Interreg
Co-funded by the European Union
Italy – Croatia

TransH2

D.2.3.2 Cross-border port hydrogen refueling feasibility study

Responsible partner: M.A.R.E FVG Involved partners: All			
Version	**Status**	**Date**	**Author**
1.0	Version 1	30.01.2026	Maritime Aerospace Renewable Energy Technology Cluster FVG
2.0	Revision 1	31.01.2026	Maritime Aerospace Renewable Energy Technology Cluster FVG
Notes:			

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Introduction

The Programme Area is characterised by a high concentration of ports along the Adriatic coastline and by an increasing policy and strategic attention to the environmental sustainability of port infrastructures and related maritime services. In this context, the adoption of low-carbon transport and mobility solutions is increasingly recognised as a relevant lever, in particular regarding the modernisation and decarbonisation of cross-border maritime connections. One of the primary goals of this project is to contribute to the sustainable cross-border sea mobility by showcasing viable applications of zero-emission fuels, such as green hydrogen, in maritime transport routes. This involves the introduction of these innovations to port authorities, transport operators, and stakeholders across the region.

The initiative is framed around the objective of supporting the transition of cross-border maritime transport towards more sustainable solutions through the demonstration of innovative concepts and the development of preliminary investment planning. In this way, it is consistent with longer-term European decarbonisation trajectories, including the objectives of the European Green Deal to significantly reduce greenhouse gas emissions from the maritime sector by 2050, and contributes to broader EU policy ambitions such as the mission to “Restore our Ocean and Waters”, which promotes reduced pollution and lower emissions in European waters.

In this context, the project addresses the potential role of hydrogen in supporting the Italian and Croatian economies through the development of elements of a hydrogen supply chain for maritime transport. Particular emphasis is placed on research and innovation activities related to hydrogen-powered vessels and the associated port-side refuelling infrastructure, with reference to the objectives set out in the European Sustainable and Smart Mobility Strategy for the progressive market uptake of zero-emission vessels towards the 2030 horizon.

Within this framework, the project activities encompass the assessment of options for greening maritime transport links, the exploration of hydrogen-based solutions for cross-border and local passenger services, and the development of conceptual designs for hydrogen-fuelled passenger vessels. In parallel, feasibility studies are carried out for selected pilot areas to assess the potential introduction of hydrogen refuelling stations within port environments.

More broadly, the adoption of emerging technologies in the maritime sector represents an opportunity to address environmental challenges while contributing to improvements in safety, environmental performance and operational efficiency. At the same time, the deployment of hydrogen solutions in maritime transport is associated with significant technical, economic and regulatory challenges. Addressing these challenges requires coordinated efforts by both public and private actors, including targeted investments, the establishment of appropriate regulatory and safety frameworks, continued research and innovation activities, and the gradual development of a coherent refuelling infrastructure network in ports.

1 Document overview and methodological framework

This study is part of the TRANSH2 Work Package 2, which addresses the greening of maritime transport links through joint research, option analysis, conceptual design and defined case studies, supporting the development of piloting activities and the involvement of targeted stakeholders.

Developed within Task 2.3, this Deliverable provides a holistic, investment-focused economic assessment of hydrogen refuelling stations across the targeted port-related use cases. It complements the technical analysis presented in Deliverable D.2.3.1, *Technical report on analysis of hydrogen fuelling stations in existing port infrastructures*. While D.2.3.1 addresses technical feasibility, system architecture, safety requirements and siting criteria for

Hydrogen Refuelling Stations (HRS) in port environments, this document focuses on economic viability, capital and operational cost structures, and financing pathways supporting the transition from technical concepts to bankable investment propositions.

The analysis integrates inputs from Task 2.2 deliverables (D.2.2.2 and D.2.2.3), which define vessel operational profiles and refuelling requirements. Together, Deliverables D.2.3.1 and D.2.3.2 support the alignment of technical and regulatory considerations with economic assessments, providing stakeholders with a coherent basis for investment decision-making. By translating technical feasibility into economic and financing parameters, the deliverable aims to reduce the gap between technical readiness and investment readiness for hydrogen refuelling infrastructure in Adriatic ports.

1.1 Background and alignment with D.2.3.1

The integration of hydrogen technologies into maritime transport infrastructure is increasingly recognised as a key enabler of the transition toward sustainable, low-emission mobility systems. In the maritime sector, this transition is particularly relevant for short-sea and regional routes, where operational patterns and energy demand profiles are compatible with early hydrogen adoption. The Adriatic Sea basin, encompassing both the Italian and Croatian coastlines, offers a particularly favourable context for the early deployment of hydrogen solutions due to its dense network of short-sea shipping routes, high frequency of ferry, Ro-Pax and Ro-Ro services, and growing regulatory and societal pressure to decarbonise maritime transport.

This transition is embedded within a multi-level policy and regulatory framework that provides strategic direction and risk-mitigation signals for investors. At the international level, commitments under the IMO decarbonisation strategy and the evolving regulatory framework for greenhouse gas reduction in shipping establish a long-term trajectory toward zero- and near-zero-emission fuels, positioning hydrogen and hydrogen-derived fuels as viable compliance options for short-sea and regional maritime transport.

This policy context is shaped by a multi-level regulatory framework —spanning IMO, EU (AFIR, FuelEU Maritime), and national strategies—that creates both strategic direction and risk-mitigation signals for investors. At the international level, commitments under the IMO decarbonisation strategy and the evolving regulatory framework for greenhouse gas reduction in shipping establish a long-term trajectory toward zero- and near-zero-emission fuels, positioning hydrogen and hydrogen-derived fuels as viable compliance options for short-sea and regional maritime transport.

At EU level, the European Green Deal and the Fit for 55 package—together with the Alternative Fuels Infrastructure Regulation (AFIR)—provide a binding regulatory backbone by setting deployment targets for alternative fuel infrastructure along the TEN-T network, including hydrogen refuelling stations. These regulatory drivers are complemented by EU funding instruments such as the Innovation Fund, the Connecting Europe Facility (CEF/AFIF), Horizon Europe, the Clean Hydrogen Partnership and the European Hydrogen Bank, which reduce early-stage investment risk through capital co-financing and demand-creation mechanisms.

On the Italian Adriatic coast, the presence of major commercial ports, industrial hubs, and energy-intensive logistics platforms—including ports with significant passenger, freight and intermodal traffic—creates strong opportunities for the integration of hydrogen refuelling infrastructure with existing port operations, industrial hydrogen demand, and emerging hydrogen production and import initiatives. These characteristics position on one side Italian ports as potential hydrogen hubs capable of serving both maritime users and adjacent hinterland mobility and industrial applications. Within this framework, Italy's National Hydrogen Strategy, port decarbonisation plans and national transport policies explicitly support the development of hydrogen hubs in major Adriatic ports, leveraging industrial demand, logistics corridors and port authority investment capacity.

On the other side, the Croatian Adriatic coastline, characterised by an extensive network of island connections, seasonal passenger flows and high ferry traffic intensity, presents a complementary use case where hydrogen technologies can support the decarbonisation of short-distance maritime services and island connectivity. This role is reinforced by Croatia's Hydrogen Strategy and National Energy and Climate Plan (NECP), which emphasise hydrogen deployment for ferry services, coastal transport and island energy systems.

This deliverable addresses the economic dimension: cost structures, financing mechanisms, and investment factors that determine how technically feasible solutions can be financially sustained and scaled. It provides an overview of the current economic landscape for hydrogen and related infrastructure networks in the Adriatic region, with particular attention to port-based refuelling solutions and their integration into existing terminal layouts and operational models. The analysis further explores key economic inputs, investment constraints, and risk factors associated with the installation and deployment of hydrogen refuelling systems in port areas (detailed in Chapter 3 for each use case) In addition, the report reviews and synthesises available funding opportunities from both public and private sources, at European, national and local levels, with specific reference to the Italian and Croatian frameworks (Chapter 4). The overarching objective is to support a structured evaluation of investment feasibility and scalability for hydrogen refuelling infrastructure across the Adriatic maritime corridor, contributing to the development of a coordinated and resilient hydrogen ecosystem on both sides of the basin.

1.2 Objectives of the investment feasibility study

The primary objective of this deliverable is to provide a transparent, evidence-based economic assessment of hydrogen refuelling infrastructure deployment in the three TransH2 pilot port areas—Trieste (Italy), Split (Croatia), and Zadar/Gaženica (Croatia)—supporting stakeholders in evaluating investment feasibility, comparing financing options and assessing scalability potential.

In line with the multi-level policy framework shaping the hydrogen investment landscape—spanning international, European, national and local governance—the deliverable is intended to support both public and private stakeholders by improving regulatory clarity and investment confidence for early hydrogen refuelling projects in Adriatic ports.

By translating long-term decarbonisation objectives and policy commitments into economic parameters, the analysis contributes to reducing the gap between technical readiness and investment readiness for hydrogen infrastructure.

Specific objectives include:

1. Quantifying capital and operational cost structures for gaseous hydrogen refuelling stations serving maritime applications, based on industry benchmarks and site-specific parameters (Chapter 3);
2. Identifying site-specific cost drivers and constraints across the three pilot cases, overviewing hydrogen supply logistics, electricity costs, and regulatory compliance requirements (Chapter 3);
3. Mapping available financing mechanisms and support instruments from EU, national, and regional sources, with explicit alignment to eligibility criteria and application timelines (Chapter 4);
4. Defining indicative optimal financing mixes that combine public funding, revenue support, and private capital for each pilot case (Chapter 4);
5. Supporting stakeholder decision-making by providing credible, comparable economic data that can inform business case development and investment planning (Chapter 5).

Overall, this deliverable aims to provide a preliminary yet structured overview of the economic implications of developing a cross-border hydrogen refuelling network, addressing key stakeholders on both the public and private sides.

1.3 Scope and boundaries: integration with technical findings

This feasibility study addresses the cross-border port hydrogen refuelling system from the investments needed at local level for matching the technical and regulatory features prepared in the Work Package 2 of the project. The scope is explicitly bounded to align with the technical baseline established in D.2.3.1:

- Compressed gaseous hydrogen (CGH_2) at 350 bar as the reference configuration;
- Tube trailer delivery as the primary supply mode for initial deployment;
- System architecture and safety requirements as defined in D.2.3.1 Chapter 4 and Chapter 5.

The economic analysis is grounded in a structured review of peer-reviewed literature, industry techno-economic studies, equipment supplier data, and policy documents from European, national, and regional sources (methodological details in Chapter 3.1–3.2). The initial part describes the general scenario in terms of hydrogen demand and market and the connected state of the art in infrastructures, with a perspective addressed to the maritime segment. In addition, a review on inputs for hydrogen refuelling stations architecture and component specifications is provided.

