Technology Roadmap

Competitive, resilient and sustainable inland waterway transport (IWT)

Contents

1. Description of the Sector

The EU Inland Waterway Transport (IWT) sector extends from the Atlantic Ocean to the Baltic Sea, the Black Sea and the Mediterranean. The European inland waterway network spans 25 Member States, 13 of which have about **41,000 kilometers** of inland waterways. The Rhine–Danube and North Sea–Rhine–Mediterranean corridors, as part of the TEN-T corridors, connect major industrial regions and logistics hubs across Europe[1]. Every year, IWT carries around **150 billion tonne-kilometres of cargo, with approximately 15,000 cargo vessels** in operation, alongside around **3,000 day-trip passenger vessels and about 430 river cruise vessels**.[2]

IWT is characterized by diverse operating conditions and market segments. The Rhine, the Danube, connected canal systems, **regional waterways and urban passenger networks differ in terms of vessel types, route length, cargo flows, waterway dimensions, bridge clearance, lock infrastructure and water-level variability.** The sector also includes a heterogeneous and ageing fleet, long asset lifetimes, a high share of Small and Medium-sized Enterprises (SMEs) and owner-operators, and strong dependence on corridor, port and fairway conditions.

These characteristics are considered in the technology roadmap, indicating that future solutions must be scalable and interoperable across the European network, while remaining flexible enough to reflect corridor-specific conditions, vessel size, propulsion needs, local energy availability and the need to coordinate vessel technologies with port, fairway, energy, and digital infrastructure.

1.1. Structure of the Fleet

The total EU Inland Waterway fleet accounts for 13,392 vessels. Vessel types differ according to the goods transported and the region of operation. In 2024, the Rhine fleet accounted for **9,160 vessels**[3] of which **6,381 were dry cargo** and **1,453 were liquid cargo vessels.** Of the **6,381 dry cargo vessels**, **3,228** operated in the Netherlands, **1,374 in Germany, 879 in France** and **873 in Belgium**. Their **loading capacity** is reported at approximately **10,000 million tonnes** in cumulative terms[4]. **The majority of liquid cargo vessels** in the Rhine countries also operate mainly in the **Netherlands, with 715 vessels**, followed by Germany with 448 and Belgium with 143, while the rest operate in France, Switzerland and Luxembourg. Their loading capacity tends to increase over the last 20 years, reaching 3.7 million tonnes in 2024.[5]

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[1] European Commission. "Rhine–Danube Corridor." *Trans-European Transport Network (TEN-T)*. Accessed March 16, 2026. https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t/rhine-danube-corridor_en see also: European Commission. "North Sea–Rhine–Mediterranean Corridor." *Trans-European Transport Network (TEN-T)*. Accessed March 16, 2026. https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t/north-sea-rhine-mediterranean-corridor_en.

[2] European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Sustainable and Smart Mobility Strategy – Putting European Transport on Track for the Future*, COM(2021) 324 final (Brussels: European Commission, 2020), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0324.

[3] Central Commission for the Navigation of the Rhine and European Commission, Market Observation for Inland Navigation in Europe: Annual Report 2025, CCNR_annual_report_EN_2025_WEB.pdf*, p. 110-113*

[4] Ibid,

[5] Ibid,

The **Danube fleet**, including Germany's vessels, **accounted for 3,324 ships of which 2,523 were dry cargo vessels and 120 were liquid cargo vessels**. The Romanian cargo fleet is the largest in the Danube area with a share of 44% of all dry cargo vessels. According to the Statistical Yearbook of the Danube Commission, the fleet operating along the Danube includes several categories of vessels such as motorized cargo vessels, tugboats, pushers and tug-pushers. The available data indicates that the Danube fleet comprises at least **515 motorized dry cargo vessels and 48 motorized liquid cargo vessels**, alongside **118 tugboats, 681 tug-pushers and 389 pushers**. These figures though represent minimum estimates due to incomplete reporting from several Member States of the Danube Commission. This structure highlights the operational importance of **push-tow navigation systems**, which allow barges to be transported in convoys along long river corridors and remain a defining feature of Danube inland navigation logistics.[6]

	Dry cargo vessels	Liquid cargo vessels	Push and tug boats	
RHINE FLEET	6,381	1,453	1,326	9,160
DANUBE FLEET	2,523	120	681	3,324
OTHER COUNTRIES *	786	0 #	277	1,063
	9,595	1,543	2,254	13,392 **

Table 1: Number of Inland Vessels per Macro-Region and Vessel type in Europe[7]

For river cruises, capacity and economic activity have increased steadily since 2004. In 2025, the **Rhine Basin** accounted for **more than 250 vessels** and, when the other regions of operation are included, **the total number of river cruise vessels reached slightly more than 400**.

[6] Danube Commission, *Statistical Yearbook of the Danube Commission 2022* (Budapest: Danube Commission, 2025), 19, https://www.danubecommission.org/uploads/doc/2025/Stat_2022/en_stat_2022.pdf.
[7] Ibid, 28

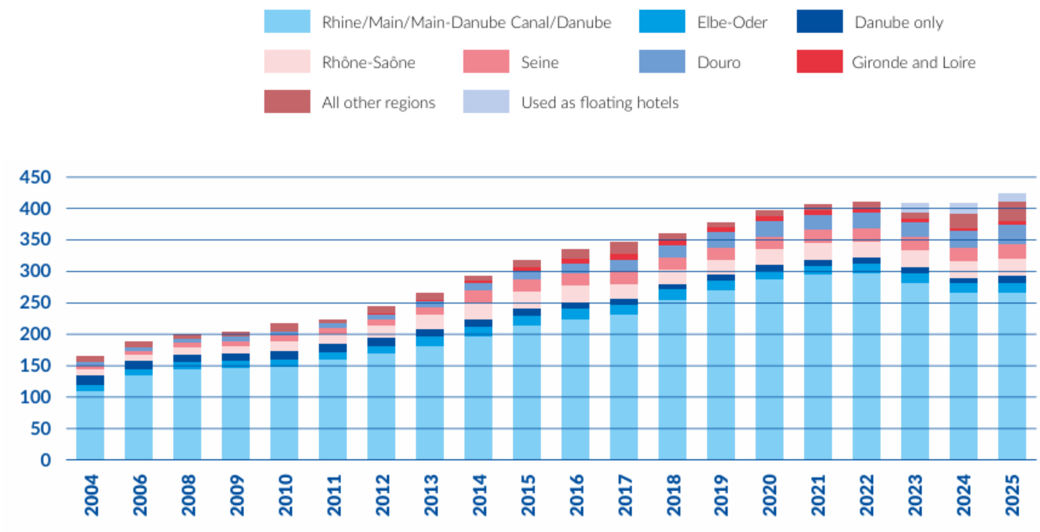

Table 2: Number of River Cruise Vessels in EU by Region of Operations (2004-2025)[8]

The estimated number of new built dry cargo vessels for the Rhine basin in 2024 was 13, compared with an average of 32 vessels per year in previous years.[9] New tanker vessels entering the market by country of registration reached a peak of 58 in 2021. In 2024**, 38 new vessels were built**, most of them registered under the Dutch flag.

