Interreg North-West Europe
H2SHIPS

System-Based Solutions for H2-Fuelled Water Transport in North-West Europe

Guidelines to implement H2 propulsion in North West Europe

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Main author	Daniele Falco
Contributors	Christian Frederic Berthon
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Table of Content

Interreg North-West Europe H2SHIPS
Project co-funded by European Regional Development Funds (ERDF)
Project webpage: http://www.nweurope.eu/h2ships

List of Tables

Interreg North-West Europe H2SHIPS
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Project webpage: http://www.nweurope.eu/h2ships

1 Introduction

The use of hydrogen as a fuel for shipping – in particular for inland waterways transportation - has gained considerable attention in recent years as it provides a green solution for cutting the pollutant emissions of ships' engines. Indeed, one of the significant advantages of using hydrogen as a fuel for ships is that it produces no harmful emissions when burned, only water vapour and represents a more compact alternative compared to battery-electric ships. Although hydrogen fuel technology has the potential for significant benefits, it is still in its early stages of development and has not yet achieved consistent market penetration. One main challenge is that hydrogen is not yet widely available in ports, and the fuel cost and the technology, hydrogen fuel cells and storage systems, are currently not competitive with conventional applications. In addition, the lack of provisions within the Regulatory Framework and uncertainties surrounding long-term policies make initiatives related to ships and supply chains even more complex.

The goal of the H2SHIPS project is to promote the adoption of hydrogen propulsion in short-sea shipping and inland waterways navigation. Work package T2 is dedicated to identifying the requirements for implementing hydrogen fuel in water transport and listing and outlining the main barriers that may hinder its development, including technical, economic, legislative, and social barriers. The project also aims to develop recommendations and best practices to overcome these barriers. While the report "*T2.1.1 Analysis and mitigation of barriers hindering the development of H2 fuel in water transport*" investigates the identified barriers, this report will focus on the best practices needed to overcome them, presented in the form of guidelines.

The project has identified guidelines in two main areas of focus:

- **Regulatory Framework:** The guidelines aim to identify the aspects of the value chain that are more sensitive to regulatory prescriptions and provide recommendations on how to manage the uncertainty related to the lack of standards and rules.

- **Value Chain Creation:** The guidelines provide best practices for financing, development of hydrogen supply, demand identification, and stakeholder collaboration to stimulate the development of local initiatives.

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2 Guidelines for regulatory constraints

The complexity of the regulations concerning hydrogen bunkering, storage, and usage as fuel for ships, has to be considered from the perspective of a transitional phase. Expertise and best practices in handling and utilizing a complex substance such as hydrogen must be the result of years of experience and projects, where lessons must be acquired, and mistakes are to be made. Stringent rules are needed to ensure the security of users and also avoid the potentially disastrous effect of incidents on the public acceptability of hydrogen propulsion. On the other hand, complexity and flexibility are needed to embed in the regulatory framework the possibility of approving innovative technological concepts. The technologies for bunkering, refuelling, storage and onboard power systems are still not consolidated. Several configurations are available, and the sector needs more time and effort to identify the best solution for different applications.

The onboard storage of hydrogen is the example most representative of this fact. Liquid hydrogen, compressed hydrogen or sodium borohydride represent viable solutions with downsides and upsides concerning ships' context and requirements.

This chapter provides an overview of the regulatory framework for hydrogen-related initiatives in the water transport sector; the main scope is to guide the reader in understanding the main actions and the regulatory agencies in charge of the process (Ivan Petar Yovchev, 2022).

The procedures investigated are:

- Vessel approval
- Storage and transport
- Bunkering

2.1 Vessel approval

According to the International Convention on the Law of the Sea, every state is responsible for the ships flying its flag. Ships receive a Certificate of Registry from government or private agencies called registries once they have demonstrated they meet specific requirements set by the flag state and get the "Certificate of Classification". These requirements are often based on international codes and standards. Obtaining certification for a hydrogen-powered propulsion system is possible, even without a comprehensive set of standards and codes, by requesting an exemption within the existing regulatory framework. The approval process used in all European countries follows the alternative assessment procedure developed by IMO for maritime vessels that use fuels with low flash points. This process requires a risk-based approach, whereby ship owners must actively demonstrate that the overall safety level of the ship is comparable to that of a conventional system rather than passively complying with a set of requirements, as it usually happens with traditional fuel. The process for identifying procedures for inland waterways is typically conducted within the framework of CESNI (the European Committee for drawing up Standards in the field of Inland Navigation). However, since hydrogen has not yet been incorporated into CESNI's set of regulations, a risk-based approach similar to the one defined by the IMO for maritime vessels is still necessary.