The following part analyses the economic related inputs connected to the installation of the HRS and identifies a list of CAPEX and OPEX together with references methodologies and calculations. For each cost category—including compression equipment, high-pressure storage, dispensing systems, control and safety infrastructure, civil works, and site integration. OPEX components—electricity for compression, hydrogen procurement and transport, maintenance, labour, insurance, and regulatory compliance—are similarly quantified, with explicit attention to site-specific variables such as distance from hydrogen production facilities and local electricity tariffs. The use cases are addressed in relation to the sites of Trieste, Split and Zadar. Each use case section provides:

- A summary of the port's role within the Adriatic maritime system and its hydrogen ecosystem maturity (production capacity, pipeline/storage infrastructure, industrial demand);
- Quantified hydrogen demand scenarios derived from vessel operational profiles and route characteristics established in D.2.3.1;

- CAPEX and OPEX considerations specific to the site, including supply chain logistics, civil works constraints, and integration with existing or planned hydrogen production assets.

The final chapters provide an overview of funding sources for hydrogen application in ports overviewing instruments activated at EU, international, cross-border, national and local level and defining a potential pathway to investments. Connection with local policies, port authority strategies, , highlighting the role of port-level governance in supporting hydrogen deployment. Connection with local policies and initiatives is provided together with a final summary on findings and a potential optimal investment framework in relation to available funding sources.

The following aspects are not addressed in this report:

- Detailed front-end engineering design (FEED) or execution-ready cost estimation (which require site surveys, equipment tenders, and contractor quotes);
- Investment-grade financial modelling with project-level IRR, NPV, and sensitivity analyses (which require confirmed offtake agreements, operational schedules, and finalized regulatory authorizations);
- Business model definition, contractual structures, or procurement strategies for station operators;
- Detailed permitting timelines and administrative procedures (partially covered in D.2.3.1 regulatory pathways section);
- Comparative analysis with other alternative fuels (LNG, methanol, ammonia) or propulsion technologies beyond hydrogen fuel cells.

These exclusions are intentional and reflect the preliminary nature of the feasibility assessment. The purpose of this deliverable is to inform early-stage decision-making, not to replace detailed engineering or financial due diligence required for final investment decisions.

1.4 Methodological approach to economic assessment

The economic assessment framework integrates quantitative cost estimation, qualitative risk factor analysis, and financing mechanism mapping. The methodology is structured as follows:

1. Cost estimation: Component-level CAPEX overview and annual OPEX calculation based on validated models (HRSAM/HDRSAM), peer-reviewed studies, and industry benchmarks (detailed methodology in Chapter 3.1–3.2);
2. Use case analysis: Consistent analytical framework applied to Trieste, Split, and Zadar, enabling cross-case comparison of cost drivers and financing pathways (Chapter 3.3–3.5);
3. Financing mechanism mapping: Systematic review of EU, national, and regional funding sources, categorized by type, eligibility, and co-financing rates (Chapter 4);
4. Optimal mix definition: Indicative financing structures combining grants, revenue support, and private capital for each pilot case (Chapter 4.5).

This consistency enables cross-case comparison and facilitates identification of common investment patterns and site-specific differentiators.

At the same time, it supports phased deployment models that align infrastructure rollout with vessel uptake, improving investment bankability by reducing utilisation risk for early hydrogen refuelling assets and by leveraging blended public–private financing mechanisms enabled by regulatory certainty across governance levels.

2 Hydrogen for maritime transport: market, infrastructure, and technology context

This Chapter provides the market, the infrastructure and the technology context needed to understand the economic assessments presented in Chapter 3, moving from global hydrogen market trends to port-level infrastructure and maritime-specific refuelling solutions.

2.1 Global and European hydrogen demand and supply trends

Understanding current hydrogen market dynamics and future trajectories is essential for assessing the commercial viability and scalability of port-based refuelling infrastructure. This section synthesizes data from the International Energy Agency (IEA), the European Union Agency for the Cooperation of Energy Regulators (ACER), and industry sources.

According to IEA data, global hydrogen demand continued to grow in 2024, reaching nearly 100 Mt, about 2% higher than in 2023, and is expected to exceed 100 Mt for the first time in 2025. The demand currently is heavily concentrated in traditional applications, particularly oil refining and the chemical sector. Globally, China is the largest consumer, with over 29 Mt (more than one quarter of global demand), followed by North America at around 16 Mt. Growth was modest in China and North America, flat in Europe, while the Middle East and India saw stronger increases, mainly driven by refining, chemical production and, in India, steelmaking. Demand growth is still driven by industrial uses where hydrogen is used as a feedstock, rather than by policies promoting low-emissions hydrogen. New applications account for less than 1% of global demand, and almost all hydrogen consumption continues to be met by fossil-based production without emissions abatement[1].

[1] Hydrogen Mobility Europe – www.h2me.eu

2.1.1 European hydrogen production and electrolyser deployment

In relation to the elaborated data, the European Union Agency for the Cooperation of Energy Regulators (ACER) reports that despite a strong 51% annual increase in installed electrolyser capacity in the EU in 2024, the installed capacity of 308 MW (2024) and the 1.8 GW capacity under construction still fall well short of a realistic trajectory toward the 2030 EU (40 GW) and Member States (48-54 GW) targets. The Agency highlights how faster expansion is needed to reach the necessary scale, gain operational experience, and eventually drive innovation to reduce costs. To achieve this, there is the strong need to provide adequate support and regulatory certainty[2].

Beyond EU-level targets, national strategies reflect differentiated ambitions in electrolyser capacity deployment.

National electrolyser capacity targets and funding

With respect to above, further data on “National Initiatives across Europe” overviews an alignment with the EU’s efforts, dedicated funding initiatives for hydrogen have been implemented across Europe in the last 3–4 years, driven by national hydrogen strategies developed in multiple countries. These strategies typically establish goals for installed electrolyser capacity and/or hydrogen utilization in final end-uses, targeting achievements by 2030. Some countries are aiming for an installed electrolyser capacity in the MW range by 2030. For example, Belgium’s federal hydrogen strategy aims to install 150 MW of electrolyser capacity by 2026, while Croatia and Estonia target capacities of 70 MW and 150 MW, respectively, by 2030. More ambitious targets are evident in other countries, such as Denmark’s strategy for power-to-X, which aims to achieve 4.7 GW of electrolyser capacity installed by 2030. France and Germany also plan to achieve high capacities, totaling 6.5 and

[2] ACER European Union Agency for Cooperation of Energy Regulators (2025) – European hydrogen markets – 2025 Monitoring Report – 2 December 2025

5 GW, respectively, by 2030. Similar targets for 2030 have been set by the Netherlands (6–8 GW), Spain (4 GW) and Sweden (3 GW). Italy, with a 5 GW target for 2030, can be classified among the high-ambition countries in Europe[3]. Figure 1 illustrates national hydrogen investment commitments across Europe.

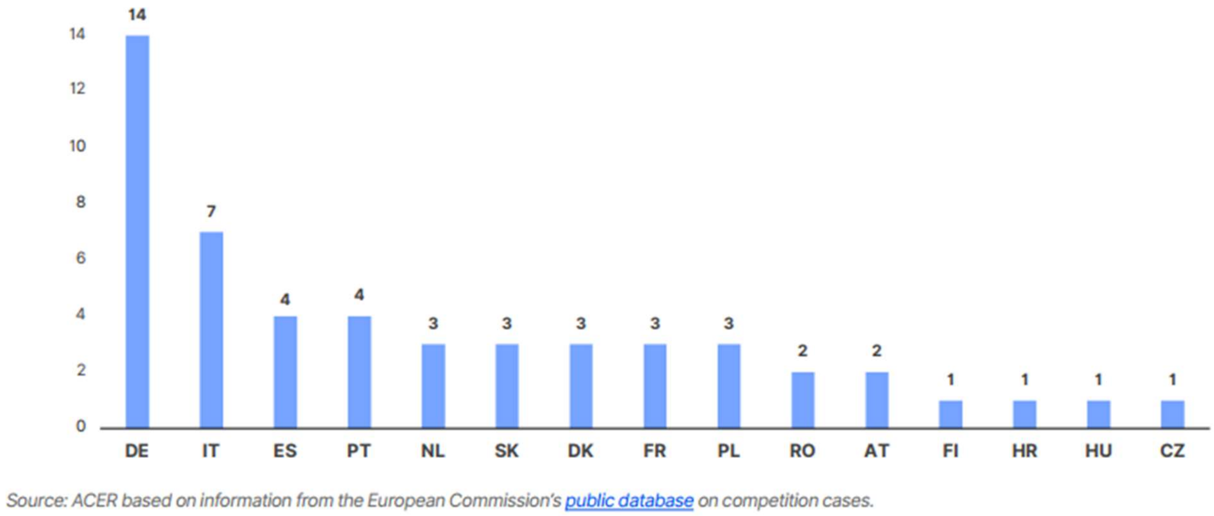

Figure 1 - Hydrogen investments at national level. Source: ACER.

2.1.2 European hydrogen bank auction results and price dynamics

An additional tool launched at EU level and connected to hydrogen production is the auction, a competitive funding process organized by the European Commission under the Innovation Fund via the European Hydrogen Bank. It is designed to allocate public support to producers of renewable hydrogen, enabling them to bridge the gap between the cost of producing green hydrogen and what buyers are willing to pay. Projects needs to be structured to present bids specifying the price per kilogram of hydrogen at which they can produce certified renewable hydrogen. The auction was reported by ACER in the monitoring report

[3] Gandiglio, M.; Marocco, P. Mapping Hydrogen Initiatives in Italy: An Overview of Funding and Projects. *Energies* 2024, *17*, 2614. https://doi.org/10.3390/en17112614

and interesting insights could be reported from the bids analysis that are reported in the following list and summarized in Table 1:

- 61 bids collected from 11 countries with a total capacity of 6.3 GW. It's lower than the 132 bids from 17 countries submitted in the first auction, totalling 8.4 GW in capacity. This could be the result of strong competition and very low bids of the first auction, which might have discouraged the participation of projects that need higher premiums.
- 36 out of the 61 bids came from Spain, indicating a high concentration and a competitive advantage of the region; out of the 34 projects with bids below 1 EUR/kg, 26 were Spanish.
- Compared to the first auction, the average bid increased by roughly 21%. The bids of the 18 selected projects (including the maritime topic and the projects selected after the withdrawal of seven initially selected projects) range from 0.33 EUR/kg to 1.88 EUR/kg. Based on the information submitted among all the bids, the levelised cost of hydrogen (LCOH) of individual projects ranges from 3.1 EUR/kg in Spain to 19.8 EUR/kg in Austria, reconfirming the wide differences across regions.
- The average LCOH was 7.1 EUR/kg, which is lower than the 9.5 EUR/kg of the first auction and the current estimates.
- Targeted offtakers, industry comes first again, followed by the mobility and hydrogen derivative sectors. Average offtake prices calculated by sector range from €3.60/kg for construction up to €14.04/kg for non-ferrous metals. Key industrial sectors demonstrate a willingness to pay that is close to the average reported LCOH. These include chemicals (6.43 EUR/kg), iron and steel (6.69 EUR/kg), maritime (7.12 EUR/kg), and refineries (7.85 EUR/kg).
- Willingness to pay for ammonia and methanol producers is significantly lower at 4.95 EUR/kg and 5.29 EUR/kg, respectively. This could be due to easier access to the global supply chain these sectors may have.
- 22 bids out of the 61 came from projects directly linked with the offtaker, 26 bids came from projects with integrated renewable energy supply, and 23 projects were

completely decentralised. The average bid of integrated projects was half compared to that of decentralised ones, indicating the importance of secured energy costs and offtake agreements.