The European inland waterway transport fleet is characterized by a structurally ageing asset base, which fundamentally shapes its operational profile and transition capacity. A significant share of vessels currently in service will remain active well into the coming decades, as full fleet renewal is neither economically nor practically feasible by 2050[10]. This results in a heterogeneous fleet composed of vessels of varying age, size, and technological capability. **Structural trends further indicate a gradual decline in smaller and older vessels, particularly small cargo units and push boats, while larger vessels are expected to increase in number due to efficiency gains and economies of scale**[11]. Consequently, the sector is marked by a dual dynamic of persistence and gradual transformation, where legacy vessels continue to dominate while incremental modernization occurs unevenly across segments.[12]

In terms of energy use, **the sector remains overwhelmingly dependent on fossil diesel, with nearly the entire fleet relying on conventional fuels for propulsion**.[13] This reflects both the long lifespan of vessels and the historical absence of viable large-scale alternatives. **Emerging fuel pathways illustrate a transition that is gradual and multi-layered.** On the one hand, drop-in fuels such as hydrotreated vegetable oil (HVO) and FAME 100 (destined for bigger vessels) offer an immediate compatibility with existing engines and infrastructure, allowing for short-term emissions reductions up 90% without major technical adaptation.[14] On the other hand, alternative energy carriers including

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[8] Ibid, 133
[9] Ibid, 117
[10] Inland Waterway Transport and Ports Sector, *Statement on the Sustainable Transport Investment Plan,*(April 2025), 5.
[11] Ibid, 4. Additionally, it has been seen by the sector that banks are not willing to finance small vessels, henceforth the transition to larger vessels.
[12] Ibid, 5.
[13] Ibid, 3.
[14] Ibid, 1.

hydrogen, battery-electric systems, and methanol require substantial modifications to vessels and supporting infrastructure and are associated with significantly higher costs compared to conventional fuels. As a result, the sector's fuel landscape is best understood as transitional and diversified, with multiple technologies coexisting as the fleet gradually adapts to new regulatory, economic, and technological conditions.[15]

The sector is also characterized by a diverse structure of companies and employment across freight and passenger activities. In 2023, **5,462 inland waterway freight transport companies** were active in Europe (EU-27 plus Bosnia-Herzegovina, Serbia and Switzerland), of which **4,725** were in Rhine countries. **The Netherlands alone account for 3,203 companies. This is translated in a big number of micro companies (1 vessel per company), often chartered by companies of a bigger size**. By contrast, the Danube region hosts a relatively small number of **261 firms**. However, these firms accounted for around 21% of EU inland waterway freight transport performance, reflecting the generally larger size of companies in the region, many of which originate from former state-owned enterprises. [16]

Private employment in IWT freight transport reached **22,844 persons in 2022**, with **81% employed in Rhine countries, 13% in Danube countries and 6% elsewhere**, while the overall number of employees declined slightly by **6% between 2010 and 2022**. In passenger transport, **4,659 companies were active in 2023**, with **42% located in Rhine countries and 13% in Danube countries**, while southern European countries accounted for **29%** and Scandinavian countries **10%** of companies; total employment in passenger transport reached **23,945 persons**, with Germany, Italy and Switzerland accounting for around **61% of all employees** in the sector[17]

Building on these structural characteristics**, automation constitutes a key driver of transformation in inland waterway transport**. The establishment of a common framework for levels of automation by the Central Commission for the Navigation of the Rhine (CCNR) provided a shared basis for assessing human–machine interaction in navigation. Automation develops along a continuum, from decision-support functions to fully autonomous operations, and remains conditioned by sector-specific constraints, including confined waterways, lock infrastructure, and manoeuvrability requirements. While offering efficiency gains and reducing crew workload, automation also raises challenges related to safety, liability, and skills adaptation. This implies the need for parallel adjustments in regulatory frameworks, operational standards, and workforce capabilities.[18]

Inland ports constitute a core component of the European inland waterway transport system, forming a continuous network that links major river basins such as the Rhine and the Danube with maritime gateways and inland industrial regions. This network connects key nodes including Rotterdam, Antwerp, Vienna, Budapest and Constanţa, reflecting the role of inland waterways as an integrated transport corridor across Europe.[19] Inland ports operate as multimodal interfaces between maritime transport and hinterland and continental distribution, supporting the movement of bulk cargo,

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[15] Ibid, 4.
[16] CCNR, *Market Observation: Inland Navigation in Europe – Annual Report 2025*, 144–146.
[17] Ibid, 143-148
[18] Central Commission for the Navigation of the Rhine (CCNR), *First International Definition of Levels of Automation in Inland Navigation*, CC/CP (18)20 (Strasbourg: CCNR, December 18, 2018), https://www.ccr-zkr.org/files/documents/AutomatisationNav/NoteAutomatisation_en.pdf.
[19] Ibid, 31-32

containers and industrial goods across regions. Transport activity is particularly concentrated in areas where port infrastructure, industrial production and logistics networks coincide, notably in delta regions and along major corridors. In these areas, dense port systems and inter-port connections facilitate the circulation of goods between seaports and inland destinations, with the Lower Rhine identified as a key example due to its "dense delta network" and strong inter-port traffic between Rotterdam, Antwerp and Amsterdam. [20]

1.2. Market Performance, Modal Share and Economic Trends in IWT

IWT represents a limited share of total EU freight volumes, but it plays a specific role in corridors with waterway capacity, industrial activity and port-hinterland flows. **It is particularly relevant for bulk commodities, construction materials, chemicals, agricultural products, containers on selected corridors and, increasingly, renewable energy carriers and circular-economy flows.** Its market performance is therefore closely linked to industrial production, seaborne trade, energy markets, hydrological conditions and the quality of multimodal connections.

At EU-27 level, **inland waterways accounted for 4.8% of the modal split of freight transport on land in 2023**. The share differs substantially across Member States: the Netherlands, Romania, Bulgaria and Belgium have significantly higher IWT shares because of favourable waterway geography, port systems and industrial-logistics structures. These differences indicate that IWT potential is corridor-specific rather than uniform across Europe[21].

The sector's economic performance has fluctuated in recent years**. Turnover in IWT freight transport in the EU-27 plus Switzerland and Serbia was approximately EUR 7.5 billion in 2023, compared with EUR 7.8 billion in 2022 and EUR 6.1 billion in 2021**. Rhine countries account for the largest share of turnover, with the Netherlands and Germany representing the main markets[22]. In the Danube region, Romania, Hungary and Serbia contribute important activity, although the company structure and fleet profile differ from the Rhine basin[23].

Recent trends underline both the opportunities and the vulnerability of the sector. Inland container transport often follows developments in seaborne trade and port activity, while bulk cargo flows are affected by the changing European energy and industrial landscape. The gradual decline of coal and shifts in traditional bulk commodities may reduce some historical cargo flows, while new flows related to renewable fuels, circular materials and industrial transformation may create new opportunities. At the same time, climate-related low-water events can constrain loading capacity and weaken service reliability. These dynamics suggest that IWT's future role will depend on the combined evolution of industrial demand, waterway reliability, fleet modernisation, digital integration and fair competition with other modes.

