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.[59] 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.[60] The leading applicants over 2011–2020 are shipbuilding groups located in Japan, Korea and China, alongside German industrial firms.[61] 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.

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[56] Ibid., 23.
[57] Ibid.
[58] Ibid.
[59] Ibid., 24.
[60] Ibid., 30.
[61] Ibid., 31, table 12.

2.3 Constraints

Table 3. Structural constraints on the European maritime technology sector

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.[62] 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.[63] 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 opacity.	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 marine equipment industry to be identified in official statistics.[64] 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.[65] Multi-tier dependency cannot be governed while it cannot be measured. Statistical invisibility is therefore itself a policy constraint.
Certification 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.
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.[66] 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.[67] In exhaust gas cleaning systems, at least 50% of turnover is reported as counterfeited. Counterfeit equipment transfers safety risk

[62] Waterborne Technology Platform, *Waterborne Technology Leadership*, 7.
[63] BALance Technology Consulting, *European Shipbuilding Supply Chain Statistics*, 21, fig. 15; 12; 13.
[64] OECD, *Analysis of the Marine Equipment Industry*, C/WP6(2022)15/FINAL, 5 and 7.
[65] Ibid., 21.
[66] Ibid., 41.
[67] Ibid., 42.

Constraint	Evidence and implication
	to the vessel and reputational risk to the original manufacturer, since incidents may be attributed to the equipment maker.[68]
Digital maturity gap.	Most digital technologies applied in the maritime sector are assessed at low maturity for both the design and the construction of products.[69] 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.
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.[70] 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%.[71] 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.

Sources: as footnoted in the right-hand column.

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, ammonia and fuel-cell systems, whose deployment depends on safety-system maturity, 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.[72]

Industrial capability is unevenly distributed across the same value chain. European yards retain world leadership in complex, high added-value vessels[73] and European suppliers hold roughly half the world equipment market,[74] yet digital

[68] Ibid., 41.
[69] Ibid., 25.
[70] European Commission, *EU Industrial Maritime Strategy*, COM(2026) 111 final, 21–22.
[71] BALance Technology Consulting, *European Shipbuilding Supply Chain Statistics*, 12 and 10.
[72] OECD, *Analysis of the Marine Equipment Industry*, C/WP6(2022)15/FINAL, 23 and 25.
[73] Waterborne Technology Platform, *Strategic Research Agenda for the European Waterborne Sector*, consolidated version 5.0 (Brussels: Waterborne TP, June 2025), 9.
[74] Waterborne Technology Platform, *Waterborne Technology Leadership*, 5.

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 opacity, 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.[75] Chapter 4 disaggregates each domain into technology tracks, operational objectives, dated capability statements, required enablers and research gaps. The domains are stated here at the level of the industrial capability they deliver; they are not restated as pathway content.

Table 4. The seven capability domains

Capability domain	Industrial capability delivered
Propulsion and integrated 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.[76]
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.[77] Production costs must fall and productivity rise by 30% against current levels by 2040.[78] 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.[79] 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.[80] 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.[81] Vessels operate as software-defined platforms with secure update, cryptographic verification and rollback capability. Operational and lifecycle data remain accessible within

[75] Ibid., 15–16.
[76] Ibid., 15.
[77] Ibid.
[78] Waterborne Technology Platform, *Strategic Research Agenda*, v5.0, 9.
[79] Waterborne Technology Platform, *Waterborne Technology Leadership*, 16.
[80] Waterborne Technology Platform, *Strategic Research Agenda*, v5.0, 9.
[81] Waterborne Technology Platform, *Waterborne Technology Leadership*, 16.

Capability domain	Industrial capability delivered
	European industrial ecosystems. Systems remain operational under degraded conditions, including navigation-signal disruption, cyber incidents and communication loss.
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. [82] 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.[83] 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. [84] 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. [85] 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. [86] 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. [87] Coordinated European engagement in international standards bodies is a sector-level priority.

Source: Derived from Waterborne TP, Waterborne Technology Leadership, 15–16, and SRA v5.0, 8–9. Disaggregated in Chapter 4.

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 is adopted at early scale, and the first modular construction lines operate across leading European yards. [88] 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. Energy-efficiency and emission-abatement technologies are deployed across the existing fleet, and battery-electric propulsion is mainstream on short, predictable, high-cycle routes. 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.

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[82] Ibid.
[83] Waterborne Technology Platform, *Strategic Research Agenda*, v5.0, 8.
[84] Waterborne Technology Platform, *Waterborne Technology Leadership*, 16.
[85] Waterborne Technology Platform, *Strategic Research Agenda*, v5.0, 9.
[86] Waterborne Technology Platform, *Waterborne Technology Leadership*, 16.
[87] Ibid., 15.
[88] Ibid., 17.

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 maritime 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.[89] 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.

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 and offshore technologies.[90] 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. 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.

The export unit at 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 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

[89] Ibid.
[90] Ibid.

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.[91]

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 5. 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. Technological Pathways

The transition toward climate-neutral maritime systems is also a transition toward 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 maritime regions of 2050 will be those capable of integrating vessels, ports, energy systems, digital infrastructure and industrial ecosystems into a coherent maritime 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.

[91] Ibid.