- 39 projects reported that their planned delivery method is via pipeline, while 13 indicated road transport.
- Cost structure of the offtake agreements, 35 out of the 61 projects reportedly opted for fixed price contracts, reaffirming the outcome of the first auction.
- Electricity supply, only 10 projects reported they plan not to use the grid at all, while more than 60% of the projects foresee the use of a PPA. The variety of reported electricity supply paths indicates the complexity of optimising electrolysers' performance to produce RFNBO-compliant hydrogen and the need to use all available options to reduce costs and increase operating hours.

Overall, auction results confirm that hydrogen production costs and willingness to pay remain highly location-specific, reinforcing the importance of local supply conditions and logistics for port-based refuelling infrastructure.

Parameter	Second Auction (2024)	Comparison with First Auction
Total bids received	61 bids from 11 countries (6.3 GW capacity)	132 bids from 17 countries (8.4 GW capacity)
Spanish concentration	36 out of 61 bids; 26 projects with bids below €1/kg	Strong regional advantage evident
Average bid price	~21% higher than first auction	Increased from previous round
Selected project bid range	€0.33/kg to €1.88/kg (18 projects)	Lower bound competitive
Average LCOH across all bids	€7.1/kg	Down from €9.5/kg in first auction
LCOH range by country	€3.1/kg (Spain) to €19.8/kg (Austria)	Wide regional variation
Targeted offtake sectors	Industry (largest), followed by mobility and derivatives	Maritime: €7.12/kg willingness to pay
Contract structure preference	35 out of 61 projects opted for fixed-price contracts	Risk mitigation priority
Delivery method	39 projects via pipeline; 13 via road transport	Pipeline preferred where available
Electricity supply approach	>60% of projects use PPAs; only 10 projects fully off-grid	Grid integration prevalent

Table 1 - Key findings from the European Hydrogen Bank second auction (2024)[4]

[4] Source: ACER (2025), European hydrogen markets – 2025 Monitoring Report

2.1.3 Maritime hydrogen demand and fleet development

Figure 2 shows hydrogen production cost trajectories based on Lloyd's Register analysis (see LR Fuel for thought 2024).

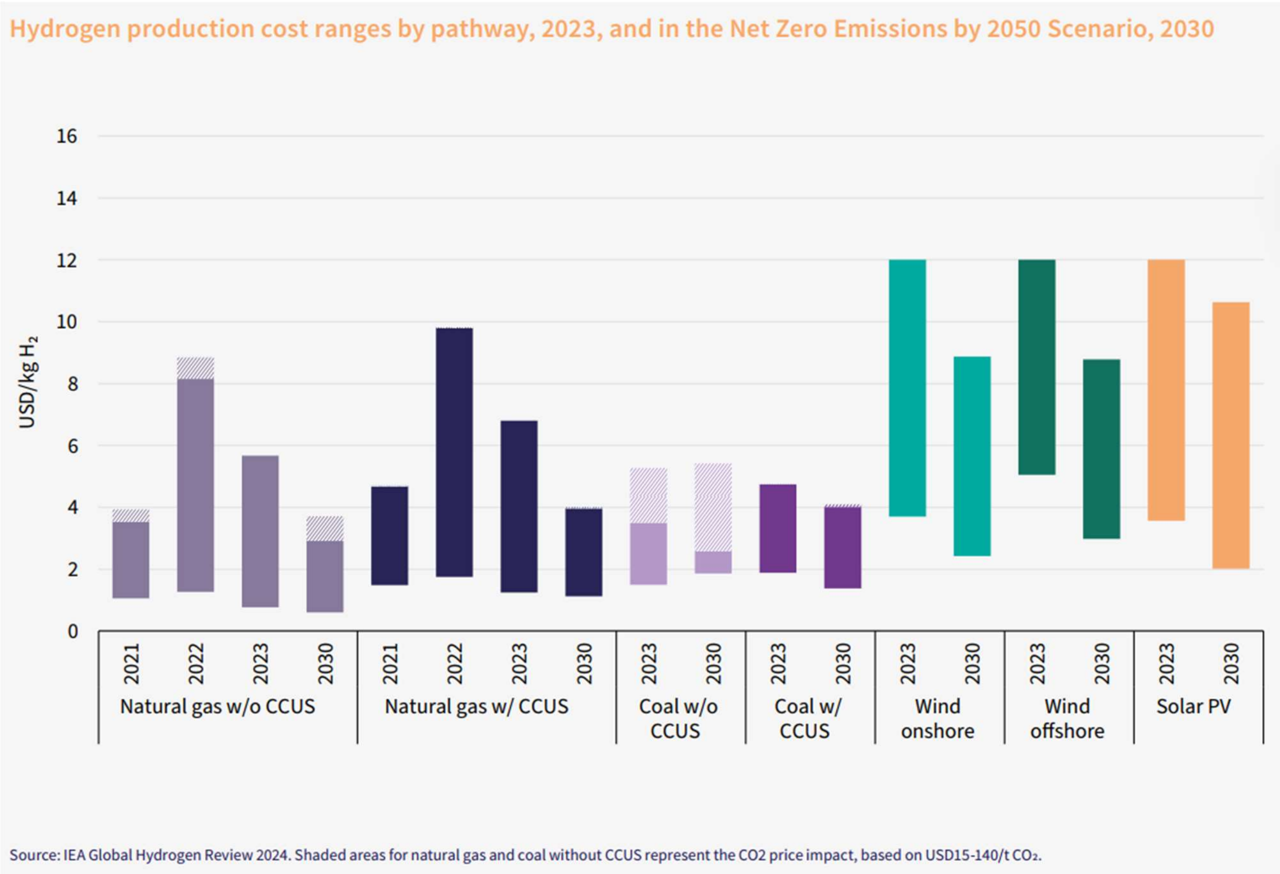

Figure 2 - Hydrogen production costs. Reference: LR Fuel for thought 2024

The fleet of ships capable of using hydrogen-based fuels is expanding, but the pace of adoption is slowing. Maritime shipping plays a dual role in the hydrogen economy: it can transport hydrogen and its derivatives and is also a potential major consumer of hydrogen-based fuels. Decarbonisation of the sector relies on a combination of alternative fuels, energy efficiency measures and wind assistance. In terms of ship operator demand, currently the developments are targeted to the ships in short sea and coastal segments, able to handle regular refuelling operations and shorter voyages without the need of large fuel tanks. In accordance with Lloyd's Register data on orderbooks, Hydrogen-powered ships currently account for 0.01% of the fleet in operation, and less than 0.5% of the orderbook, totalling 40 vessels. Hydrogen capable vessels are represented in the car/ passenger ferry segment, container ships, cruise ships, ro-ro cargo ships, and tugs. Hydrogen applications across the fleet include the use of hydrogen as the main fuel in dual-fuel ICEs, as a fuel for power cells supplying energy for main propulsion, and the use of fuel cells to meet auxiliary energy demands such as hotel loads in port[5]. In 2024, Clarksons reported 12 new orders for vessels capable of using hydrogen as a fuel on delivery[6].

Methanol has emerged as the most technologically mature alternative marine fuel for decarbonisation, supported by a growing fleet of vessels and available bunkering solutions. Industry data indicate that there are already hundreds of methanol-capable ships either in service or on order, with several hundred additional vessels designed to operate on methanol or dual fuels such as methanol and conventional fuel. According to Lloyd's Register analysis of Clarkson's data, the alternative-fuel capable orderbook includes approximately 385 ships capable of using methanol alongside other fuels such as LNG, hydrogen and ammonia, reflecting strong interest in methanol as a transitional fuel choice.

Methanol can be produced from renewable biomass or synthesized from low-emissions hydrogen combined with captured CO_2 (so-called "e-methanol"), and first commercial e-methanol production plants are now coming online, illustrating progress in supply chain development.

[5] Lloyd's Register (2024), Fuel for thought, Hydrogen, www.lr.org/fuelforthought

[6] Green Technology Tracker: Record Investments in Alternative Fuel https://www.clarksons.com/home/news-and-insights/2025/green-technology-tracker-record-investments-in-alternative-fuel/

However, key challenges remain: green methanol availability is limited, and its supply is constrained by the availability of sustainable feedstocks and renewable hydrogen, which in turn depend on electrolyser deployment and low-carbon electricity. This has contributed to tight fuel supply conditions and higher fuel costs, making long-term offtake agreements essential for producers and shipowners alike. As a result, some carriers have moderated methanol orders, and recent market data show a decline in methanol share of newbuild orders as hydrogen and LNG alternatives compete amid cost and availability uncertainties.

In the longer term, fundamental limits on sustainable biomass and the high cost of synthesizing fuels such as e-methanol from atmospheric CO_2 or renewable hydrogen could restrict scalability, particularly for deep-sea applications. This has led many stakeholders to consider carbon-free fuels such as ammonia and hydrogen as more promising end-state solutions. Ammonia, though less mature technologically than methanol, benefits from significant regulatory attention and industry testing, while hydrogen itself—due to its low volumetric energy density and demanding storage requirements—is currently better suited to short-range vessels and demonstration projects rather than widespread deep-sea use.

Furthermore, hydrogen production costs remain relatively high for low-carbon pathways. Recent techno-economic reviews indicate that green hydrogen produced via electrolysis typically ranges from roughly $3.5 to $6.0 per kilogram under current cost structures, reflecting high electrolyser and renewable energy input costs, further reinforcing the overall higher cost challenge for hydrogen-derived fuels compared with methanol and other alternatives. Together, these dynamics illustrate that while hydrogen-based fuels are gaining attention in the maritime shipping decarbonisation agenda, constraints related to fuel supply, cost, infrastructure readiness and technology maturity continue to slow their widespread adoption relative to methanol and other alternative fuels.

2.2 Hydrogen infrastructures deployment: current state and gaps

This Chapter examines the current state of hydrogen transport and storage infrastructure development, with particular attention to pipeline networks, port terminal capacity, and supply chain readiness. The TYNDP 2024 Hydrogen Infrastructure Gaps Identification report, prepared by ENTSOG, provides the primary reference of this study.

The TYNDP 2024 Hydrogen Infrastructure Gaps Identification report connects on ACER's reports on hydrogen and acknowledges how large-scale hydrogen infrastructure requires substantial upfront investment, even while early demand is uncertain. The importance of pipelines in terms of economies of scale is highlighted: constructing a 2 Mt/a (48-inch ≈1.2 m) pipeline costs less than 3 times than a 150 kt/a (20-inch ≈ 0.5 m) pipeline, while providing nearly 15 times the capacity. For repurposed pipelines, where the main asset is already in place, investments can be as low as one-fifth of those for new hydrogen pipelines. With this regard and in connection to long lead times and initially limited demand, pipeline networks are typically oversized to accommodate expected utilisation growth.