Figure 1 describes the actions to be taken to approve a hydrogen vessel according to the IMO process; this is designed not as strictly linear but rather as a series of iteration loops occurring at each phase. The main actors are the Submitter (Ship Owner) and the Administration (Entity in charge of ship approval in the state where the ship is registered). To some extent, a certification agency can replace the Administration. At the same time, other parties that participate in the process typically include the design team, external consultants who conduct specialized analyses or tests, port state control officers, and the vessel's crew.

The initial step in the approval process is the "Preliminary Design" phase, which involves discussing the ship's design and the innovative power train and/or fuel storage and identifying the relevant guides and standards necessary for Approval. During this phase, the Submitter is expected to provide a detailed description of the system, including preliminary arrangement drawings, identification of interfaces with other systems/operations (such as refuelling), and a list of codes and standards used. This phase aims to identify and describe any items that require special attention and then, during the Definition of Approval Basis phase, to plan how both the Administration and the Submitter will handle these items. The Approval Basis is a document which includes requirements for risk analysis and the formal process to obtain Preliminary Approval.

The "Analysis of the Preliminary Design" represents the second step of the procedure, the purpose is to verify, considering the prerequisites fixed by the Administration in the definition of the Approval Basis, if the design is feasible and no unacceptable risks are identified during the operations.

The preliminary design is enriched with an Hazid/Hazop analysis, which consists of the investigation of the potential risks due to accidents or the operation of the ships, and the definition of the measures to prevent them or contain the effects. The Submitter will be required to arrange a workshop for hazard identification and management; this structured brainstorming aims to identify all relevant hazards and their consequences and mitigating measures already to be included in the design. The workshops provide a unique meeting place for designers, engineers, operational and safety personnel, and Administration representatives to investigate and discuss concepts and their associated hazards. In this phase, the approval process is further detailed with the requirements the final design needs to satisfy.