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[20] Ibid, 35

[21] Inland Navigation Europe (INE), *Industrial Maritime and Port Strategies: Joint Statement* (Brussels: Inland Navigation Europe, June 3, 2025), https://www.inlandnavigation.eu/wp-content/uploads/2025/06/Industrial-Maritime-and-Port-Strategies-Statement-FINAL-250603.pdf., 1-3

[22] Central Commission for the Navigation of the Rhine (CCNR) and European Commission. *Market Observation for Inland Navigation in Europe: Annual Report 2025.* Strasbourg and Brussels, 2025. https://inland-navigation-market.org/wp-content/uploads/2025/11/CCNR_annual_report_EN_2025_WEB.pdf, p.149

[23] *Ibid, 150*

1.3 Waterway Operational Challenges

Water level conditions are a central operational parameter for inland navigation. In Europe, inland waterways are classified under the CEMT system according to their capacity to accommodate vessels, with classes determined by vessel dimensions and infrastructure constraints such as locks and bridge clearance[24]. For the Rhine, low-water severity is assessed through the **Equivalent Water Level (EWL)**, while the Danube uses the **Low Navigable Water Level (LNWL)**, defined as the water level exceeded during 94% of days a year.[25]

The number of days below critical thresholds varies significantly by year and corridor. The years 2018 and 2022 stand out as particularly difficult low-water years for both Rhine and Danube navigation, whereas 2024 recorded favorable conditions at Rhine Gauge stations. These variations illustrate that IWT performance is sensitive not only to market demand but also to hydrological conditions. Climate change is expected to increase the frequency and severity of droughts and extreme events, making climate resilience a structural technology and infrastructure issue rather than a temporary operational concern.

The sector's technology transition should therefore address vessels, ports, fairways and digital systems together. Climate-neutral propulsion alone will not be sufficient if corridors cannot provide reliable navigation conditions, energy supply, digital connectivity, safety management and multimodal interfaces.

[24] United Nations Economic Commission for Europe (UNECE), *Standardization of Inland Waterways: Proposal for the Revision of the Classification Adopted by the European Conference of Ministers of Transport in 1992 (Resolution No. 30)*, ECE/TRANS/SC.3/WP.3/2022/4 (Geneva: UNECE, 2022), https://unece.org/sites/default/files/2022-02/ECE-TRANS-SC.3-WP.3-2022-04e.pdf.

[25] *Ibid., p. 71-73*

2. Drivers and Constraints

2.1. Policy and market drivers

The transformation of inland waterway transport is driven by the interaction of climate regulation, multimodal transport policy, sectoral programming, investment instruments, environmental constraints on the water cycle, defence and dual-use requirements, and industrial competitiveness policy. [1] The most important drivers are set out below.

- **EU Climate Law Regulation:** (EU) 2021/1119 sets a binding climate-neutrality objective for the Union by 2050,[26] in pursuit of the Paris Agreement long-term temperature goal.[27] It establishes a binding 2030 net domestic GHG-reduction target and the Union aim of negative emissions thereafter[28]. The December 2025 political agreement on the amendment of the Climate Law adds a 2040 headline target of a 90% net GHG reduction relative to 1990, with a contribution of up to 5% from high-quality international credits,[29] formally adopted by the Council on 5 March 2026. The amended framework provides a stable trajectory to 2050 and a predictable investment signal for fleet renewal, fuel supply and waterway infrastructure.[30]
- **Sustainable and Smart Mobility Strategy:** The Strategy operationalises the Climate Law for transport along three pillars: making all modes more sustainable, making sustainable alternatives widely available within a multimodal system, and putting the right incentives in place.[31] It targets a 25% increase in inland waterways and short sea shipping by 2030 and 50% by 2050, the market readiness of zero-emission vessels by 2030, and a multimodal TEN-T equipped for sustainable and smart transport by 2050.[32] It links these objectives to alternative-fuel supply, port electrification and the transformation of ports into zero-emission multimodal and clean-energy hubs, operationalised for inland waterways through NAIADES III.[33]

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[26] European Union, *Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 Establishing the Framework for Achieving Climate Neutrality and Amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ("European Climate Law")*, Official Journal of the European Union L 243, July 9, 2021, https://eur-lex.europa.eu/eli/reg/2021/1119/oj.

[27] "This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by: (a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change". United Nations Framework Convention on Climate Change (UNFCCC), *Paris Agreement* (2015), 3, https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf.

[28] European Union, *Regulation (EU) 2021/1119*, 1.

[29] European Commission, "EU Agrees on a 2040 Climate Target That Sets a Clear Path towards a Decarbonised and Competitive Economy," press release, https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_25_2967/IP_25_2967_EN.pdf.

[30] Council of the European Union, "2040 Climate Target: Council Gives Final Green Light," press release, March 5, 2026, https://www.consilium.europa.eu/en/press/press-releases/2026/03/05/2040-climate-target-council-gives-final-green-light/.

[31] European Commission, *Sustainable and Smart Mobility Strategy – Putting European Transport on Track for the Future*, COM(2020) 789 final (Brussels, December 9, 2020), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0789, 5.

[32] Ibid., 5–6.

[33] Ibid

- **NAIADES III Action Plan (2021–2027):** NAIADES III is the sectoral implementation layer for IWT, structured around two objectives: increasing modal share and steering the sector towards zero-emission operations.[34] It mobilises Horizon Europe, the Connecting Europe Facility and the revision of the TEN-T Regulation, advances zero-emission vessels and alternative-fuel infrastructure, and positions digitalisation as a central enabler through the revision of the River Information Services Directive and a single access point for corridor information.[35] The mid-term evaluation indicates limited modal-shift impact under baseline conditions and a stronger response only where improved fairway conditions, higher fleet utilisation and stable financial incentives, including the internalisation of CO_2 costs, are combined.[36]
- **Sustainable Transport Investment Plan:** STIIP shifts the EU policy focus from target-setting to investment mobilisation for renewable and low-carbon fuels in aviation and waterborne transport.[37] It identifies an investment need of around EUR 100 billion by 2035 and finds that existing support mechanisms have not delivered sufficient market impact, with many projects remaining at demonstration stage.[38] It promotes coordinated use of the Innovation Fund, InvestEU, EIB financing and Horizon Europe, together with market-based instruments such as double-sided auctions to provide long-term price certainty and bridge the producer–off-taker gap.[39]
- **Water Resilience Strategy:** The Strategy places the restoration of the natural water cycle at the centre of EU policy action, identifying climate change, pollution and overexploitation as structural pressures that have reduced both the quantity and the quality of water.[40] It introduces water availability and quality as structural parameters for inland navigation, since fairway depth and reliability depend on stable hydrological conditions, while droughts, over-abstraction and climate change alter water levels and operational predictability.[41] It applies the "water efficiency first" principle, strengthens monitoring of water abstraction and deploys smart water-management systems, positioning water as a limiting factor in infrastructure planning, corridor management and operational decision-making.[42] It also signals competition with water-intensive uses such as hydrogen production, energy systems and industrial processes, reinforcing trade-offs between transport, energy and industrial water demand.[43]
- **Military Mobility framework:** The proposal for a Regulation on military mobility embeds defence requirements into the design, operation and governance of the Union's transport system through

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[34] European Commission, *NAIADES III: Boosting Future-Proof European Inland Waterway Transport*, COM(2021) 324 final (Brussels, June 24, 2021), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0324, 17.
[35] Ibid, 17
[36] European Commission, Directorate-General for Mobility and Transport (DG MOVE), *EU IWT Policy beyond 2027 Workshop: Final Draft Technical Summary* (Brussels: Conference Centre Albert Borschette, January 19, 2026), organised by DG MOVE Unit D3, Inland Navigation Europe (INE) and PLATINA4Action, 3–4.
[37] European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Sustainable Transport Investment Plan*, COM(2025) 664 final (Brussels, November 5, 2025), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2025:664:FIN, 3.
[38] Ibid., 8–9
[39] Ibid., 9–12.
[40] European Commission, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Water Resilience Strategy* (Brussels, 2025), https://environment.ec.europa.eu/publications/water-resilience-strategy_en, 3.
[41] Ibid., 3.
[42] Ibid.
[43] Ibid., 4–5.