2.2.1 Port infrastructure and import terminal development

As outlined in the aforementioned report, approximately 120 new hydrogen-based fuel terminals and port infrastructure developments are planned by the end of the decade. While the focus of the announcements is on ammonia handling, a larger number of methanol facilities are already under construction, mainly to support maritime bunkering. The announcements suggest a more diversified supply base across exporting ports compared to importing countries. Worldwide, in addition to earlier announcements in Australia, Brazil, Egypt, Namibia and Mauritania, further progress over the past year includes also potential ammonia export infrastructure developments, such as the AM Green–Port of Rotterdam agreement for Indian exports, the Chbika project in Morocco, new projects in the Aqaba Special Economic Zone in Jordan, and more than USD 2 billion in engineering, procurement and construction (EPC) contracts awarded for the Ta'ziz chemicals hub port infrastructure in Ruwais, United Arab Emirates.

2.2.2 European hydrogen supply-demand balance and cross-border flows

In 2030, the Projects of Common Interest (PCI)/Project of Mutual Interest (PMI) on hydrogen infrastructure level's extra-EU imports are limited to shipped imports through the PCI reception terminals in Belgium, Germany and the Netherlands. The overall contribution of shipped hydrogen imports is rather limited when compared to the overall EU hydrogen demand. Therefore, in this infrastructure level, European demand for hydrogen is currently met by a combination of domestic production through electrolysis and hydrogen production using natural gas. However, these sources are not sufficient to fully meet the demand. In 2030, on the advanced hydrogen infrastructure level, Europe would receive imports also from e.g. North Africa, contributing to the reduction of hydrogen demand curtailment via higher utilisation rates of interconnected supply corridors.

According to this IGI/TYNDP 2024 assessment for 2030, countries can be grouped as follows based on yearly hydrogen supply–demand balance:

1) Countries that export more than they import (net exporters): Sweden, Finland, Denmark, Spain, Portugal and Bulgaria — these countries have a production surplus relative to domestic demand.
2) Countries that import more than they export (net importers): Poland, Czechia, Greece, Romania and Belgium — demand exceeds domestic production and import sources are key to meeting needs.
3) Transit countries that import more than they consume: Germany, Italy, Austria, France, the Netherlands, Estonia, Latvia and Lithuania — these countries both import hydrogen and act as cross-border conduits within the European hydrogen network given their central infrastructure role.
4) Isolated countries (with limited cross-border connections and little to no net trade flow): United Kingdom, Ireland, Luxembourg, Slovenia, Croatia, Malta, Cyprus, Switzerland, and the cluster Bulgaria–Greece — these economies are comparatively

isolated within the PCI/PMI infrastructure scenario and rely primarily on domestic sources or face constrained supply[7].

Relating to TransH2 project, some implications could be made, for example:

- Italy is classified as a transit country, reflecting its strategic role in potential hydrogen corridors from North Africa (via Sicily and Southern Italy) and its integration into Central European networks. This positioning supports the development of port-based hydrogen infrastructure in Trieste, which could serve as a node in trans-Alpine hydrogen flows (see Chapter 3.3).
- Croatia is categorized as an isolated country with limited cross-border infrastructure connections in the 2030 PCI/PMI scenario. This classification underscores the importance of domestic hydrogen production capacity and the strategic value of early-stage pilot deployments such as those planned for Split and Zadar/Gaženica (see Chapter 3.4–3.5).

2.2.3 Port-proximate hydrogen production potential

The analysis from the IEA states that on announced low-emissions hydrogen projects expected by 2030, more than 130 of today's main ports could have capacity for more than 100 kt/a of hydrogen production located within a 500 km radius, and almost 150 ports could access at least 50 kt/a. This indicates that a volume of low-emissions hydrogen may be available near existing global ports, though the scale and distribution of supply vary considerably across regions. For the TransH2 pilot cases, this underscores the importance of proximity to production capacity—a factor that strongly differentiates Trieste (with

[7] ENTSOG (2024) - Ten-Year Network Development Plan 2024 | Hydrogen Infrastructure Gaps Identification Report

enforced production at Monfalcone and planned in the Hydrogen Hub Trieste) from Split and Zadar, where supply chain logistics will be more challenging (Chapter 3).

2.3 HRS Architecture and components for maritime applications

2.3.1 Brief review on hydrogen storage options for maritime applications

As introduced in D.2.3.1, the hydrogen used to power fuel-cells, or any power system in general, can be stored inside a vessel of a vehicle in several possible ways:

- Direct storage, with in pure form, without any chemical transformation, only modifying the physical properties to increase the density, since gaseous H2 at ambient conditions has really poor volumetric energy density;
- Other H2 carriers, if hydrogen is converted into other energy carriers to increase the energy density, the safety in the fuel management or for logistic reasons. In some cases, the hydrogen carrier can be used as it is to run the power system.

Since hydrogen potential as a marine fuel is strongly connected to how it is stored aboard vessels, the compressed gaseous with high-pressure pressure vessels can represent a reasonable solution. The hydrogen at ambient temperature and pressure has a very low volumetric energy density, it must be compressed to around 350 bar for the marine use considered for the scope of the project and requires heavy, high-strength tanks that balance weight and volume constraints against safety and fuel capacity. Such pressurized storage is technologically mature and widely used in land mobility, but on ships it presents challenges for space utilization and structural design due to tank size and required support systems.

The alternative to gaseous storage is liquid hydrogen storage, where hydrogen is cooled to cryogenic temperatures (below approximately −253 °C) to achieve much higher volumetric energy density. Cryogenic storage tanks use advanced insulation to maintain low temperatures and manage boil-off which represents both energy loss and safety consideration. Despite the high energy cost of liquefaction and cryogenic system complexity, these tanks take up less space than equivalent gaseous systems, making them attractive for larger or longer-range vessels[8].

Beyond direct physical storage of hydrogen gas or liquid, solid-state storage using metal hydrides has emerged as another technique. In this approach, hydrogen chemically bonds with metals or alloys to form stable hydrides, allowing storage at much lower pressures (often near ambient) and improving safety by eliminating high-pressure gas. The trade-off is increased weight and slower hydrogen release kinetics, which currently limits their use to niche applications rather than main propulsion for large vessels. However, research projects like REMEDHYS[9] are exploring metal hydrides to create safer, compact storage alternatives, demonstrating ongoing interest in this area.

In addition to the above-mentioned storage systems, there are indirect hydrogen carriers that fundamentally change how hydrogen is stored and delivered aboard ships. Techniques such as Liquid Organic Hydrogen Carriers (LOHCs) chemically bind hydrogen to organic liquids at moderate temperatures and pressures, creating a liquid fuel that can be stored and handled similarly to conventional marine fuels. While technically not pure hydrogen, LOHCs allow vessels to carry a hydrogen “carrier” that can be catalytically dehydrogenated to release hydrogen when needed, offering logistical benefits at the cost of added system complexity and energy loss during the release process.

2.3.2 Review on HRS architecture

A HRS is a specialised facility designed to store and dispense hydrogen fuel for vehicles or other mobile applications, ensuring safe and interoperable refuelling in accordance with internationally recognised standards. In technical terms, it comprises equipment for

[8] Kumar N., Lee S., Park S. (2024), Advancements in hydrogen storage technologies: A comprehensive review of materials, methods, and economic policy, Nanotoday, Volume 56, June 2024, 102302.

[9] https://www.remedhys.eu/ - Recycled Metals for Aboveground Hydrogen Storage

receiving, storing, compressing, (and in some cases cooling) hydrogen, along with dispensing systems that deliver hydrogen at specified pressures (commonly 350 bar for heavy-duty vehicles and 700 bar for passenger/light-duty refuelling) to ensure safe and efficient transfer into onboard tanks. HRS are defined and regulated through international and European standards such as the ISO 19880 series, which sets out general requirements for the design, installation, commissioning, operation, inspection and maintenance of gaseous hydrogen fuelling stations, and related standards like EN 17127/ISO 17268 that specify refuelling interface and interoperability requirements for gaseous hydrogen dispensers[10].

In relation to the TRANSH2 project priorities, the adopted refuelling configuration is based on a staged compression, storage and dispensing chain, articulated as follows:

Gaseous hydrogen supply → low-pressure compression and buffer storage → high-/medium-pressure booster compression and buffer storage → accumulator → pre-cooling unit → dispenser.

2.3.3 HRS components

In the light of understanding components and costs, this paragraph recaps the description provided in D2.3.1 and describes a functional breakdown of HRS subsystems and their function, summarized in the following list:

1) Hydrogen Supply Source options: pipeline, production unit (not needed), gaseous tube trailer, cryogenic storage;
2) Low/medium pressure hydrogen: low pressure storage, low pressure compressor.
3) High/medium pressure hydrogen: high pressure / booster compressor, high/medium pressure buffer storage, vaporizer, high pressure cryo-pump;

[10] RCS HY https://rcs.now-gmbh.de/en/hydrogen-refueling-stations/

4) Pre-cooling and dispensing: refrigerating unit, dispenser[11].

The components involved are outlined below, while their technical specifications and associated cost implications are addressed in Chapter 3.2.

Low compressor unit

Low-pressure compressor unit is used to boost hydrogen coming from the supply source (e.g. tube trailer, pipeline, buffer storage) up to an intermediate pressure so it can be efficiently transferred into high-pressure storage banks and ultimately dispensed at the target pressure.

Compressor unit

Hydraulic or diaphragm piston unit, to boost H2 pressure up to fuelling levels 350bar (alternative is 700bar). Compressors are the components necessary to bring the H2 from the outlet low pressure up to the medium and high-pressure levels. They turn on when the pressure of the tanks goes below a certain threshold value. The charging of the cascade vessels occurs with opposite order with respect to the overflow refuelling discharging: the high-pressure tanks are the first to be filled up by the compressor, in order to always guarantee the possibility to refuel vehicles up to the maximum pressure. In general, the cascade storage charging is performed when the storage is not refuelling, once the minimum pressure value has been reached. Usually, a multi-stage compressor is used between the LP tank and the MP tank and another one between the MP and HP.

Components options: Dry piston reciprocating compressors, Diaphragm compressors, Ionic liquid compressors.

[11] Argonne National Laboratory – Hydrogen refueling station analysis model (HRSAM) https://hdsam.es.anl.gov/index.php?content=hrsam

Pre-cooling unit

It is mandatory in the 700 bar refuelling, it can be avoided in the 350 bar refuelling if a slow filling is performed. It is necessary to cool down the hydrogen from the storage before refuelling and preventing the heating of the vehicle tank.

Cooling System (Chiller/Heat Exchanger)

Removes heat generated during compression, ensuring thermal stability and safe handling, often cooling to -40°C.

Buffer Tanks

Intermediate storage tanks for low-pressure H2 before compression and high-pressure storage for fuelling; the low-pressure tank, collects the H2 coming from the electrolyser, and stores it at a pressure ranging in general between 20 and 200 bar. Since the operating pressure of this first stage is quite low, it can be used a simple type I vessel (see the following paragraph), made of steel.

Medium pressure tanks

The hydrogen storage systems are classified in 5 different coded types, according to the specific materials and structure (Palazzolo, 2021).

- Type I: tanks made entirely of metal, steel in general. This storage type is still the most diffused for low pressure applications, since it is the least expensive;
- Type II: metal vessels wound by a fibre reinforced polymeric hoop structure;
- Type III: metal liner fully-wrapped with a fibre reinforced polymeric composite material;
- Type IV: polymeric liner fully-wrapped with a fibre reinforced polymeric composite material;

- Type V, all fibre reinforced polymeric composite material construction, without an inner liner. This is the latest technology, currently not mature at the commercial level for hydrogen storage applications.