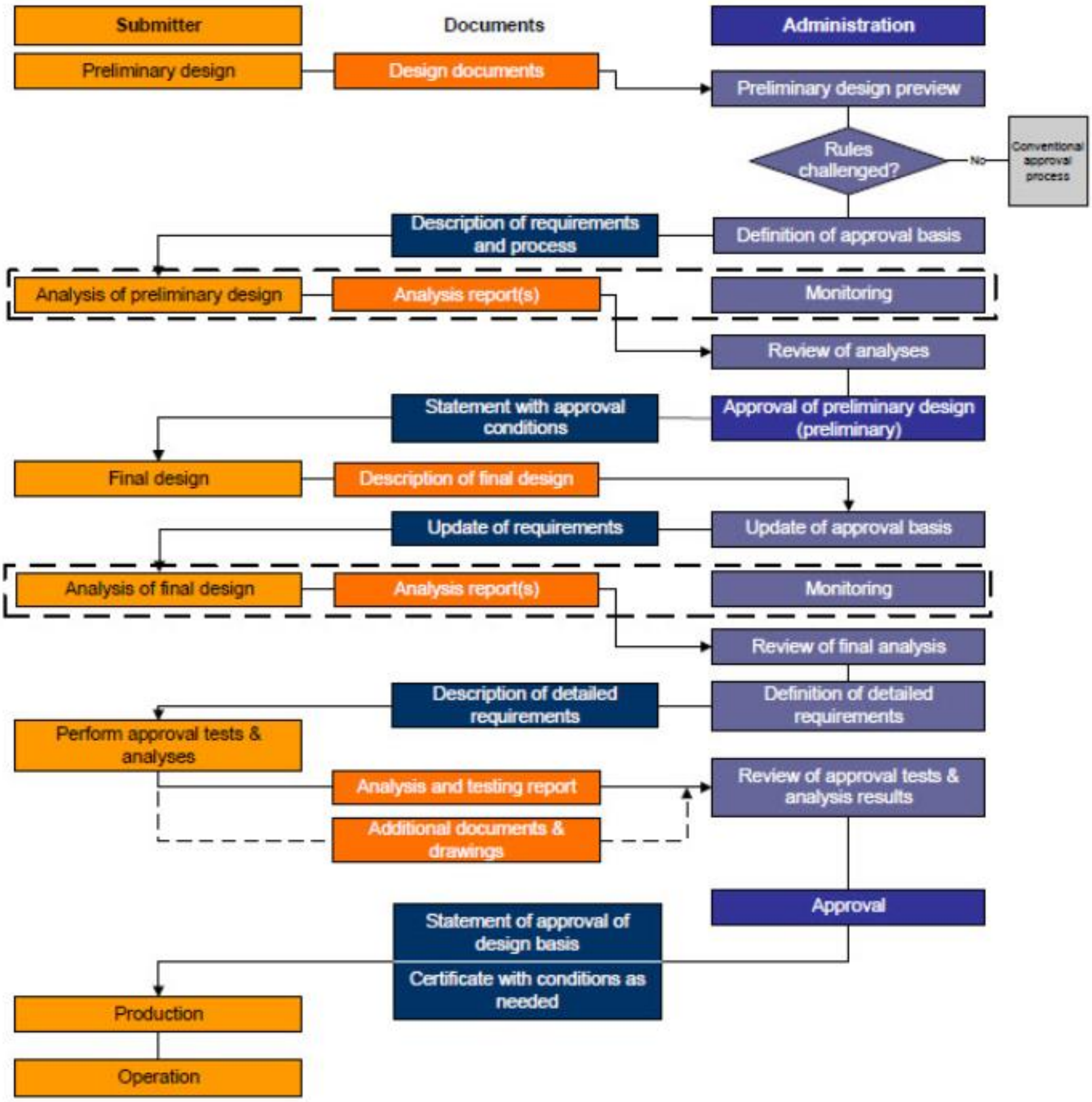

Figure 1 - Design and Approval Process Source: International Maritime Organization (2013), Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments, MSC.1/Circ.1455, p. 7.

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Once the main hazards and potential failure modes, along with corresponding precautions and control procedures, have been described, the Administration will issue a "Preliminary Approval". This Approval serves as evidence of the project's validity and may be helpful when dealing with project partners, financial institutions, and additional regulatory agencies. The Preliminary Approval serves to guide the Submitter in prioritizing the most critical issues that were identified during the initial review process. However, it is important to note that the issuance of preliminary Approval by the Administration does not guarantee final Approval; it merely confirms that the project design is feasible and suitable for its intended application and that no major obstacles were discovered. The Preliminary Approval should be accompanied by a list of conditions outlining the necessary requirements and steps the Submitter must take to meet the final approval criteria, as well as a list of required documents.

Following the preliminary Approval, the Submitter will advance into the next phase of the project, which involves the definition and presentation of the "Final Design". This phase corresponds to a more detailed version of the ship design, and the Administration has the faculty to update the Approval Basis with new or more detailed requirements.

Once accepted the final design, the Administration defines the:

- Procedures and experiments required to confirm eventual assumptions made, for example, during the quantitative risk analysis.
- Level of quality control during manufacturing and installation.
- Operational limits as well as maintenance procedures to be respected.

The Administration can require further engineering analyses to verify that the design is feasible with respect to intentions and overall safety in all phases of the process. The types and extent of the analyses and tests depend on the novelty level, confidence in analyses, and the extent of experience with similar concepts. Models used for the analyses, input data, and results are documented and submitted to the Administration for review.

Once the ship has passed all tests and met all safety requirements, the Submitter can apply for Approval and Certification.

The development of vessel approval rules is already on the agenda both at the international and European levels, and handbooks have already been published for hydrogen-fueled vessels by classification societies such as DNV and ABS. The Handbooks provide the main practices and the knowledge collected until now by the certification agencies about hydrogen applications for ships.

IMO has published a draft interim guideline for the usage of fuel cells onboard ships, but further steps are needed in the classification of hydrogen as a fuel. The inclusion of hydrogen

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as fuel and fuel cell guidelines in the IGF code represents the milestones towards the definition of a comprehensive set of rules to overcome the "Alternative Design Assessment" for the certification of Hydrogen vessels.

The EU and CCNR are also cooperating in the Framework of CESNI for the development of the standard for the inclusion of fuel cells in the current regulatory Framework (CESNI/PT/FC - Temporary working group on technical requirements for fuel cells onboard inland navigation vessels). Additionally, as part of the 2022-2024 work program of the Committee, the drafting of requirements for the use of alternative fuels in inland navigation vessels is envisaged. The priority is firstly on the storage of methanol, then on hydrogen storage.

The pathway which can be auspicated for the development of the regulatory framework for hydrogen ships consists of joined actions and collaborations of local authorities (ports, ship owner associations, fuel suppliers) and regulatory bodies (CESNI on a European scale and national authorities) in the framework of pilot projects. At this stage, the role of each stakeholder (shipowner, port authority, national or international institution) is limited if the efforts are not coordinated. A comprehensive cluster of stakeholders working together and sharing information can enhance the definition of regulations and standards jointly defined and reduce the risk of acceptance once the ship is built. The harmonization function of regional and European regulatory bodies involves consolidating insights gained from pilots and establishing standards. This can make it easier for other potential adopters to replicate and transfer the best practices, promoting widespread adoption. Regulatory bodies have to harmonize the best practice of each certification agency, limiting any variability in the provisions among the certification agency. The final set of standards and rules is also expected to be integrated into the current regulatory framework and not create any inequality between the grade of safety required from conventional systems and the hydrogen-based ones.