harmonised cross-border procedures and uninterrupted, secure movements.[44] It requires inland waterway transport, alongside other modes, to be adapted to dual-use functions capable of supporting both civilian logistics and military operations, with redundancy to road and rail networks and a contribution to crisis-response logistics.[45] It reinforces resilience against physical and hybrid threats and provides for coordination and pooling of transport capabilities across Member States and with NATO allies using EU-based infrastructure.[46]

- **EU Industrial Maritime Strategy:** The Strategy positions inland waterway transport within Europe's maritime industrial ecosystem, identifying IWT as an underutilised capacity constrained by ageing fleets, fragmented infrastructure and slow technological uptake.[47] It supports a follow-up to NAIADES III oriented towards port modernisation, infrastructure resilience and the deployment of zero- and low-emission vessels alongside digital and automated solutions, linked to Horizon Europe research ecosystems and the Zero Emission Waterborne Transport Partnership.[48] It signals forthcoming Land and Multimodal Transport Guidelines and revised State aid frameworks designed to support fleet renewal and address cost differentials with road transport.[49]

2.2. Constraints

Inland waterway transport contributes to European decarbonisation through modal shift and energy efficiency, but its transition is structurally constrained by cost asymmetries, fuel availability, hydrological variability, knowledge and digital gaps, and governance fragmentation.[50] The main constraints are set out below:

- **Cost gap between renewable and fossil fuels.** A persistent price differential between alternative and fossil fuels distorts market conditions and significantly increases operational expenditures for IWT operators.[51] Operators, particularly SMEs, lack the ability to pass these costs onto customers, which reinforces a first-mover disadvantage and discourages early adoption.[52] Existing policy frameworks have produced only marginal improvements in modal share, with measurable progress occurring primarily where strong financial incentives and the internalisation of CO_2 costs are combined.[53]

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[44] European Commission, *Proposal for a Regulation of the European Parliament and of the Council on Establishing a Framework of Measures to Facilitate the Transport of Military Equipment, Goods and Personnel across the Union*, COM(2025) 847 final (Brussels, 2025), https://transport.ec.europa.eu/document/download/4557a31a-0444-4489-a26f-2ef156f10d9f_en?filename=COM_2025_847.pdf.
[45] Ibid., 27.
[46] Ibid., 27.
[47] European Commission, *Communication on an EU Industrial Maritime Strategy* (Brussels: European Commission, 2024), https://transport.ec.europa.eu/document/download/2cda36ec-b5fc-4cc9-9091-a8014ba8177e_en?filename=communication_on_EU_industrial_maritime_strategy_3.pdf, 12–13.
[48] Ibid., 12–13.
[49] Ibid., 20.
[50] Inland Waterway Transport Sector, *Statement on the Sustainable Transport Investment Plan*, 1–2
[51] Ibid.
[52] European Commission, EU IWT Policy beyond 2027 Workshop: Final Draft Technical Summary (Brussels: European Commission, 2026), 22.
[53] Ibid.

- **Fuel availability and the chicken-and-egg dynamic.** Drop-in fuels such as Hydrotreated Vegetable Oil (HVO) are technically deployable across the existing fleet without engine modification.[54] Supply remains constrained, costs remain higher than fossil equivalents, and the business case for SME operators is weak.[55] Investment in zero- and low-emission vessels depends on the availability of fuel infrastructure, while infrastructure deployment requires sufficient demand, producing a structural mutual dependency that slows uptake on both sides of the market.[56]
- **Hydrological variability and climate impact.** Climate change increases the frequency of droughts, alters water quality and degrades the ecological condition of inland waterways, with direct effects on both transport performance and ecosystem services.[57] Reduced water levels limit vessel payload, increase unit costs and disrupt industrial supply chains that rely on waterborne transport, including for water supply to energy production, agriculture and industrial clusters.[58]
- **Multifunctionality of inland waterways.** Inland waterways function simultaneously as transport corridors and as ecological corridors supporting biodiversity, water regulation and nature-based solutions, which makes sustainability inherently systemic rather than sectoral.[59]This multifunctionality generates trade-offs between transport, environmental and industrial water uses that cannot be resolved through transport policy alone.
- **Knowledge and capacity gaps.** Effective planning is limited by insufficient monitoring, modelling and forecasting capacities, and by a partial understanding of the multifunctional role of inland waterways within broader environmental and economic systems.[60] These gaps weaken the evidence base for corridor-level decisions and reduce the quality of cost-benefit assessments underpinning investment.
- **Policy silos and sectoral fragmentation.** Transport, energy, agriculture and environmental objectives are pursued independently, leading to conflicting or suboptimal outcomes for inland waterway transport.[61] Policy effectiveness depends on combining measures into a coherent and integrated framework rather than on isolated interventions.[62]
- **Digital governance fragmentation.** The absence of integrated digital governance, including data-sharing protocols, interoperability standards and cybersecurity frameworks, limits the efficiency and resilience of the system.[63] This fragmentation constrains real-time corridor management and the deployment of automation, predictive maintenance and condition-based logistics.
- **Governance and administrative burden.** Governance structures combine fragmentation, inconsistent interpretation and uneven enforcement across Member States.[64] Coordination of funding and infrastructure planning across Member States remains limited.[65] Excessive administrative burden and overlapping reporting requirements divert resources from

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[54] Inland Waterway Transport Sector, Statement, 1–2.
[55] European Commission, EU IWT Policy beyond 2027 Workshop, 22.
[56] European Commission, EU IWT Policy beyond 2027 Workshop, 6–7.
[57] Inland Navigation Europe (INE), *Towards a New EU Climate Resilience Framework* (Brussels: Inland Navigation Europe, n.d.), 2.
[58] Ibid
[59] Ibid,1
[60] Ibid., 2
[61] European Commission, EU IWT Policy beyond 2027 Workshop, 6–7.
[62] Ibid.
[63] European Commission, EU IWT Policy beyond 2027 Workshop, 3–4.
[64] INE, *Climate Resilience Framework*, 4–5.
[65] INE, Climate Resilience Framework, 2.

implementation and innovation.[66] Funding structures remain insufficient for long-term planning, and effective implementation requires clearer policy direction, measurable targets and stronger coordination between the EU and national levels.

3. Target Capabilities

3.1 2035: Early deployment phase

By 2035, inland waterway transport must operate as a partially decarbonised, digitally supported and interoperable component of European logistics chains. Vessels must run on a mix of low- and zero-emission energy carriers, including drop-in fuels and hybrid propulsion, while maintaining operational reliability and cost-efficiency. The system must ensure availability of basic alternative-fuel infrastructure and onshore power supply at key nodes, enabling continuous operations. The transition relies on the deployment of sustainable alternative energy carriers and cross-sectoral integration across logistics and energy value chains.[67]

Vessels, ports and infrastructure must be digitally connected, with in-advance data exchange and early-stage automation for routing, traffic management and energy use.[68] The system must integrate into multimodal logistics chains, with synchronised operations between inland waterways, ports and hinterland transport. Retrofitting capacity must scale to enable fleet transition, and operations must demonstrate initial resilience to climate variability through adaptive vessel deployment and basic waterway management. These capabilities require coordinated deployment of innovation and system integration across stakeholders.[69]

3.2 2040: Scale-up and system integration phase

By 2040, the system must deliver fully integrated, zero-emission and digitally optimised operations across the waterborne ecosystem. Vessels must operate on zero-emission energy carriers supported by widely available and interoperable infrastructure, in line with the objective of eliminating harmful emissions.[70] Operations must rely on advanced digital systems, supporting high levels of automation, remote control and continuous system optimisation. Smart vessels, smart ports and smart administration and infrastructure must operate through real-time data exchange and advanced automation.[71]