In general, it is widely acknowledged that for pressures higher than 300 bar, the composite materials-based vessels are the most practical solution, in terms of cost and performance, especially type III and IV. For a given design pressure, producing a type I vessel requires a much higher vessel thickness with respect to a composite material based one, to guarantee the necessary mechanical resistance properties, which has 2 effects: higher cost for the material used and higher weight of the system, resulting in a lower energy storage density.

Other advantages of composite material-based vessels with respect to metal vessels are the higher corrosion resistance and hydrogen embrittlement. This last phenomenon, typical of metallic materials, consists in the adsorption and diffusion processes of the atomic hydrogen in the material with consequent cracking propagation and irreversible damages to the material internal structure, leading to ductility and maximum strength reduction. Corrosion and embrittlement can significantly affect also the fatigue resistance of the component, that for composite materials is higher than steel. As a result of this improved mechanical performance, the expected lifetime of the composite material vessels is extended with respect to the metal vessels one (later on in the project we will assume a lifetime of 30 years for the type III and IV vessels).

One of the main concerns for the composite materials in general is represented by the end-of-life decommissioning, since, at the moment most of the composite materials, especially the FRP can't be recycled, differently than steel vessels. Some thermoplastic resins as a possible matrix material are under research, to allow the separation of the fibres from the matrix and the recyclability of this last one (Palazzolo, 2021).

Control & Safety Systems

A gaseous hydrogen refuelling station requires a set of integrated control and safety systems to ensure safe and reliable operation throughout hydrogen storage, compression and dispensing. Core systems include an Automated Control and Monitoring System (typically PLC-based) supervising pressure, temperature and flow; a fully independent Emergency Shutdown System (ESD) capable of rapidly isolating hydrogen supply; and hydrogen Leak Detection and Flame Detection Systems installed in all critical areas and linked to alarms and shutdown logic. Additional essential elements are pressure relief devices and safety valves, certified hydrogen-compatible piping and components, breakaway couplings at dispensers, and properly designed venting and ventilation systems to prevent hydrogen accumulation. These technical systems are complemented by hazardous area classification, explosion-proof electrical equipment, fire-fighting provisions, and operational measures such as access control, clear signage and trained personnel, as defined in international standards such as ISO 19880-1 for gaseous hydrogen refuelling stations (detailed safety requirements and risk assessment methodologies are provided in D.2.3.1 Chapter 5)[12].

Dispenser

The dispenser is the interface between the HRS and the user. While it shares some characteristics with conventional fuel dispensers, hydrogen dispensers incorporate additional components and safety features to comply with the stricter requirements of hydrogen facilities. Key aspects include:

- *Nozzle communication*: In advanced HRS, the nozzle is equipped with an infrared communication system linking the station to the vehicle, continuously monitoring temperature and flow rate during refuelling.

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[12] OECD (2023), Risk-based Regulatory Design for the Safe Use of Hydrogen, OECD Publishing, Paris, https://doi.org/10.1787/46d2da5e-en .

- *Refuelling protocol compliance*: The process follows SAE J2601, which defines limits on pressure ramp rates and conditions under which refuelling is prohibited, considering ambient temperature, initial tank pressure, and target fill pressure.
- *Standardized procedure*: Refuelling begins with a preparation phase where vehicle tank pressure and temperature are measured and refuelling parameters are calculated. After an airtightness check, hydrogen transfer commences, with continuous monitoring to keep the tank temperature below 85 °C. At the end, any residual hydrogen in the connection pipe is safely vented before nozzle disconnection.

The SAE refuelling protocol allows hydrogen filling at three standard velocities:

- *Slow*: up to 30 g/s (1.8 kg/min)
- *Normal*: up to 60 g/s (3.6 kg/min)
- *Fast*: up to 120 g/s (7.2 kg/min)

Most HRS are equipped with multiple nozzles, enabling simultaneous refuelling of several vehicles, even at different pressures (e.g., 700 bar for cars, 350 bar for trucks). The number and design of nozzles must be carefully optimized, as they significantly influence both the cost of the dispenser and the speed of the refuelling process.

As per Palazzolo (2021) and NREL (2015), common HRS layouts include:

- Gaseous H_2 overflow refuelling
- Gaseous H_2 refuelling using a booster compressor
- Liquid H_2 refuelling with cryo-pump and evaporator

2.3.4 Transitional HRS approach for project use cases in the Adriatic Sea basin

In accordance with the use cases developed in the project, hydrogen delivery by road transport is considered as a feasible and operationally flexible logistics option to supply limited and targeted quantities of hydrogen to port-based refuelling stations, particularly in early deployment phases or in contexts characterised by constrained and uncertain demand.

This approach builds on operational concepts and logistics arrangements already established in hydrogen refuelling stations for road vehicles, allowing for partial transferability of practices, procedures, and safety management frameworks. In this perspective, road-based hydrogen delivery is assessed as a transitional and enabling solution supporting the project's immediate operational objectives—namely, the refuelling of a vessel operating on a defined route—while also serving as a preparatory step for further analysis and development of alternative supply configurations and refuelling modalities to be considered in subsequent project phases or at higher deployment scales. This does not imply a preferred or long-term supply configuration for ports envisaged to evolve into major energy hubs or distribution nodes, for which different and more scalable solutions would be required.

Largest options currently in use in Spain for road vehicles use a 45-foot high-capacity tube trailer with a working pressure of 517 bar and designed to transport up to 1.3 tonnes of compressed hydrogen on EU roads. It is intended to support hydrogen refuelling stations (including in Germany and elsewhere in Europe) and represents one of the largest commercial tube trailer configurations currently developed, in other solutions the gas is compressed and stored at pressures higher than 180 bar[13]. This option would be preferable to pipeline systems: the latter would require significant upfront investment and dedicated infrastructure corridors transporting hydrogen at 40 to 80 bar that are not yet available (cost implications of tube trailer delivery are analysed in Chapter 3.2).

The station layout is designed to supply hydrogen in gaseous form and is based on a dedicated compression strategy. Hydrogen is stored at low pressure levels—below 350 bar—which do not allow direct dispensing through simple pressure equalisation. Refuelling is therefore carried out using a booster compressor that increases the gas pressure to the

[13] Caponi, R.; Bocci, E.; Del Zotto, L. (2022), Techno-Economic Model for Scaling Up of Hydrogen Refueling Stations. Energies 2022, 15, 7518.

required dispensing level and is activated exclusively during refuelling operations. Compared to the compressor used for filling high-pressure cascade storage systems in an overflow refuelling configuration, the booster compressor operates with a lower compression ratio, reflecting its role as an on-demand pressure-increasing device rather than a continuous compression unit. From a safety perspective, hydrogen stored in dedicated pressure vessels does not inherently pose an explosion hazard in the absence of an ignition source and oxidant. As with other energy carriers, hydrogen is flammable when mixed with air under specific conditions. Available risk assessments and operational experience indicate that, when appropriate design, operational, and safety measures are applied, hydrogen refuelling systems can achieve safety levels comparable to those of established fuels such as petrol or natural gas, without implying equivalence or reduced safety requirements.

The automotive industry has agreed globally on a pressure of 700 bars for hydrogen in cars – the pressure of hydrogen storage systems is mechanically controllable -. In the maritime sector the most recent developments in terms of HRS for refuelling are implemented with gaseous hydrogen at 350bar with concrete examples in Germany and Italy (NatPower H).

2.4 Existing HRS systems for ships: benchmarks and lessons learned

This chapter provides a contextual framework for the maritime hydrogen refuelling within the broader HRS deployment landscape. After reviewing global infrastructure development trends, it examines operational maritime installations, that provide empirical benchmarks for capital costs, operational models, and early-stage challenges relevant to the TransH2 pilot cases.

2.4.1 Global overview and maritime benchmarks

As described in Chapter 2.3, hydrogen refuelling stations (HRS) are dedicated facilities designed to enable the safe and metered delivery of hydrogen fuel through the integration of reception, compression, storage, control, safety, and dispensing systems. At the current state of the art, HRS worldwide are predominantly based on gaseous hydrogen, typically operating at 350 bar—commonly adopted for buses, trucks and selected industrial mobility applications—and 700 bar, which is standard for passenger fuel-cell vehicles. While large-scale deployment has progressed most significantly in Asia and North America, particularly within road transport networks, applications in the maritime sector remain limited and are primarily confined to pilot and demonstration projects, including the early references discussed in Deliverable D.2.3.1.

In Europe, the HRS network is expanding progressively but remains in a ramp-up phase, with installations predominantly serving road transport fleets in countries such as Germany (more than 100 stations), France (41 stations), the Netherlands and the Nordic region. Worldwide the leading countries in Hydrogen investments are Japan, China and USA, e.g. the California state. Recent years have seen a marked increase in new HRS projects for both light- and heavy-duty vehicles, while maritime refuelling solutions are continuing to evolve through targeted pilots rather than mature, standardised deployments. An up-to-date overview of existing, planned and completed hydrogen refuelling infrastructure at both European and global level is provided by the publicly available databases hosted on *H2stations.org*, developed in the context of Hydrogen Mobility Europe and subsequent international monitoring initiatives.

Figure 3 illustrates the current distribution of operational hydrogen refuelling stations worldwide.

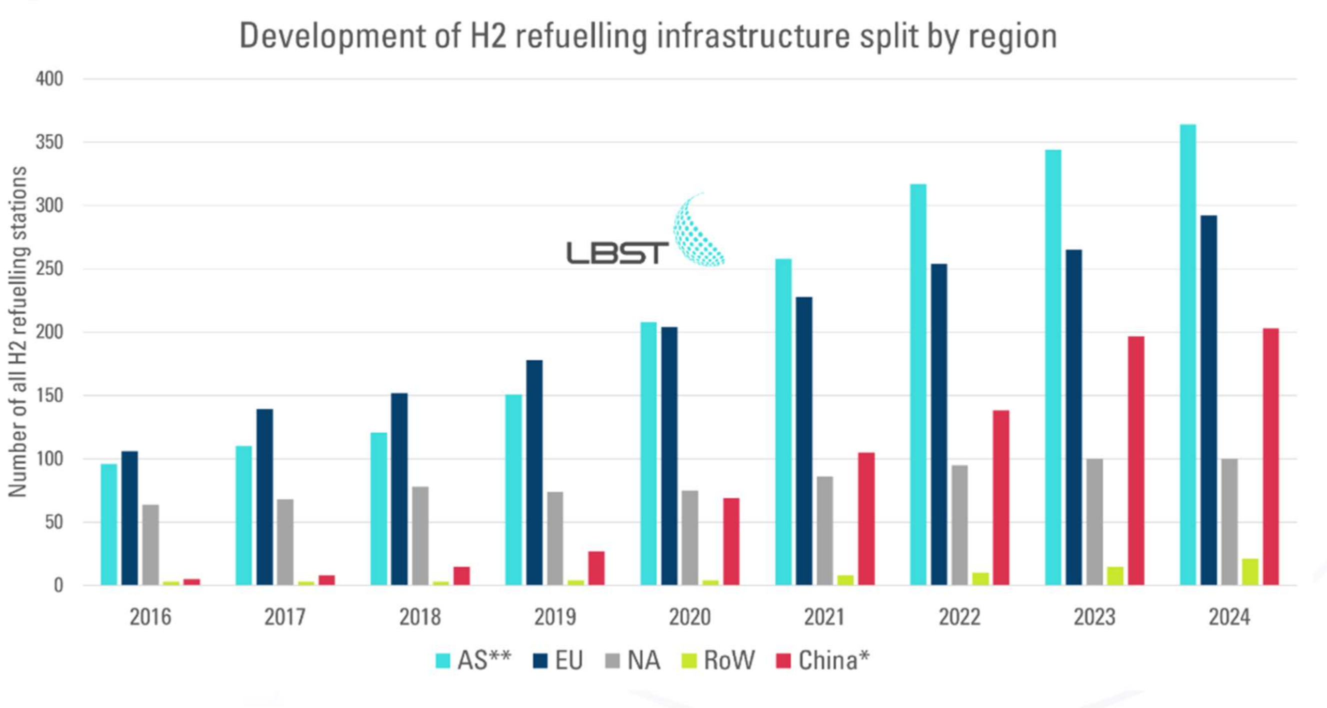

Figure 3 - Refuelling infrastructure at global level, source https://www.h2stations.org/statistics/

At national level, complementary mapping tools are available, including those developed by H2IT, providing an overview of hydrogen-related infrastructure in Italy. In Croatia, planned developments related to HRS deployment are outlined in the document "*Hydrogen Strategy of the Republic of Croatia until 2050*" issued by the Ministry of Economy and Sustainable Development in 2022.