2.2 Hydrogen storage

The regulation for hydrogen storage, transport and bunkering differs according to the size of the project and the location. The risk associated and the subsequent acceptance is, to a certain extent, linked to the total amount of hydrogen stored, transported or bunkered. Besides, the location is also to be considered when evaluating the prescriptions to be enforced. Generally, there are three types of regulations to be consulted, and they can be derived from energy law, land use regulations, and health and safety regulations. These sets of rules are generally defined on different levels; European, National, and Regional.

At the European level, some of the more relevant acts for hydrogen storage include:

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- Directive 2012/18 on the control of major-accident hazards involving dangerous substances (Seveso Directive). This directive prescribes risk assessments for storage facilities that intend to store more than 5 tons of H2 and additional requirements for facilities storing more than 50 tons.
- Directive 2014/34 (ATEX) on the harmonization of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres.
- Directive 2001/42 on assessing the effects of certain plans and programmes on the environment (SEA Directive) and Directive 2014/52 on assessing the effects of certain public and private projects on the environment (EIA Directive)

2.3 Bunkering of compressed or liquid hydrogen

Regarding the regulatory aspects of bunkering, there are currently no concrete regulations, requirements, or technical guidelines for hydrogen bunkering. Risk-based assessments are usually needed to define safe distances and procedures for H_2 bunkering.
Some guidances which can be taken as references include standards for LNG bunkering or on-road hydrogen refuelling station.

Table 1, ISO Standards with relevance for H2 bunkering (Ivan Petar Yovchev, 2022)

Standard	Title	Description
ISO 17268:2020	Gaseous hydrogen land vehicle refuelling connection devices	Defines the design, safety and operation characteristics of gaseous land vehicle refuelling connectors
ISO 4126-1:2013	Safety devices for protection against excessive pressure - Part 1: Safety valves	General requirements for safety valves irrespective of the fluid
ISO/TS 18683:2015	Guidelines for systems and installations for supply of LNG as fuel to ships	Guidance on minimum requirements for the design and operation of LNG bunkering facility
ISO 20519:2017	Ships and marine technology — Specification for bunkering of liquefied natural gas fuelled vessels	Requirements for LNG bunkering transfer systems and equipment
ISO 13984:1999	Liquid hydrogen — Land vehicle fuelling system interface	Characteristics of liquid hydrogen refuelling and dispensing systems on land
ISO 13985:2006	Liquid hydrogen — Land vehicle fuel tanks	Specifies the construction requirements for refillable fuel tanks for liquid H_2 in land vehicles
ISO 21012:2006	Cryogenic vessels — Hoses	Design, construction, type and production testing and marking requirements for non-insulated cryogenic flexible hoses

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Table 2, List of EN standards with relevance for hydrogen bunkering

Standard	Title	Description
EN 17127:2018	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols	Minimum requirements for interoperability of public hydrogen refuelling points
EN 17124:2022	Hydrogen fuel - Product specification and quality assurance for hydrogen refuelling points dispensing gaseous hydrogen - Proton exchange membrane (PEM) fuel cell applications for vehicles	Specifies quality characteristics of H2 fuel at hydrogen refuelling stations for use in proton exchange membrane

3 Building a hydrogen economy

To overcome the issue of hydrogen availability is paramount to establish an ecosystem of private and public entities, each contributing to one or several scopes in the Hydrogen value creation chain. Each scope corresponds to specific activities which can be related to the production, storage, and usage of hydrogen but also to authorization procedures, financing of the projects, and institutional/political support. In the context of enabling hydrogen solutions for water transport, ports assume crucial importance. They can be the spatial reference around which build the ecosystem representing the energy hubs that can facilitate the connection of the supply and utilization nodes, the latter consisting not only of water transport but also of industry, on-road mobility, and equipment for port operations.