Infrastructure must function adaptively and resiliently, with dynamic traffic management, integrated energy systems and climate-adapted design capable of handling extreme weather conditions.[72] Operational safety must reach near-zero accident levels, supported by advanced monitoring systems, predictive maintenance and cyber-secure operations.[73] The system must be capable of large-scale

[66] European Commission, EU IWT Policy beyond 2027 Workshop, 3–4.
[67] European Commission and Waterborne Technology Platform, *Strategic Research Agenda for the European Waterborne Sector* (Brussels: Waterborne Technology Platform, June 2025), 9, https://www.waterborne.eu/images/250708_Strategic_Research_Agenda_Final.pdf.
[68] Ibid., 9.
[69] Ibid., 6.
[70] Ibid., 9.
[71] Ibid., 11.
[72] Ibid., 14.
[73] Ibid., 10.

retrofitting and affordable production, ensuring rapid deployment of new technologies across the fleet.[74]

3.3 2050: Full transformation phase

By 2050, inland waterway transport must operate as a fully zero-emission, autonomous, climate-resilient and system-integrated backbone of European transport and industrial ecosystems. All harmful emissions must be eliminated, and digitalisation must fully unlock data-driven operations, enabling highly efficient, reliable and sustainable transport systems.[75]

Operations must be fully autonomous or highly automated, with vessels navigating independently or in coordination through fully digitalised infrastructure and decision-making systems.[76] Ports must function as integrated energy and logistics hubs, managing energy flows, cargo and multimodal connectivity while ensuring zero-emission operations and circular resource use.[77]

Infrastructure must be fully climate-resilient, adapting to extreme hydrological and environmental conditions while maintaining continuous operations.[78] The system must operate as a "system of systems", integrating transport, energy, environmental monitoring and blue economy activities, including offshore energy, underwater operations and logistics coordination, positioning inland waterway transport as a key enabler of the broader blue economy and European resilience.[79]

[74] Ibid., 12.
[75] Ibid., 9.
[76] Ibid., 9.
[77] Ibid., 16–17.
[78] Ibid., 14.
[79] Ibid.

4. Technology Pathways

4.1 Future propulsion and energy systems enabling a climate-neutral inland waterway transport fleet

The energy transition in the sector requires scalable, safe and efficient zero-emission propulsion technologies with an emphasis for affordable new and retrofittable solutions due to the nature of the SME dominated sector, shallow draft and moderate speeds taking into consideration the specificities of the fleets in different corridors and waterway operations.

Cost competitive propulsion and energy systems are to remain technology agnostic considering the regional value chain capabilities, including but not limited to biofuels, advanced batteries, fuel cells, hydrogen and hydrogen derivatives and hybrid architectures and renewable-assisted propulsion, mostly solar hybrid systems.

4.1.1 Operational objective(s)

Enable cost efficient, climate neutral inland navigation through propulsion and energy systems optimised for short to medium corridor operations, high and new retrofit potential and shallow draft constraints

4.1.2 Target capability 2035, 2040 and 2050

By 2035 – searching for the most cost competitive solutions

- Safe handling and operation of all of new technologies and fuels to be adopted – verified, sufficient and adequate trainings and procedures in place.
- Battery-electric vessels operating on short and medium corridors. Scalable and affordable battery-electric kits for vessels operating on urban and regional corridors and associated charging systems based on a combination of solutions tailored to real-world uses (TRL 8-9):
    - Recharging at quayside during downtime,
    - Intermediate fast recharging,
    - Sequenced charging during downtime (locks, stopovers),
    - Battery transfer or swapping (battery swapping) where appropriate
- Energy flexible upgrade concepts for using sustainable alternative fuels (regionally most attractive fuel) – the entire value chain committed in green corridor approach (TRL 6-8)
- hybrid + solar retrofit concepts validated for legacy barges (TRL 6-7)
- hydrogen fuel-cell, or other cost competitive zero emission hydrogen fuelled pilots on core TEN-T inland corridors (TRL 8-9)

By 2040 – narrowing down on the most cost competitive solutions

- Updated safe handling and operation of new technologies and fuels to be adopted
- standardized zero-emission propulsion solutions deployable across corridors TRL7-9
- corridor-based zero emission bunkering and charging infrastructure operational (regionally most attractive energy) TRL7-9
- containerised modular energy systems adaptable to barge dimensions TRL8-9
- corridor-based hydrogen (or hydrogen derivative) and charging infrastructure operational (regionally most attractive fuel) TRL7-9
- early adopters in the market (TRL 8-9).

By 2050 – operating with the most cost competitive solutions

- Updated safe handling and operation of new technologies and fuels to be adopted TRL9
- fully climate-neutral fleet and refuelling/charging infrastructure TRL9
- standardised modular propulsion architecture suitable for both retrofit and newbuild vessels TRL9
- large scale deployment of zero-emission propulsion technologies in inland waterway transport. TRL9

4.1.3 Required enablers directly linked to this pathway

- corridor-based charging and renewable energy supply
- Standardised electrical drive train for inland ships
- Standardised battery and charging systems
- EU IWT emission standards and enabling legislation/regulation to create energy price level playing field to reward low and zero emission switch
- Regulatory sandbox followed by reform of existing technical EU legislation into goal-based legislation
- harmonised inland fuel safety rules, ES-TRIN and ADN
- SME-accessible financing instruments
- port-waterway energy integration
- standardised retrofit certification, ES-TRIN
- Certified training, CESNI

4.1.4 Key research gaps (linked to achieving the objectives, building on the current state-of-play).

- Scalable and affordable zero-emission solutions
- high energy density and lightweight batteries compatible with shallow draft
- lightweight hydrogen storage – bridge clearance constraints
- fast battery swapping for corridor operations and corridor-based approach to charging infrastructure, integrated with electricity grids and operational procedures
- modular zero emission energy conversion retrofit integration
- energy-system optimisation for variable load profiles.
- Cost efficient fuel flexible energy conversion systems

4.2 Intelligent safety, security and resilience as foundational enablers

As vessels and operations become more digital and complex, safety and security will become defining features of competitiveness and resilience. Research will drive the development of predictive safety ecosystems, autonomous incident response, enhanced sensing, climate and cyber-resilient infrastructures and new methods for safe fuel handling and emergency management. These innovations will be essential for unlocking remote and automated navigation, enabling alternative fuels and protecting Europe's strategic waterborne assets.

4.2.1 Operational objective(s)

Achieving safe and resilient waterway and shipping operations during the energy transition requires regulatory frameworks that evolve alongside new energy conversion technologies. Combining digital safety and security monitoring with environmental protection and resilience ensures inland navigation meet both operational and sustainability objectives. Development of phased deployment pathways from assisted navigation and remote operations with reduced crew towards higher levels of automation, based on validated operational safety cases under harmonised European frameworks, including defined roles for shore-based operators and onboard fallback crew.