In Italy, the national H2 refuelling infrastructure landscape shows targeted deployment under PNRR funding, with road-oriented stations dominating.

Figure 4 - Map of hydrogen related projects under the National Resilience Plan, Hydrogen Valleys, Hydrogen refuelling stations and IPCEI related projects. Source: https://www.h2it.it/ Italian Hydrogen Association. In Yellow – Hydrogen Valleys, in Green – road refueling stations, in Orange – rail refueling stations, in Purple – IPCEI projects.

From the analysis of the already existing HRS at European level, most of them are designed to refuel cars, heavy duty vehicles and buses fleets.

Existing hydrogen-powered vessels are currently refuelled primarily through mobile solutions, typically based on tube trailers supplied from off-site hydrogen production facilities and temporarily positioned at dedicated quays.

The development of multimodal HRS in strategic port locations may therefore represent an enabling option to support both current pilot vessels and potential future investments, while mitigating the risk associated with limited initial demand.

Current refuelling practices typically distinguish between 700 bar storage systems for passenger vehicles—driven by space optimisation requirements—and 350 bar storage for heavy-duty vehicles and maritime applications, where larger storage volumes are generally available.

While road-based HRS dominate current European deployments, maritime applications represent an emerging niche with distinct logistical, technical, and regulatory requirements. The following section examines operational maritime HRS installations that provide empirical benchmarks for the TransH2 deployment scenarios.

2.4.2 Maritime-specific HRS: operational examples

In the maritime sector, hydrogen refuelling infrastructure is still at an early stage of development, with only a limited number of operational installations and demonstration projects currently in place. One of the first concrete examples of a multimodal hydrogen refuelling station serving maritime applications was commissioned in 2021 at the Port of Antwerp, developed by Ekinetix for CMB TECH [14]. At the time of commissioning, the absence of a commercially mature hydrogen-powered vessel market led to a design approach focused on multimodality: the station was intended to serve both road-based fuel cell electric vehicles and a small number of pilot hydrogen-powered vessels, notably Hydroville and HydroTug. These vessels represent early maritime demonstrators based on hydrogen-fuelled internal combustion engines, reflecting the exploratory nature of initial hydrogen adoption pathways in shipping.

More broadly, the current generation of hydrogen-powered vessels in Europe is often refuelled through mobile solutions, typically based on tube trailers supplied from off-site hydrogen production facilities and temporarily positioned at dedicated quays. While operationally flexible, such arrangements highlight the limitations of ad hoc refuelling in

[14] CMB TECH Hydrogen Refuelling Station - https://cmb.tech/h2-infra/hydrogen-refuelling-station

terms of scalability and long-term integration. In this context, the development of multimodal hydrogen refuelling stations in strategic port locations can act as an enabling measure, allowing infrastructure to be shared across multiple transport modes, supporting existing pilot vessels, and reducing investment risk in situations where maritime hydrogen demand remains limited or uncertain.

The European landscape of maritime hydrogen refuelling infrastructure can therefore be characterised as nascent but evolving, combining a small number of operational facilities with a growing portfolio of pilot and demonstration projects. A further operational benchmark is represented by the hydrogen refuelling installation at the Port of Ostend (Belgium), developed within the ISHY programme, which supports hydrogen bunkering for dedicated service vessels and demonstrates the technical feasibility of port-based hydrogen refuelling under controlled conditions.

Additional initiatives illustrate the geographical diversification of maritime hydrogen refuelling efforts across Europe. In the Mediterranean area, the NatPower H initiative is developing a network of hydrogen refuelling points across Italian marinas and ports, primarily targeting recreational and small commercial vessels (see D.2.3.1). Early operational use has already been demonstrated through the refuelling of the ALBA vessel in Monaco, where green hydrogen at 350 bar was supplied to a hydrogen-powered training vessel. In the Baltic region, the Port of Klaipėda (Lithuania) is advancing a green hydrogen production and refuelling project intended to serve port operations, including the supply of hydrogen to dedicated service vessels. In parallel, industry partnerships between hydrogen infrastructure developers and marine integrators are exploring broader deployment opportunities in selected European ports, supporting the progressive expansion of maritime hydrogen refuelling infrastructure in line with decarbonisation objectives.

3 Use cases in the project area

This chapter presents the economic assessment framework and its application to the three TransH2 pilot cases. Section 3.1 outlines the analytical approach and modelling tools, while Section 3.2 defines the common methodological assumptions, data sources, and cost estimation principles. Sections 3.3–3.5 apply this framework to the Trieste, Split, and Zadar cases, providing site-specific CAPEX and OPEX considerations, demand scenarios or indicative financing pathways.

The economic analysis focuses on the costs associated with the installation and operation of hydrogen refuelling stations, integrating technical and operational inputs with data drawn from relevant studies and literature, and ensuring a consistent basis for comparison across the three project use cases.

3.1 Methodological framework and analytical

The economic analysis adopts a component-level cost estimation methodology calibrated to the specific technical configuration defined in D.2.3.1 and Chapter 2.3: gaseous hydrogen delivery via tube trailer, compression to 350 bar, high-pressure storage, and dual-arm dispensing systems. The analysis is aimed to support transparent and comparable cost analysis across pilot cases and to allow scalability for investment-related evaluations.

To support optimisation of HRS design and the estimation of associated technical and economic parameters, established modelling tools developed by Argonne National Laboratory with support from the U.S. Department of Energy were selected as a basis: the *Hydrogen Refuelling Station Analysis Model* (HRSAM) and its heavy-duty variant, *the Heavy Duty Refuelling Station Analysis Model* (HDRSAM). These models are specifically conceived to simulate hydrogen refuelling station configurations, incorporating cost and performance data for individual components (e.g., compressors, storage, and dispensers) within a defined system boundary that extends from hydrogen supply delivery to the dispenser output. While originally designed for refuelling applications in the light- and heavy-duty vehicle sectors, this analytical foundation can serve as a reference point for evaluating potential station costs in other use cases, including maritime refuelling scenarios.

HDRSAM family of models focus on detailed HRS-specific use cases and incorporate industry sourced default parameters and consider explicit modelling of subsystems such as buffer and cascaded hydrogen storage, compression cooling, and dispensing. HDRSAM includes updated 2022 cost parameters and supports custom hourly hydrogen demand profiles, pressure and volume calculations for storage sizing, energy estimates for compression and cooling, and gaseous HRS topology with buffer storage and cascaded refuelling. This topology is especially flexible for 350 and 700 bar refuelling via electrolysis-based local hydrogen production[15]. Figure 5 illustrates the HRSAM modelling framework and its component-level cost allocation logic.

[15] Minguez B.G., Cardona P., Valiño L., Ocampo-Martinez C., Siemon L., Serra M. (2026), Techno-economic analysis of a renewable hydrogen refuelling station network: The case study of Spain, International Journal of Hydrogen Energy 198 (2026) 152325.

HYDROGEN REFUELING STATION ANALYSIS MODEL (HRSAM)

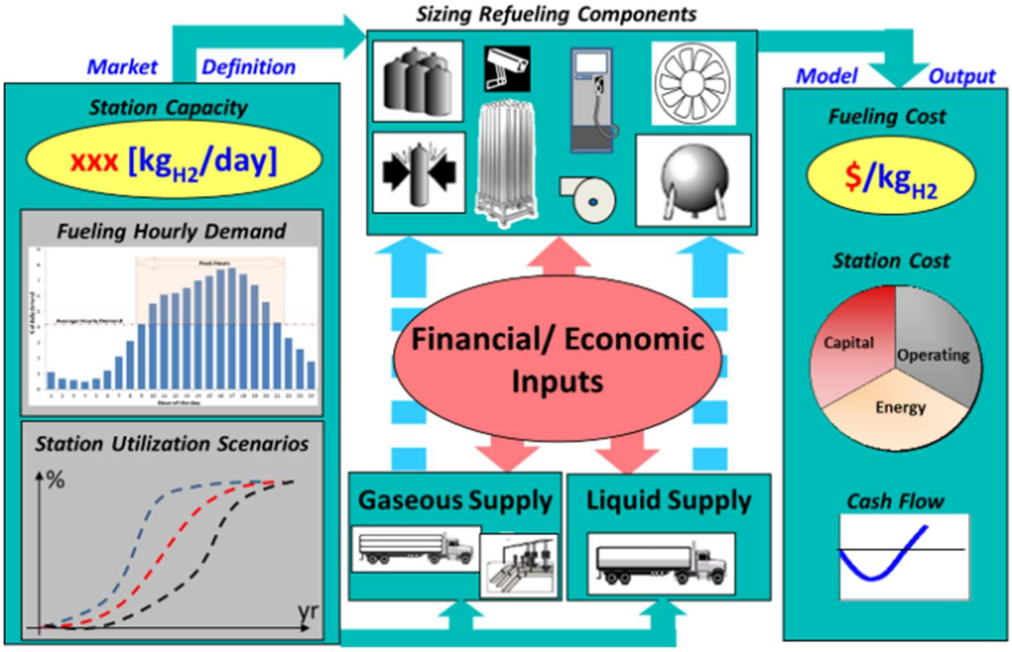

Figure 5 - HRSAM model, Argonne National Laboratory https://hdsam.es.anl.gov/index.php?content=hrsam

3.1.1 Scenario inputs

The following baseline configuration parameters apply to all three use cases, derived from the vessel operational profiles established in D.2.2.3 and the technical architecture defined in D.2.3.1, Chapter 4:

- Station type: delivering gaseous hydrogen;
- H2 source: hydrogen from tube trailer, produced off-site, coming from a local source;
- Dispensing method: refuelling by booster compressor (as described in Chapter 2.3).