The Heilbronn University and Fraunhofer Institute propose an example of how an ecosystem can be built in the guidebook "*Building A Hydrogen Economy The Example Of Inland Ports The Example Of Inland Ports*"(Hochschule Heilbronn and Fraunhofer-Institut, 2022). This approach consists of 7 steps identified to be executed not in a linear way but instead in parallel or even in a different order based on the intrinsic characteristics of the players and the general context:

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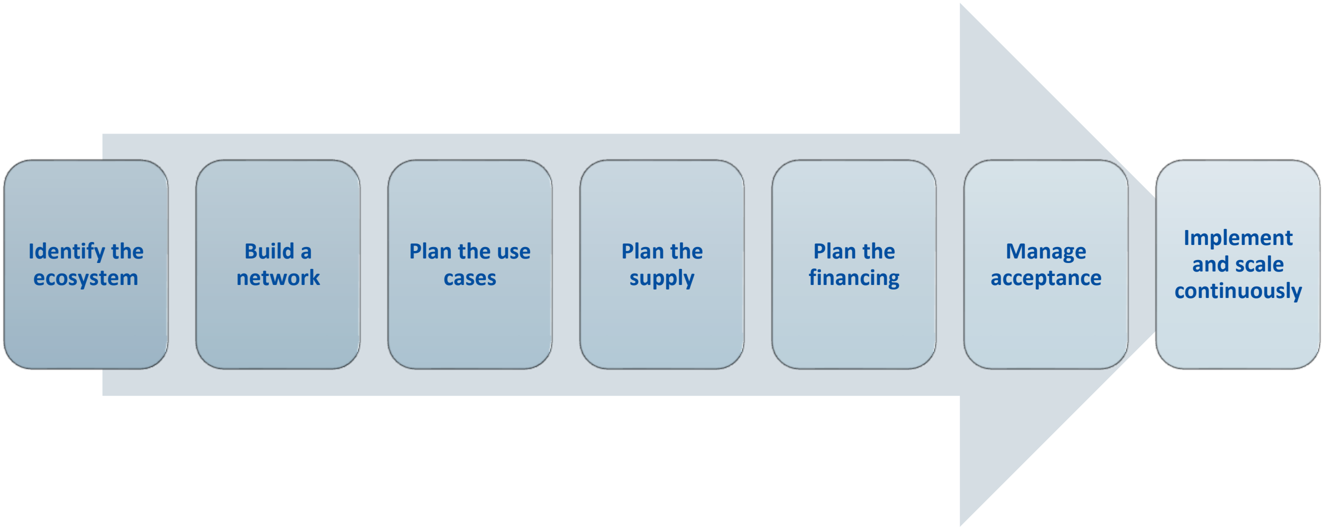

Figure 2, Steps for Building A Hydrogen Economy (Hochschule Heilbronn and Fraunhofer-Institut, 2022)

3.1 Identify the ecosystem

An ecosystem consists of stakeholders who cooperate and interact with each other to establish and continuously improve the value chain. In the case of hydrogen, the potential demand and the sources are two key elements that must be identified from a local perspective.

Hydrogen has proven a sustainable solution for several applications: fuel for ships, heavy-duty vehicles, and cars, feedstock for chemical products (ammonia, methanol, or synthetic fuel), and energy vector in the industry (steel production). Therefore, the range of potential users is wide and can vary from ship owners, logistic operators, and public transport to industries that can represent an important booster quickly scaling up the size of the ecosystem, increasing the volumes of Hydrogen demand.

Concerning hydrogen sources, the production can be local with an electrolysis capacity installed in the proximity of the port and electricity from the grid or remote, with the port assuming the role of a hub on a broader supply network. Local production is envisaged as the favourite configuration in an initial phase when limited availability of hydrogen must be ensured to the final users of the ecosystem.

The identification of the sources and the users must then be followed with a local analysis of the actors which operate in the port context to identify which elements of value creation could be occupied or supported. Production and usage are only the ending points of the chain. Transport, financing, regulation, and technology providers/developers are other fundamental bricks of the whole value chain.

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Project webpage: http://www.nweurope.eu/h2ships

The scheme below summarises the typical roles and some proposals of types of companies or entities that could assume that role.

Table 3 Hydrogen Ecosystem roles and potential actors in ports

Green Energy generation	Local energy providers such as municipal utilities, large energy providers, owners of vacant land for PV systems
H2 -generation (local)	Local energy suppliers such as municipal utilities, supraregional energy suppliers, industrial companies.
H2- provider (remote)	Suppliers of gases, supra-regional energy suppliers
H2 -Transport	freight forwarders, logistics companies (trailers with ADR approval), rail transport companies, shipping companies, gas network operators, terminal operators, energy suppliers, service station operators
H2 -storage	Energy suppliers, gas network operators, industrial companies
H2 -Use	Logistics companies, shipping companies, transportation companies, terminal operators, industrial companies, and energy providers.
Actors to create framework conditions	Local and regional government, port operators
Networking players	Intermediaries such as economic development agencies, chambers of commerce
Actors from research and development	Research institutions, consulting, and development service providers