4.2.2 Target capability 2035, 2040 and 2050

By 2035

- Collision avoidance concepts utilising automatic vessel to vessel, shore to vessels and shore to shore communication for non-RIS users (e.g. boating) TRL7
- Collision avoidance deployment utilising automatic vessel to vessel/port to vessels and vessel to port communication TRL8
- Automatic safety incident communication concepts vessel to vessel/port to vessels and vessels to port TRL7
- Automatic re-routing guidance system based on risk of incident and/or occurred incidents considering current traffic and weather conditions TRL7
- Cyber security resilience of data and systems – cyber redundance concept TRL8
- Enhanced forecasting capacity to inform navigation and planning conditions (climate change and water levels) (TRL 8)
- 4-level (ship/infrastructure/information/logistics) affordable and scalable climate proof shipping concepts (TRL8)
- Augmented reality solution for navigating in harsh conditions TRL7

By 2040

- Automatic safety incident communication deployment vessel to vessel/port to vessels and vessel to port TRL8
- Automatic re-routing guidance system based on risk of incident and/or occurred incidents considering current traffic and weather conditions deployment TRL8
- Cyber redundance deployed TRL9
- Autonomous inland waterway navigation deployed in corridors TRL8

By 2050

- Autonomous inland waterways navigation (not necessarily equal to unmanned)

4.2.3 Required enablers directly linked to this pathway

- Reliable, redundant cross-border connectivity infrastructure (including latency, bandwidth and failover performance) with standardised fallback procedures in case of communication failure as a prerequisite for safe remote inland navigation
- Standard communication protocol for collision avoidance, automatic vessel to port communication. Ports and congested areas to have designated safety zones and procedures in case of emergency.
- Cross-border acceptance of remote & automated navigation concepts
- EU goal-based regulation regarding technical and manning requirements which enables smart shipping, including harmonised European rules for remote/automated vessel operations and standardised human-machine interaction frameworks between vessel and shore

4.2.4 Key research gaps (linked to achieving the objectives, building on the current state-of-play).

- Integration of assisted and automated navigation systems in remote environments
- Barriers of introducing assisted and automated operation
- Risk-based design of operations under variable connectivity conditions
- Incident response models for loss of connectivity scenarios
- Build introduction pathways for assisted and automated operation
- Validation of remote/automated operations safety, security and resilience cases under real traffic conditions
- Automation of traffic control centres for enhanced AI-driven corridor management

4.3 Fully connected, automated and data-driven inland waterborne systems

The future waterborne system will function as a continuously connected network where vessels, ports, waterways and logistics nodes share data and optimize operations in real time and in advance. Priorities include interoperable digital architectures, remote and autonomous vessel functions, advanced sensing and communication systems, and AI-driven traffic and logistics coordination. These developments will increase efficiency, lower emissions and open the door to new business models built around service provision and lifecycle optimization. Smarter operation of ships and fleets, supported by AI, can help optimize fleet operations and improve collaboration between shore and vessel. This increases efficiency and reduces emissions, while robotic operation and maintenance can be used in hazardous or uncrewed areas to improve safety and reliability.

4.3.1 Operational objective(s)

Connected shipping with constant data flows is a key enabler for vessel and fleet optimisation, safety on and along inland waterways and in mixed areas and above all autonomous and semi-autonomous navigation and operation

4.3.2 Target capability 2035, 2040 and 2050

By 2035

- Reliable and continuous high-bandwidth connectivity along inland waterways, including cross-border corridors
- Redundant communication architectures (e.g. 4G/5G/satellite hybrid solutions) to ensure safe remote/automated operations
- Develop and disseminate data standards to facilitate interoperability of software solutions and data transfers

- Deployment of Corridor Management Services and Remote Operations Centres (ROC) supervising multiple vessels under defined safety and security frameworks (TRL7-8)
- Emission data and reporting available for customer according to ISO14083

4.3.3 Required enablers directly linked to this pathway

- EU goal-based regulation which allows & enables smart shipping covering harmonised European regulatory frameworks for remote operations, including ROC recognition, defined human roles, fallback procedures, certification pathways and cross-border operational acceptance. Harmonised cross-border telecom infrastructure and roaming performance standards
- Minimum bandwidth and latency requirements for safe remote and assisted navigation
- Standardised shore-to-ship communication protocols
- Interoperability between RIS, vessel systems and shore-based control systems
- Recognition of Remote Operations Centres as formal operational entities (similar to VTS/ATC)

4.3.4 Key research gaps (linked to achieving the objectives, building on the current state-of-play).

- Multi-vessel supervision models (one operator supervising multiple vessels)
- Data latency and reliability requirements for remote navigation
- Cybersecurity frameworks for remote vessel, shore and remote control centre operations
- Performance of communication networks in critical areas (e.g. locks, bridges, border regions)
- Fail-safe operational concepts under degraded connectivity conditions
- Integration of multi-channel communication (cellular, satellite, radio)

4.4 Human-centred design and a future-ready inland workforce

The sector's future success depends on people as much as on technology. In the IWT and Ports sector, people are at the centre, without neglecting the impact of digital transformation on the individual. Digitalisation leads to a mixed environment where people interact intensively with rapidly changing technology. Digitalisation contributes to solve current and future labour shortages by digitally upskilling the workforce and creating attractive jobs for young and old in research and operations. R&I will advance human-machine teaming, intuitive decision-support systems, ergonomic design and workload optimization. Next-generation training ecosystems, including XR and digital simulation, will prepare the workforce to operate increasingly automated, data-rich and alternative fuel-based systems. Social sustainability and safe working conditions will remain essential pillars. AI and human–machine interaction: clear rules are needed for ethical use, transparency, liability, and responsible monitoring of crew workload and performance using AI and XR.

4.4.1 Operational objective(s)

Development of adaptive, real-time decision support systems tailored to human operators onboard and onshore. Investigation of real-time simulation and optimization methods that enhance voyage planning and execution through human-centred, data-driven operational models.

To prepare the workforce for the green and digital transformation, updating legislation, supporting lateral entry into the profession and providing targeted funding for training are essential steps.

4.4.2 Target capability 2035, 2040 and 2050

By 2035

- AR/VR assisted navigation concepts demoed, mixed area, congested areas, narrow straight, shallow waters, arrival/departure
- AR/VR assisted concepts demoed for decision making support in harsh conditions, incidents

By 2040

- Remote and autonomous navigation and operation demonstrated in corridors (not equivalent to unmanned)

4.4.3 Required enablers directly linked to this pathway

- AR/VR capability and usability on real life situations, share of VR/AR may depend on route, segment, region etc.
- Harmonised definitions of onboard fallback roles and defined fallback procedures and minimum competency requirements for onboard crew
- European training and certification standards for remote operators (ROC operators)
- Standardised approach for reduced crew concepts

4.4.4 Key research gaps (linked to achieving the objectives, building on the current state-of-play).

- Human factors in more technology centred, remote/automated navigation, shore and control centres (fatigue, situational awareness, workload)

4.5 Forward looking regulation, standardization and system-level corridor integration

Regulation will shape markets and determine the global relevance of European innovation. RD&I will support the development of standards, certification schemes and regulatory sandboxes for new fuels, autonomy, data governance and cyber resilience. System-level planning tools will guide investments in ports, waterways, energy networks and logistics hubs to ensure that physical and digital infrastructures evolve in parallel with technological advances. This integrated approach is essential for deployment at scale. Standardizing user interfaces can improve safety and make systems easier to use and integrate

4.5.1 Operational objective(s)

Forward looking regulation is key. Staying the course is more important than have ideological shifts every 4-5 years. An uncertain environment will in general decrease the willingness to invest. European standards on calculation emission footprints of goods shipped and persons travelled needs to be established in order to have an open and transparent way of stating comparable environmental consequences of each voyage.

Common standards are also needed for system level integration, various systems and module “speak the same language”.