3.1.2 Technical and logistics inputs

Table 2 summarizes the common operational parameters for the reference use cases, based on a single vessel operating a regional route with two refuelling cycles per day. These parameters are used to size HRS components and estimate energy consumption, with site-specific adjustments applied in Ch. 3.3–3.5.

Inputs	**Quantity**	**Notes**
Fleet n. of vessel (≈600kg charge)	1	Two charges per day
Max dispensed amount of H2 per vessel per day	≈1.200kg	
Fuelling rate (among 1.8, 3.6 or 7.2 kg/min)	≈4.5 kg/min	Reference 600kg loaded in 135 minutes
N. of loading arms for refuelling	2	
Vessel fuelling operation (Regional route)	≈135 min	Over 300 working days + 20 min port stay
Vessel sailing operation	≈50 min	
On-board storage type	Type 3 or 4	Vessel cylinders
Annual hours of operation – plant	≈1.800h	2 charges of 3 hours per day over 300 working days
Max yearly plant utilization – Reference regional route	≈360 000kg	≈1.200 kg over 300 working days

Table 2 – Technical and logistics inputs

When considering costs and reference indicators for the use case, some references were provided through ERRIN information on connected Horizon Europe call bringing specific inputs on articulated cost targets for multi-purpose hydrogen stations (serving road, rail, airport, and harbour users) — including key CAPEX and OPEX metrics tied to throughput capacity[16]:

- CAPEX targets:
  - 0.65-2.5k€/(kg/d) for 350 bar gaseous H2 stations;
- Annual maintenance costs OPEX:
  - €0.35 / kg (350 bar)
  - €0.50 / kg (700 bar) — roughly consistent with integrated station maintenance costs.
- Hydrogen supply price targets:
  - €2/kg (350 bar), ~€3/kg (700 bar) under future cost-reduction pathways.

This performance-based costing framework is especially useful for comparing different station capacities and pressure regimes and is used to shape EU funding and design criteria.

3.1.3 Fuel rate

As reported by ACER, the average cost of RFNBO (Renewable Fuels of Non-Biological Origin) hydrogen around 8 EUR/kg in the EU, currently remains four times higher when compared to conventional hydrogen from natural gas (just over 2 EUR/kg). Expectations for liquified natural gas (LNG) and CO2 emission allowance price levels favour fossil-fuel hydrogen in the short-term. At the same time, a slow deployment of electrolysers limits economies of scale, delaying the anticipated reductions in related capital costs. Issues connected to renewable electricity costs further undermines these cost-reduction prospects and there is the need of increasing the demand to maintain the sector, focusing on those segments that are most

[16] ERRIN https://errin.eu/calls/demonstration-and-deployment-multi-purpose-hydrogen-refuelling-stations-combining-road-and

capable of absorbing significant amounts of RFNBO hydrogen with limited additional support, such as the mobility sector.

Electricity supply costs, excluding grid tariffs, can represent up to 50% of the levelised cost of renewable hydrogen, with significant regional variation across the EU. Areas with abundant renewable resources and high renewable penetration, such as Spain, already offer favourable conditions for hydrogen production, while further decarbonisation of the power sector will broaden renewable hydrogen opportunities across Europe (ACER, 2025).

Regional cost differentials and their implications for Trieste, Split, and Zadar are discussed in Sections 3.3–3.5.

3.1.4 Transport cost

The cost for hydrogen offtakes includes the cost of transportation as well and, potentially, storage of hydrogen. Hydrogen pipeline networks would represent a cost-efficient solution, but limited deployment of hydrogen networks makes the assessment of the transportation cost difficult. Experience from Germany and the Netherlands, where network developers have updated initial network cost estimates upward, indicates the uncertainties of early cost assessments. Cost estimates for hydrogen transport and storage show wide variability, as they depend strongly on assumptions such as the reuse of existing gas infrastructure and network utilisation rates. As a result, unit transport costs and end-user tariffs are difficult to predict, and similar uncertainty applies to storage needs and their cost impact on final users. Current expected (Denmark) and established (Germany, Netherlands) hydrogen transport tariffs, when compared with hydrogen production costs and literature estimates for pipeline transport (~0.1–1.8 €/kg), suggest that network tariffs currently represent only a limited share of the total hydrogen cost, particularly during the market ramp-up phase. However, these tariffs are positioned at the lower end of estimated transport costs, and a future combination of higher network tariffs and declining hydrogen production costs could make transport a more significant cost component over time (ACER 2025). In addition to production costs, hydrogen delivery by high-pressure tube trailers — a common interim supply method for refuelling stations — contributes to overall cost: techno-economic analyses indicate that transport costs by truck trailer typically remain below approximately €2 per kg for delivery capacities above ~1.25 t/day over distances up to ~300 km, but rise above that level for longer distances, making logistics a non-negligible component of delivered hydrogen cost (see site-specific transport cost analysis in Ch. 3.3–3.5)[17].

In relation to tube trailers as the hydrogen input is no more at 20bar but at 250bar, the required energy to pressurize the hydrogen for the cascade storage filling is significantly lower. The initial investment is lower, because the tube trailer left in place to supply the HRS takes the place of the LP storage (Palazzolo 2021).

3.1.5 Bunkering support vessel

Estimating the cost of a small hydrogen bunkering/support vessel (a ship capable of bunkering hydrogen to short-sea shipping vessels) is challenging because, as of now, there are no widely commercialized hydrogen bunker ships in service (unlike LNG bunkering vessels for natural gas). Consequently, there are no publicly available definitive price tags from shipyards for a hydrogen bunkering vessel per se. However, we can piece together a reasonable cost range and context by comparison with existing and historic data for similar vessels and reported studies.

LNG bunker vessel with 7,000 m3 storage capacity can cost upward of $58 million USD (~€53–55 million) depending on specifications and market conditions[18]. Recently, Fratelli Cosulich Group placed an order with the Chinese shipyard CIMC SOE for a new LNG bunkering vessel of 5,300 dwt, designed to carry 8,000 m³ of LNG and 500 m³ of MGO (Marine Gas Oil), with

[17] Griñán G., Gómez-Acebo T. (2026) Techno-economic analysis of hydrogen transport: comparison between tube trailer and pipeline. Renewable Energy Focus Volume 57, June 2026, 100820

[18] Bureau Veritas (2020) https://marine-offshore.bureauveritas.com/insight/outfitting-world-small-scale-lng-and-bunkering-vessels

delivery scheduled for summer 2023. The company stated that the total investment for the vessel is approximately USD 45 million. Technically, the vessel was equipped with Wärtsilä dual-fuel propulsion and power-generation systems, a Wärtsilä Gas System cargo-handling plant with fiscal LNG/Natural Gas measurement (both quantitative and qualitative), an LNG sub-cooling system to improve boil-off gas management and reduce environmental impacts and cargo losses, and an azimuth propulsion/manoeuvring arrangement with twin bow thrusters for high manoeuvrability in port operations[19].

In relation to the potential transportation of Hydrogen through a dedicated supporting vessel, a dedicated study simulates the cost that integrated CAPEX and OPEX associated, fuel and emission related costs. Other indicators could be reconnected to time for the round trip, loading and unloading operations and safety margins to manage delays. Studies for accurate evaluation should assume parameters as ship speed, crew costs and fuel costs. Studies were performed in the last years on OPEX in United Kingdom and reported operating costs (OPEX) of a small hydrogen bunkering support vessel can be estimated by analogy with small-scale LNG bunker vessels, which share similar operational and safety requirements. Key cost components include crew wages and provisions, maintenance and repairs for the vessel and specialized hydrogen handling equipment, insurance (hull, machinery, and P&I), and port fees and administrative expenses. Additional hydrogen-specific considerations, such as safety compliance, certification, and operator training, may slightly increase OPEX compared with LNG vessels. For a vessel of approximately 35 m in length with ~300 m³ hydrogen capacity, annual OPEX is expected in the range of €0.7–1.3 million, depending on crew size, operating hours, maintenance needs, and terminal call frequency. These estimates reflect

19 https://www.corrieremarittimo.it/shipping/fratelli-cosulich-ordinata-una-nave-per-il-bunkeraggio-di-gnl-valore-45-milioni-di-dollari/

both the scale of the vessel and the complexity of hydrogen transfer operations while drawing on published data from small-scale LNG bunkering operations as a benchmark[20].

The relevance of bunker vessel economics to the Trieste use case is discussed in Ch. 3.3.4.

3.2 CAPEX and OPEX estimation: data sources and calculation methods

A common methodology is structured to provide overview on economic and cost related aspects to be considered for the realization of a hydrogen refuelling station in the targeted use cases. The methodology aims to identify potential constraints to be considered, the inputs needed and the expected outputs. Key assumptions and data are deepening definition and references for CAPEX and OPEX together with additional reference costs that might arise. The assessment on the methodology was carried out through an analysis of existing literature and data available.

3.2.1 Inputs

The following inputs are required for cost estimation and are applied consistently across all three use cases:

- Fuelling demand parameters (daily throughput, refuelling frequency, seasonal variation)
- Cost and of refuelling components as a function of throughput and manufacturing volume.
- Economic and financial parameters (depreciation periods, lifetime assumptions)
- The distance from the production point to the site (critical for transport cost; Caputo et al. 2022 demonstrates cost sensitivity to delivery distance).

[20] UK DISS (2023) Investment into Two 7.500 cbm LNG Fuelled Bunker Vessels for Long-term Time Charter https://ukdiss.com/examples/investment-lng-fuelled-bunker-vessels.php

Inputs	Quantity	Notes
Fleet n. of vessel (600kg charge)	1	Two charges per day
Max dispensed amount of H2 per vessel per day	1.200kg	
Fuelling rate (among 1.8, 3.6 or 7.2 kg/min)	4.5 kg/min	Reference 600kg loaded in 135 minutes
N. of loading arms for refuelling	2	
Vessel fuelling operation (Regional route)	135 min	Over 300 working days + 20 min port stay
Vessel sailing operation	50 min	
On-board storage type	Type 3 or 4	Vessel cylinders
Annual hours of operation – plant	1.800h	2 charges of 3 hours per day over 300 working days
Max yearly plant utilization – Reference regional route	360.000kg	

Table 3 - Inputs for the economic analysis

3.2.2 Outputs

The economic assessment produces an overview on the following outputs to be applied for each use case:

- Levelized cost (EUR/kg) of hydrogen refueling
- Contribution of station components to levelized cost of hydrogen
- Capital, operating and maintenance costs of station components
- Considerations on specific site, inputs affecting costs.

An insight, for the different scenarios, is carried out by defining a set of basic constraints, that in general are the minimum conditions to be satisfied in refuelling station, based on assumptions defined in the hydrogen scenario mentioned in the previous section.

The booster compressor configuration, according to several studies and TCO calculations is the most expensive, in particular in a multi-hose configuration, which is the most common one. Additional hoses for a system with this layout are much more expensive than for the overflow ones.