This roadmap defines the R&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 seven pathways below correspond directly to the R&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 climate-neutral 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. 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 maritime energy architectures.

For shipbuilders operating across diverse vessel portfolios — spanning ferries, tugs, workboats, offshore support, naval platforms and beyond — the imperative 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. 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.

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 and methanol propulsion

Ammonia and methanol 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 alternative fuels and onboard emissions monitoring.

Wind-assisted propulsion and energy-saving technologies

Wind-assisted propulsion reduces total energy demand and improves 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.

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.

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 engines widely deployed in retrofit and newbuilds; hydrogen fuel cells in pilot and early commercial applications
- Wind-assisted propulsion 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

- Climate-neutral fleet across all vessel categories; 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

Strategic conclusion

The future of maritime 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 R&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.

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.

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 maritime 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.

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 maritime 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.

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 in welding, cutting, assembly and material handling at pilot scale
- First AI-enabled engineering environments operational for design, planning and quality assurance

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

4.2.5 Key research gaps

- Robotics for high-variability ship assembly, outfitting and interior installations
- 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

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 maritime 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 maritime 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 marine 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 alternative-fuel environments
- Simulation-based certification methodologies accepted by classification societies
- Lifecycle optimisation tools integrating structural health, maintenance and residual value data

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 toward 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 maritime systems

Digital sovereignty is a core determinant of maritime competitiveness, resilience and operational independence. A common European maritime 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.

Maritime operating systems, middleware and orchestration layers become strategic control points. Europe should develop a shared maritime 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, maritime 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. 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 maritime systems, ensuring full interoperability; protection of data and intellectual assets; cyber-resilient operations; integration across maritime ecosystems;

independent European maritime software capability; lifecycle data retained within European industrial ecosystems; and resilient maritime 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
- Maritime data governance frameworks established; pilot maritime digital infrastructure operational
- Cybersecurity certification frameworks for maritime 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 maritime digital infrastructure operational across major maritime ecosystems
- Fully operational European maritime software stack — OT, IT and connectivity — reducing dependency on non-European platform providers
- Advanced cybersecurity systems, alternative PNT 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 maritime ecosystem

- Fully integrated digital maritime 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 maritime operating ecosystem exported globally and adopted as industry standard

4.4.6 Key research gaps

- Maritime software architecture: common operating systems, middleware and API standards
- European maritime digital infrastructure, distributed maritime 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 maritime systems
- AI-based optimisation across vessel systems integrated with lifecycle and fleet management platforms

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 R&I investment must ensure that the platforms, standards and governance frameworks underpinning maritime digital systems remain under European industrial and regulatory control.

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 maritime systems that combine AI, advanced sensing and human expertise into continuously improving operational ecosystems.

4.5.1 Operational modes and autonomy development

Autonomy is a strategic capability enabling resilient maritime 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 maritime 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.

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 maritime 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 maritime operations combining vessels, remote operation infrastructure and lifecycle support
- European autonomy and cognitive maritime technology exported globally
- Cognitive and autonomous systems fully integrated into maritime 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

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 maritime 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, 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 maritime systems. Training must include digital engineering and production, human–machine interaction, XR/VR, cybersecurity, data governance, alternative fuels and AI-enabled systems. 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 maritime 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 maritime companies
- AI-enabled engineering and decision-support standard across the maritime technology sector
- European maritime competence ecosystems exported globally through training partnerships and workforce development programmes

4.6.5 Key research gaps

- Human–machine interaction for complex maritime 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

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 maritime 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. 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.

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, 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 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

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
- 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 maritime regulation

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

4.7.6 Key research gaps

- Certification of new propulsion systems: 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 maritime systems

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.

This roadmap reflects the R&I priorities of Waterborne TP Section 3.1 (Resilient, Competitive and Sustainable Maritime Technology Sector). It is grounded in the strategic ambitions shared across the European maritime technology sector: platform-based production, fuel-agile zero-emission systems, AI-enabled engineering, digitalisation and data sovereignty, lifecycle services, circularity, resilient supply chains and dual-use industrial capability.

5. Key enablers and deployment

The pathways in Chapter 4 build on a strong European base: leadership in complex vessel construction and marine equipment, mature battery-electric and hybrid solutions in selected segments, growing uptake of 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.

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; 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. 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 alternative fuels, autonomous systems, advanced materials and digital technologies. 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 maritime 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 maritime data models, software standards and secure edge and cloud infrastructure are required to support interoperability and lifecycle digital threads. 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. 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, 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. 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. 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 and fleet renewal programmes can create lead markets for ferries, workboats, research vessels and other strategically relevant vessel types. 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.

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.

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.

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

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.

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.

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. Stronger European control over critical technologies, software, data, supply chains, repair, retrofit and recycling capacity will reinforce strategic autonomy and resilience.

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.

6.4 Safety, digitalization and workforce impacts

Cyber-secure software architectures, resilient positioning, automation and digital assurance will improve vessel reliability and operational safety. 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.

6.5 Innovation and European leadership

Closer links between research, industrial demonstration, certification and deployment will shorten time to market and improve SME participation. European leadership in international standards and certification will strengthen export opportunities and support global uptake of European maritime technologies.

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 and certification capabilities required for cruise, ferries, inland waterways, oceangoing and short sea shipping, offshore operations, ports and the Blue Economy.