3.2 Build a network

Establishing the necessary infrastructure for the production, storage, transportation, and conditioning of hydrogen, as well as the associated technology costs for end-users, presents considerable risks throughout the entire hydrogen value chain. To manage these risks, ensuring a high degree of synchronization in objectives and timelines among the various network actors is essential. A network that involves multiple stakeholders also has the potential to pose threats to investment returns. This may occur, for instance, if an actor in the network invests at an inappropriate time or overestimates the scale of correlated projects. As an example, a ship owner investing in a hydrogen ship with a delivery date set one year prior to the construction of a bunkering station or requesting a bunkering volume that exceeds the available supply may encounter such problems.

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Besides the synchronization, other necessary actions to strengthen the network are: exchanges with entities from outside the ecosystem to benefit from political actions consisting of financial schemes or regulations, exchanges with research entities about the latest developments of hydrogen related-technologies, cross-regional actions for the establishment of extensive supply chains, cross-regional research of players which could fill eventual gaps in value creation.

A single stakeholder or a group could centrally coordinate and promote the exchanges within and outside the ecosystem. The coordinator must be highly committed, well-known, and wield significant influence inside and outside the network.

3.3 Plan the use cases

The environment of inland ports offers various potential use cases for hydrogen that can contribute to reducing climate-damaging emissions; they can be both part of the port operations and navigation or related to industrial clusters in the port area. The establishment of an ecosystem should begin with the identification of the cases and an assessment to choose the most convenient ones for the specific case. The following table proposes a list of potential H2 applications near ports.

Table 4, Potential H2 applications near ports

Industry • **Refineries:** de-sulfurisation of crude oil • **Steel production** • **Chemical plants**: Methanol, Ammonia • **Other industries for electricity or heat production**	**Mobility and transport** • **Light Duty Vehicles** • **Heavy Duty vehicles** • **Ships** • **Trains**
Power sector • **Electricity generation** • **Electricity storage**	**Residential heat and power generation** • **Blending with natural gas** • **H2-powered boilers** • **Combined Heat and Power system**

The key factors a decision maker should take into account for defining the potential of each use case are:

- Performance and availability of the enabling technology: each application requires specific technological units, which can be pretty mature, as in the case of hydrogen use for ammonia production, or still under development or in the industrialization phase, as in the case of hydrogen-based power systems for trucks or ships. A useful method to evaluate maturity is by comparing the performances of such components to conventional units using fossil fuels.

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- Added value: when evaluating or comparing hydrogen-based applications to conventional ones, the primary benefit is reducing climate-damaging emissions. Therefore, minimizing hydrogen's carbon content is crucial, such as using renewable energy to power the electrolyzer. Furthermore, tracking and demonstrating the environmental sustainability of the entire value chain is essential.
- Permit and Legal Framework: being hydrogen a hazardous substance given its high flammability, special permissions and authorization procedures usually characterize hydrogen-related projects. For example, hydrogen ships may not be allowed to sail in highly populated areas like city canals or bunkering close to highly sensitive buildings (schools, crowded centres). The construction of hydrogen-fuelled ships must consider the context of the use and ensure ship operations will not pose any unsustainable risk for the authorities.
- Opportunities for funding and political support, for example public/private funding programs targeting energy sector decarbonization, can facilitate the "capital raising" phase, and political support can boost social acceptance and authorization procedures.
- Social aspects: The development of H2 applications may have social implications, especially concerning people's perception of risks, air quality, and employment opportunities.
- Economic efficiency: The economic sustainability of the initiative should take into account the whole value chain. In addition to the investment costs for acquiring the required technologies and constructing the supply infrastructure (such as H2 storage), the operating costs have to be considered.
- Hydrogen availability: the potential of local production capacity as well as the possibility to benefit from a distributed supply chain, are important to evaluate if the demand can be satisfied.

Once identifying the use case, a more comprehensive analysis to investigate the coupling potentials of the different use cases is also necessary; merging the demand coming from several applications can be beneficial for the ecosystem allowing the sharing of the investment cost for infrastructures (buffer storage, bunkering facilities, pipeline).

3.4 Plan the supply

Supply planning is a specular activity to be carried out with the identification and development of the use cases; a long-term and scalable supply strategy must be developed in line with the planned applications and the capacities for H2 procurement and generation. Planning the supply means identifying the sources of hydrogen, local production or import, and developing supply corridors intercepting existing ones or creating new ones.