4.5.2 Target capability 2035, 2040 and 2050

By 2035

- EU goal-based regulation which allows & enables smart shipping covering hharmonized European regulatory frameworks for remote operations, including ROC recognition, defined human roles, fallback procedures, certification pathways and cross-border operational acceptance. Harmonised cross-border telecom infrastructure and roaming performance standards
- Minimum bandwidth and latency requirements for safe remote and assisted navigation
- EU regulatory framework with binding targets and mechanism to drive and support the transition of IWT towards zero-emission performance
- European standards of how calculation emission footprints of goods shipped and persons travelled, based on example ISO 14083. Even if there is a standard, the interpretation of the standard is not black or white. Common practices for the interpretation to enable fair comparison about the cumulative emission/ton/nm (SI would be kg/kg/m)

By 2040

- Standard communication interfaces on all equipment

4.5.3 Required enablers directly linked to this pathway

- Common best practice interpretation of standards, ex ISO 14083
- Standard communication ID for all equipment onboard

4.5.4 Key research gaps (linked to achieving the objectives, building on the current state-of-play).

- Interpretation of standards making the comparison between vessel types, technology used fair and harmonised.

5. Enablers and Deployment

The pathway-specific enabling conditions noted above identify what is needed for each technology area. This section highlights how these conditions can be deployed across corridors, fleets, ports, institutions and markets.

5.1. Corridor-based deployment and system integration

Deployment should be organised around strategic inland waterway corridors and inland ports. The Rhine, Danube and other TEN-T inland waterway corridors should function as living deployment environments where vessels, ports, energy suppliers, infrastructure managers, shipyards, equipment manufacturers, classification societies, authorities and logistics users jointly develop scalable solutions. This approach reflects current practice in EU-funded and sector-led initiatives, where clean-energy infrastructure, digital services, hydrogen corridors, battery-container exchange systems and remote-operation concepts are increasingly tested in real operating environments.

A corridor-based approach is necessary because the feasibility of each technology depends on the full operating system: vessel type, route length, cargo profile, fairway depth, water-level variability, port infrastructure, energy availability, grid capacity, terminal operations, lock and bridge constraints, safety procedures and commercial demand. Initial deployment should therefore prioritise routes with high traffic density, predictable operations and strong potential for early uptake.

Initial deployment corridors should validate clean-energy supply, bunkering and charging, battery-container exchange, digital traffic management, lock and berth coordination, water-level and voyage planning information, emission reporting, remote-operation procedures, safety cases and business models. The aim should be to move from individual pilots to replicable corridor packages that can be transferred to less dense, more complex or more climate-sensitive waterways.

5.2. Clean energy supply, refuelling and charging infrastructure

Energy availability is a key condition for the transition of inland navigation to a zero-emission mode of transport. Certified sustainable drop-in fuels such as HVO can already be used in existing engines and refuelling systems and should be treated as a short-term transition option for the current fleet. However, reliance on a single fuel would create risks related to availability, price and competition with other sectors. Battery-electric propulsion, hydrogen, methanol and other renewable energy carriers therefore need to be developed in parallel.

Battery-electric solutions and exchangeable battery containers are already entering early operational use on suitable routes, while hydrogen fuel-cell vessels and related infrastructure are being demonstrated. These developments show that different energy pathways will be suitable for different operating profiles. Battery-electric solutions are most relevant in the near term for predictable routes with regular terminal calls, such as container shuttles, ferries, passenger vessels, urban logistics and short-distance push operations. Hydrogen, methanol and other renewable fuels will require dedicated bunkering infrastructure, safety procedures, storage solutions and integration with renewable energy production and distribution systems.

Ports and terminals should become the main energy nodes of the inland waterway system. They should provide onshore power supply, high-capacity charging, battery exchange, renewable-fuel bunkering and links to local energy systems. OPS should gradually evolve from hotel-load supply at berth towards charging infrastructure for propulsion batteries, including intermediate fast charging, overnight charging and sequenced charging during regular downtime. Clean-energy infrastructure should be planned at corridor level, linking vessel demand, port capacity, grid readiness, fuel availability, safety requirements and logistics flows.

5.3. Fleet retrofitting, shipyard capacity and industrial readiness

Because much of the inland fleet will remain in operation for decades, retrofitting must be a central deployment pathway. Demonstration projects and early conversions show that retrofitting existing vessels is technically possible, but wider uptake will require modular and repeatable solutions for different vessel categories, routes and business models.

Standardised propulsion modules, battery systems, fuel storage arrangements, electrical drivetrains, energy-management systems, after-treatment systems, control systems and safety packages can reduce costs, shorten installation time, simplify certification and make uptake more accessible for SMEs and owner-operators. Shipyards, equipment manufacturers, classification bodies, port authorities, training institutions and finance providers should therefore prepare for repeated retrofit programmes rather than one-off pilot conversions. Demonstration projects should increasingly move towards replicable retrofit packages, shared technical specifications, pre-certified components and service models that combine technology, maintenance, energy supply and financing.

5.4 Digital infrastructure, data governance and smart corridor management

Digitalisation is a prerequisite for efficient, safe and resilient deployment. River Information Services, voyage planning tools, water-level information, traffic services, energy-efficient navigation tools and remote-operation demonstrations already show the value of digitalisation for IWT. The next step is to connect these tools into interoperable corridor services.

Reliable connectivity, common data standards, cyber-secure communication, real-time traffic and fairway information, berth and lock availability, emission reporting and multimodal logistics integration are needed to support safe and efficient operations. The modernisation of River Information Services should provide the foundation for this wider digital corridor architecture. By 2035, priority should be given to continuous and reliable connectivity along key corridors, including cross-border sections and critical areas such as locks, bridges, urban waterways, port approaches and congested traffic zones. By 2040, digital systems should support advanced corridor management, predictive traffic planning, automated reporting, integrated energy planning and remote-operation support. By 2050, digital infrastructure should enable highly automated and, where appropriate, autonomous vessel operations within a cyber-secure and interoperable system of systems.

5.5. Regulation, standards and certification

A stable, goal-based and technology-neutral regulatory framework is essential for investment certainty. Frameworks for automation levels, technical standards and pilot authorisations are already being developed and used, while demonstrations are helping regulators and industry understand the safety, operational and certification needs of new technologies. Further harmonisation is needed for alternative fuels, battery systems, hydrogen, methanol, hybrid propulsion, modular energy containers, remote operations, automation, cybersecurity and emergency response.

Regulatory sandboxes should be used to test new concepts under controlled conditions and should feed into permanent certification pathways when technologies mature. This is particularly important for remote operations, reduced-crew concepts, automated navigation, exchangeable energy containers, hydrogen systems and high-voltage battery-electric installations.

5.6. Finance, business models and market uptake

The main deployment barrier is often not technological readiness but the absence of a positive business case. Renewable fuels and zero-emission technologies remain more expensive than conventional diesel, while many operators cannot easily pass higher costs to cargo owners or passengers. This creates first-mover disadvantages and delays investment, especially among SMEs and owner-operators.

EU, national and regional funding has supported demonstrations and early deployments, while new models such as energy-as-a-service, battery-as-a-service and green corridor partnerships are emerging. Wider deployment will require financial instruments that support retrofitting, infrastructure, renewable-fuel cost gaps, first movers and SME operators. These may include grants, guarantees, low-interest loans, de-risking instruments, contracts for difference or similar mechanisms, and revenue recycling from market-based instruments where applicable. Public procurement, green transport contracts, cargo-owner commitments, cooperative fuel purchasing and shared infrastructure models should also be used to create demand and reduce market risk.

5.7 Climate resilience, safety and security

Technology deployment must be combined with climate-resilient infrastructure and operations. Water-level information, hydrological forecasting, traffic management and digital navigation support are already used to manage operational risks, while safety procedures for alternative fuels and high-voltage systems are being developed through pilot projects and technical standards. These efforts need to be strengthened through vessel design, fairway management, port planning and corridor operations that address low-water adaptation, shallow-draft optimisation, dynamic loading, predictive water-level services, resilient port infrastructure and emergency response.