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Local production can be advantageous if a large amount of low-carbon electricity is available locally at a low cost, e.g. ports close to offshore wind farms, or even if there are good possibilities for integrating hydrogen production into existing energy systems using electricity surplus or waste heat. Some other factors to be considered when local production is investigated are space availability for the installations and the permits to be required.

Import of Hydrogen can occur in different modes; the most investigated are listed below; each solution has its upsides and downsides to be evaluated on a case-by-case basis. Producing hydrogen in areas with a high renewable energy capacity could lead to low production costs, but the transport cost should also be accounted for. The import solution may be more convenient when low production costs and optimized investment costs offset the transport cost.

The main factors to be considered when the best configuration is investigated are: the maturity of the storage, handling, and transportation technology, the overall energy efficiency of the supply chain, the possibility of using existing infrastructures and the legal framework.

Table 5, Hydrogen Transport Alternatives

	Transport Form	Implementation	Capacity	Distance
Pipeline	Gaseous	Long-term, under investigation	Big Volumes	Long and medium distance
Truck	Gaseous, Liquid, Chemical storage (LOHC, Ammonia)	Short term	Small Volumes	Short distance
Train	Gaseous	Midterm	Medium Volumes	Short and medium distance
Ship	Gaseous, Liquid, Chemical storage (LOHC, Ammonia)	Short terms for Ammonia, Methanol Long term for liquid hydrogen	Big Volumes	Long and medium distance

3.5 Plan the financing

The supply chain and usage of hydrogen entail significant upfront investments due to the high equipment acquisition costs. Hydrogen storage requires materials and equipment with advanced technical capabilities, as it must be stored under extreme conditions. Additionally, since hydrogen applications are relatively new, production still operates on a small scale, resulting in high manufacturing costs.

Furthermore, the political framework often shows uncertainties about the strength and the timing of hydrogen penetration in the energy sector, raising the risk of private initiatives.

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Some actions are recommended during the fundraising phase to reduce the investment risks:

- In order to ensure a long-term commitment of the stakeholders and reduce the associated risk, it is recommended to distribute the investment as gradually as possible during the lifetime of the projects and share the financial risk homogeneously among the stakeholders.
- Public funding reduces the risk of hydrogen-related projects; the EU periodically publishes call for proposal and allocate funds to develop pilot projects. Also, private credit institutions have allocated funds to finance projects related to ESG (environmental, social, governance) criteria.
- The involvement of well-capitalized and well-known companies can be a key factor when high investment and visibility are required.
- The synergies with other projects in terms of scopes and sharing of knowledge are other important factors to consider.

At a European Union level, notable initiatives for supporting research and innovation are:

- **Horizon Europe**; the EU's leading research and innovation funding initiative with a budget of €95.5 billion. It addresses climate change, supports the attainment of the UN's Sustainable Development Goals and enhances the competitiveness and growth of the EU. The Zero Emission Waterborne Transport (ZEWT) is a partnership under the Horizon Europe grant funding scheme designed to support the introduction of clean ships operating on renewable energy.
- **Clean Hydrogen Joint Undertaking (CHJU**); The Clean Hydrogen Joint Undertaking is a public-private partnership that provides funding for research and innovative projects related to various aspects of the hydrogen value chain (production, conditioning, storage).
- **Connecting Europe Facility for Transport**; the EU's fund that supports infrastructure investments and related activities for implementing the Trans-European Transport Network (TEN-T). As part of these activities, sustainable and innovative mobility solutions are supported.
- **ETS Innovation Fund**; The world's largest funding programme for the demonstration of innovative low-carbon technologies. The total budget is € 25bn for 2020-2030 and is fed directly by the carbon taxation system over fossil fuel-based applications.

Additionally, the sector can benefit from other support schemes and initiatives such as the Green Shipping Guarantee Programme (GSGP) and the Renewable and Low-Carbon Fuels Value Chain Industrial Alliance

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Project co-funded by European Regional Development Funds (ERDF)
Project webpage: http://www.nweurope.eu/h2ships

3.6 Managing social acceptance

The success of an innovation process in the energy sector depends not only on the performance and the level of maturity of the corresponding technology but also on the public acceptance of the innovation. A general definition of public acceptance is "*the chance to get the explicit or implicit consensus of a group or person for specific concepts, measures, proposals or decisions*"(Klaas Visser, 2020).