Safety and security must remain central to deployment. Alternative fuels and high-voltage electrical systems introduce new operational risks, while digitalisation and remote operations increase cyber exposure. Harmonised safety procedures, emergency-response plans, crew training, cybersecurity requirements, incident reporting, resilience testing and fallback procedures should accompany every deployment phase. For remote and automated operations, particular attention should be given to loss-of-connectivity scenarios, human responsibility, traffic interaction and cross-border operational acceptance.

5.8 Skills, workforce transition and social acceptance

The green and digital transition will change the skills required in inland navigation. Training needs are increasingly recognised in projects dealing with alternative fuels, automation, remote operations and digital navigation, and simulators and digital training tools are already being used or tested for complex operational scenarios. Training and certification should be updated for alternative fuels, electrical systems, digital navigation, cybersecurity, automation, remote operations, emergency response and emission reporting.

Remote and automated operations require particular attention to human factors, workload, situational awareness, fatigue, responsibility allocation and fallback roles. These issues should be addressed from the start in all remote and automated operation concepts. XR, simulators and digital training platforms can support upskilling, especially for complex or high-risk scenarios such as fuel handling, low-water navigation, congested port approaches, incidents, degraded connectivity and remote-operation procedures. Social dialogue, targeted training funding and flexible pathways into the profession will be necessary to ensure that the transition is socially sustainable and helps address labour shortages rather than intensifying them.

5.9. Deployment milestones

By 2035, selected clean-energy and digital corridors should be operational. Sustainable drop-in fuels should be available under stable conditions; OPS should be deployed at key nodes; first high-capacity charging and battery-swapping solutions should be in commercial use on suitable routes; hydrogen and methanol pilots should operate under clear safety frameworks; and digital corridor services should support voyage planning, water-level information, emission reporting and first remote-operation applications.

By 2040, deployment should move from pilots to scale. Zero-emission propulsion solutions should be commercially available for the main vessel segments and supported by interoperable charging and refuelling infrastructure along core corridors. Digital corridor management, emission reporting, remote-operation support, predictive fairway management and cyber-secure data exchange should become standard practice. Retrofit packages and certification pathways should be sufficiently mature to support large-scale uptake across Member States and river basins.

By 2050, inland waterway transport should operate as a climate-neutral, digitally integrated and climate-resilient system. Vessels, ports, waterways, energy systems and logistics platforms should function as an integrated network supporting zero-emission transport, reliable multimodal supply chains, circular-economy flows, crisis resilience and European industrial competitiveness.

6. Expected Impacts (task Secretariat)

The implementation of this roadmap is expected to support the transformation of inland waterway transport into a cleaner, more resilient, digitally connected and commercially viable component of the European transport system. The impacts will depend on the coordinated deployment of clean-energy infrastructure, fleet retrofitting, digital corridor services, regulatory certainty, finance, climate resilience and skills development.

6.1. Environmental and climate impacts

The roadmap is expected to eliminate greenhouse gas emissions from inland navigation through the use of certified sustainable drop-in fuels, cleaner engines, energy-efficiency measures and operational optimisation in the short term, and through battery-electric propulsion, hydrogen, methanol and other renewable energy carriers in the medium and long term. It should also eliminate air pollutant emissions, particularly in ports, urban waterways and densely populated river corridors, through shore-side electricity, cleaner propulsion systems and improved voyage planning.

6.2. Modal shift and logistics-chain impacts

Cleaner, more reliable and better-connected IWT services can strengthen the role of inland navigation in multimodal logistics chains. Improved corridor management, water-level information, berth and lock coordination, emission reporting and multimodal data exchange can make IWT a more predictable and transparent option for shippers, ports and logistics integrators. This can support modal shift, especially for bulk cargo, containers, construction materials, industrial inputs, circular-economy flows and regular port-hinterland connections.

6.3. Competitiveness and industrial impacts

The roadmap will strengthen the competitiveness of the European IWT sector and the wider waterborne technology ecosystem. Retrofitting, clean propulsion, digital systems, battery-container solutions, hydrogen applications, shore-side power and remote-operation services can create demand for European shipyards, equipment manufacturers, ports, energy suppliers and technology providers. Repeatable retrofit packages, standardised components and service-based business models will support move innovation from individual pilots to scalable market applications.

6.4. Port and energy-system impacts

Inland ports and terminals will become key energy and logistics nodes. Their role will expand from cargo handling towards shore-side electricity, high-capacity charging, battery exchange, renewable-fuel bunkering, energy management and digital corridor services. Coordinated planning of vessel demand, grid capacity, renewable energy supply and terminal operations can reduce deployment risks and improve infrastructure use.

6.5. Safety, security and climate-resilience impacts

The roadmap will improve safety and resilience through digital navigation support, water-level forecasting, predictive maintenance, traffic coordination and incident communication. It will also support safer deployment of alternative fuels, high-voltage systems, automation and remote operations through harmonised safety procedures, cybersecurity requirements, emergency-response planning, fallback procedures and crew training. Climate-resilient vessel design, adaptive fairway management and resilient port infrastructure will improve service continuity under changing hydrological conditions.

6.6. Digitalisation and operational-efficiency impacts

The roadmap will accelerate the development of a digitally connected IWT system. Modernised RIS, interoperable corridor services, real-time fairway information, voyage optimisation, automated reporting, emission monitoring and multimodal data exchange can improve efficiency, reliability and infrastructure use. In the longer term, these systems will support remote operations, automated navigation functions and higher levels of vessel automation where appropriate.

6.7. Workforce and social impacts

The roadmap will change the skills profile of inland navigation. Crews, port workers, terminal operators, shipyard personnel, equipment manufacturers, inspectors, traffic managers and public authorities will need new competences in alternative fuels, electrical systems, digital navigation, cybersecurity, automation, remote operations, emergency response and emission reporting. Digital training tools, simulators, XR applications and updated certification schemes can support upskilling, while human-centred design and social dialogue will be needed to ensure that the transition is safe and socially sustainable.

6.8. Governance, regulation and market-transformation impacts

The roadmap will support a more coherent deployment framework through harmonised standards, certification procedures, regulatory sandboxes, cross-border acceptance and technology-neutral rules. It will also help shift the sector from demonstration to deployment by linking technology development with finance, infrastructure, public procurement, green corridor agreements and market demand.

6.9 Impact milestones and monitoring

By 2035, the roadmap will deliver visible early impacts in selected clean-energy and digital corridors, including increased use of sustainable drop-in fuels, OPS at key nodes, first commercial battery-electric and battery-swapping applications, hydrogen and methanol demonstrations, early remote-operation applications and interoperable digital services.

By 2040, zero-emission propulsion solutions will be commercially available for the main vessel segments, retrofit packages and certification pathways will be mature, charging and refuelling infrastructure available along core corridors, and digital corridor management, predictive fairway services and emission reporting are a standard practice.

By 2050, inland waterway transport operates as a climate-neutral, digitally integrated and climate-resilient mode, supporting zero-emission transport, reliable multimodal supply chains, circular-economy flows, crisis resilience and European industrial competitiveness.

Progress will be monitored through a limited set of indicators, including greenhouse gas emissions, air pollutant emissions, share of vessels using renewable or zero-emission energy solutions, number of retrofitted vessels, availability of OPS and charging or bunkering infrastructure, corridor reliability, modal share, accident and incident rates, digital reporting coverage, trained workers and demonstration solutions reaching commercial deployment.