The guidelines for effective management of the social acceptance of the ecosystems are as follows:

- Identify the target groups and evaluate under which sphere they can be affected or involved in establishing a hydrogen ecosystem. Acceptance must come from directly affected actors, who are part of the H2 ecosystem, and indirectly affected ones located near H2 storage facilities, refuelling stations, or other facilities. Public institutions represent a target group as well.
- Identify and evaluate acceptance-related factors. The safety of the installations and the perceived unfairness due to the high cost of the technology are the main negative factors to be considered when evaluating the public acceptance of the different groups of stakeholders. The contribution to lowering pollutant emissions and creating new jobs are instead the leverages to drive the consensus among the different groups.
- Identify and implement acceptance measures, including general information and educational events, to diffuse a fair perception of hydrogen risks and benefits, use demonstrators to communicate the solutions, and involve the communities and institutions in the planning and development of the activities. For internal stakeholders to increase acceptance, it is essential to communicate and clarify the scopes and contributions of each ecosystem entity, distribute the risk among the actors as much as possible, and include companies with a positive and well-known image.

In the case of water transport, social acceptance may be crucial to ensure the willingness to pay an extra fee for using green transport means. The shipping company or simple passengers could accept this cost if it is clear that the ship contributes to a zero-emission transport system.

3.7 Implement and scale continuously

The construction of an ecosystem must be followed by continuous monitoring and improvements. The development of new technologies can enable new use cases or increase the performance of the equipment for storage and transport. The achievements and developments of parallel projects and the establishment of new supply corridors can enable new synergies and new opportunities for the ecosystem. The creation and improvement of qualified human resources are paramount to sustaining the development of the value chain. Monitoring the KPI of the system's units is fundamental to keeping track of the effects of improvements and improving the quality of the system. Such KPIs could be H2 quantities consumed by the use cases, plant and supply failures, emissions, maintenance times, and operational costs. The ecosystem members must also be committed to promoting the image and social acceptance of the value chain by communicating the results and significant achievements.

3.8 Specific drivers of the ecosystem for hydrogen uptake in the shipping sector

Within the framework of a cross-sectoral ecosystem promoting hydrogen applications, some specific drivers concur with the promotion of hydrogen as an alternative fuel for ships.

The commitment of ship owners is crucial to initiate hydrogen uptake into the shipping sector; any efforts to establish infrastructure will be futile until they express an interest in adopting alternative fuels. However, companies and government entities can also play a crucial role in promoting this transition. They can encourage ship owners to switch to cleaner fuels by implementing rules and regulations or by creating a demand for "green" transportation of their goods. Other actors that could drive this shift are the Shipyards themselves. If a Ship Yard has experience with a particular technology, they could assist in constructing a pilot in a port, such as the Neo Orbis, to gain more experience and demonstrate to ship owners what is possible (Wieger Peet, 2023).

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4 Conclusion

The uptake of hydrogen in the shipping sector must face several issues linked to the absence of a regulatory framework, political uncertainty, lack of infrastructures and maturity of the technology. To manage these challenges, all stakeholders must collaborate and synergize their efforts to create a performing and fair value chain.

An ecosystem of several actors, such as technology providers, energy providers, port authorities, political and legislative actors, and ship owners, is needed due to the high risk of the investment and the need to maximize the economic return.

The development of pilot projects is an essential stimulus for technology developers, regulatory actors and market players. A pilot project is a small-scale ecosystem that groups entities from several sectors, such as ship owners, shipyards, and port authorities, with technology providers (Fuel Cell or hydrogen tank manufacturers) and energy providers. The framework of pilot projects is key to initiating collaborations and boosting the synergies required for creating solid ecosystems.

Some best practices for ecosystem creation that can be highlighted are:

- The usage of public funding to reduce investment risk
- The involvement of social parties and public authorities
- Identifying a networking actor facilitates effective coordination and homogeneous growth of the value chain.

Port authorities can play a crucial role in the whole ecosystem. They can act as stakeholder management and networking, bridging market and governmental actors and putting together local actors to bring additional value to the ecosystem. Furthermore, key roles in the context of the shipping sector will also be reserved for the shipowner, which represents the adopters of the technology, the logistic company, which can push the ship owner to shift to green fuel by imposing sustainability requirements on goods transported, and shipyards which can promote new technologies to their clients based on their experiences.

Due to the absence of codes and standards, risk-based assessments are typically required for ship certification and other infrastructure-related initiatives. However, the more information that is collected through demonstrators and pilot projects, the faster a comprehensive set of rules can be identified.

Overall, hydrogen applications for ships are still in the "Pioneers" phase, and pilot projects are needed to demonstrate the technologies and accumulate experience. A lot of energy and tenacity are required to deal with the absence of rules, standards, and technology readiness. However, with each project, progress is made towards demonstrating and creating a hydrogen economy for the maritime sector.

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