3.2.3 Key assumptions & data sources

A first assessment on hydrogen refuelling station was made in the case study of ports of Port of Antwerp-Bruges, Duisport & WaterstofNet. Those assessed the lifetime, the energy consumption in kWh/kg, the annual maintenance cost in EUR/kg and the CAPEX in relation to kEUR/kg/day. The CAPEX for one refuelling station was estimated in 680.000 to 1.000.000€ while the OPEX (maintenance and energy) in 472.000€. The data were referred to a simulation of 400kg of H2 per day[21].

Another CAPEX estimation overviewed components, compressor power, O&M operation and management including electricity cost in a dedicated study (8% of the CAPEX) (Caponi et al. 2022).

Data are provided from a 2024 estimate in a study by the Aberdeen City Council, costs from the report are converted in euros in relation to the average exchange rate in April 2024[22]. The study assesses hydrogen refuelling of 250 kg/day but the refuelling capacity can increase up to 680 kg/day without changing equipment but doubling the number of tube trailers deliveries or connected to the site.

In the techno-economic model developed by Perna et al. (2022) for a 450 kg/day hydrogen refuelling station, the hydrogen storage and distribution section (i.e., the downstream HRS block after production) represents a significant standalone investment. Specifically, the paper reports a total CAPEX of about €1 770 k, composed of € 214.2 k for compressor C2, € 1 296.2 k for the ionic compressor system (including high-pressure storage and refrigeration), and € 260 k for the dispenser. The associated OPEX (O&M only) for this section

[21] Clean Hydrogen Partnership (2023), Study on hydrogen in ports and industrial coastal areas, Report 3, Case studies December 2023, www.clean-hydrogen.europa.eu ISBN 978-92-9246-428-8.

[22] ARUP (2024) Aberdeen City Region Hydrogen Refuelling Study, Final Issue Report, Reference: Aberdeen H2 Refuelling Report Final ISSUE v2, Issue 30 April 2024.

is estimated at 50.8 k€/year, split into 17.1 k€/year for compressor C2, 25.9 k€/year for the ionic compressor + storage + refrigerator, and 7.8 k€/year for the dispenser, based on the component O&M percentages adopted in the study[23].

The following tables describes the costs from the Aberdeen study.

Cost detail	Cost amount	Info – quantity required
Cooling unit – compressor chiller	464 000 – 700 000€	4 - unit cost 116 000 – 175 000€
High pressure compressor	1 750 000 – 2 216 000€	2 unit 875 000 – 1 108 000€
Low pressure compressor	1 750 000 - 2 216 000€	2 units 875 000 – 1 050 00€
High pressure storage	350 000 – 465 00€	5 - unit cost 70 000 – 93 000 € 600 kg buffer 350 bar
Low pressure storage	1 050 000 - 1 380 000€	6 - unit cost 175 000 – 230 000€
Dispenser	116 000 – 170 000€	1 or 2 - unit cost 116 000-170 000€
Dispenser chiller (Light duty)	116 000 – 233 000€	1 - unit cost 116 000 – 233 000€
Site air compressor	17 000 – 21 000€	1 or 2 - unit cost 17 000 – 21 000€
TOTAL	**5.6M € – 7.4M €**	
Extra cost - Tube Trailer	466 000 – 700 000€	2 units
Extra cost - Fueling control system	500 000 €	SAE J2601 + mechanical protections
Extra cost - Process integration skid	500 000€	Valves, piping, racks, system integration

Table 4 - Inputs for the economic analysis

3.2.4 OPEX overview

The operational expenditure (OPEX) of a gaseous hydrogen refuelling station (HRS) is mainly driven by energy and hydrogen supply costs, maintenance, and operational services. The largest share typically comes from hydrogen procurement or on-site production electricity consumption, including power for compression, cooling, and dispensing, which can

[23] Perna, A.; Minutillo, M.; Di Micco, S.; Jannelli, E. (2022) Design and Costs Analysis of Hydrogen Refuelling Stations Based on Different Hydrogen Sources and Plant Configurations. Energies 2022, 15, 541. https://doi.org/10.3390/en15020541

represent 40–60% of total OPEX depending on electricity prices and station utilisation. Maintenance and servicing of critical components (compressors, storage vessels, valves, safety systems) account for a significant portion of costs due to high safety and reliability requirements, followed by personnel, monitoring, insurance, and regulatory compliance costs. Additional OPEX items include equipment replacement (wear parts), data and control systems, and periodic inspections, with overall annual OPEX commonly estimated at 3–6% of total CAPEX, strongly influenced by throughput, duty cycle, and local energy tariffs. (Caponi et al. 2021[24], Palazzolo 2021).

Transport

Transport related costs for trucks – that consists of the tractor unit housing the driver's cab and the trailer unit. A track requires and investment of 0.29 M€ - value for 2022. The trailer unit and the capacity are related to the cargo. A compressed gaseous H2 trailer with a truck of 500 kg and CAPEX of 0.57 M€ (value retrieved adjusted for inflation to 2022) is referred. The trucks' lifetime is assumed to be 12 years. Operator 40.000€/y wage with operating working time 45 weeks annually with 8 hours shifts over 5 days. Further operating costs are related to fuel consumption and distance from the port[25]. For a wide description of the site-specific transport cost calculations see Ch. 3.3–3.5.

[24] Caponi R., Monforti Ferrario A., Del Zotto L., Bocci E. (2021) Hydrogen refueling station cost model applied to five real case studies for fuel cell buses, E3S Web of Conferences 312, 07010 (2021), 76° Italian National Congress ATI

[25] Restelli F., Spatolisano E., Pellegrini L.A., Cattaneo S., De Angelis A.R., Lainati A., Roccaro E. (2024) Liquefied hydrogen value chain: A detailed techno-economic evaluation for its application in the industrial and mobility sectors. International Journal of Hydrogen Energy Volume 52, Part B, 2 January 2024, Pages 454-466

Labour cost

The operating labour yearly cost: understand whether include for the monitoring and correct operation of the refuelling station, based on operation time of the terminal together with gross monthly salary on annual basis. The expenses are related to personnel required for plant operations and are determined referring to number of operators required per shift and the average annual wage of an operator es. Italy 40.000 € per year.

Calculation presented in Table 5 is obtained by multiplying the unitary cost (€/man·h) by the total number of labour hours per year. Palazzolo estimates an investment needed of 10.5M €, 1.5m € of Operation and Maintenance, related costs for energy are 7.8€. The data are referred to tube trailers via trucks charged 800 kg/day over the working week and 1520 kg/day over Saturday and Sunday. The costs include production and electrolyzers that contribute significantly to the CAPEX side and to the costs for energy.

OPEX input costs	**Reference unit**	**Details**
Labour cost (on yearly basis) ARUP (2024)	116 000 – 175 000€	
Electricity cost (energy consumed * electricity price) ARUP	9 300 – 11 600	350kW 8h/day
Transport cost (Caponi et al 2021)	0,423€/km + 20% profit	
Transport cost: vehicle leasing cost (Caponi et al 2021)	2 150€/month vehicle	
Insurance	56 000-74 000€	1% of CAPEX
Property taxes	42 000-55 000€	0,75% of CAPEX
Licencing and Permits	56 000-74 000€	0,1% of CAPEX
Operating, maintenance & repairs for compressors	140 000 - 170 000€	4% of compressor capital
Operating, maintenance & repairs for cooling units	9 200-14 000€	2% of cooling unit capital
Operating, maintenance & repairs for storage	14 000-18 000€	1% of storage capital
Operating, maintenance & repairs for electrical components	N. A.	1% of electrical capital
Operating, maintenance & repairs for dispensers	2.300-4.000€	1% of dispensers' capital
Operating, maintenance & repairs for remainder	N.A.	1% of remainder capital
General and administrative expenses	N.A	20% of total labour cost
Extra cost (Rent of the site)	€/(m2*month)	Related to the site

Table 5 - Contributions : Palazzolo 2021, Caponi et al 2021.

Cost of energy

Electricity prices for industrial (non-household) consumers in the first half of 2025 both in Italy and in Croatia were among the highest in the EU, with Italy's average around €0.23 per kWh (including network and non-recoverable taxes) for medium-sized non-household users. In the same period, this price was higher than in many EU countries (e.g., France, Germany, Spain)[26]. The electricity prices drive the operational costs associated with on-site production. As already explained, for this reason green hydrogen production could be a competitive solution for large-scale systems, especially if coupled with low electricity prices. The electricity price could be a critical factor significantly influencing the final LCOH, causing an average 16% increase every 0.02 €/MWh (Caponi, Bocci and Del Zotto 2022).

Cashflow analysis simulation

In relation to cost contributions calculation, it is provided a discounted cash flow analysis for each component, characterized by specific economic parameters and cash flows. The reference inputs are: expected lifetime, that varies from one to the other, and the depreciation time period. This last one is set equal to the default value of 5 years for all the components, while the maximum lifetime values of each equipment are reported in Table 6.

Description	**Depreciation years**
Compressor	10 years
Cooling unit	15 years
Storage	30 years
Electrical components	30 years
Dispenser	10 years
Remainder	30 years

[26] EUROSTAT https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics

Table 6 - Estimates from Caponi (2022) and Palazzolo (2021).

3.3 Use case - Port of Trieste

This section applies the economic assessment framework established in Ch. 3.1–3.2 to the Port of Trieste pilot case, providing context on the port's strategic role, hydrogen demand scenarios, CAPEX and OPEX considerations, and local hydrogen production initiatives that differentiate Trieste from the Croatian pilot cases.

3.3.1 Objectives and scope – reference to maritime traffic, cargo traffic, hydrogen ecosystem and related stakeholders

The Port of Trieste is Italy's largest commercial port on the northern Adriatic and offers a compelling strategic base for potential hydrogen refuelling infrastructure aimed at short-sea shipping due to its existing maritime, logistics, and energy ecosystem. As a Free Port with an extensive layout of terminals and deep-water berths (up to 18m natural draft), Trieste handles a broad mix of cargo including liquid bulk, dry bulk, Ro-Ro (roll-on/roll-off), and container traffic, and serves as a key Mediterranean gateway to Central and Eastern Europe via extensive rail and road networks.

Energy infrastructure, too, positions Trieste well for future hydrogen activity: the port is already a significant energy hub handling large volumes of liquid hydrocarbons, and it is evolving toward green energy production with the Hydrogen Hub Trieste project under construction, featuring a 5 MW electrolyser and solar park aimed initially at land-based transport decarbonisation but laying groundwork for expanded hydrogen supply capacity. For short-sea shipping users and operators, the combination of deep-water access, multi-cargo terminals, strong intermodal links, a competitive operator base, and nascent hydrogen production infrastructure suggest Trieste could serve as a strategic refuelling hub, particularly if port stakeholders integrate hydrogen bunkering into future energy and terminal planning in alignment with shipping decarbonisation pathways.

3.3.2 Possible users and market analysis

Reference to potential scenarios

Trieste's structured port system comprises major container terminals, multipurpose terminals, Ro-Ro terminals and intermodal links that regularly dispatch trains to markets in Germany, Austria, Hungary, and beyond—reportedly with rail modal share above 50% of freight movement, a figure high by European standards. This intermodal efficiency and hinterland connectivity strengthen its attractiveness to operators looking to integrate alternative fuels like hydrogen into short-sea shipping chains, where rapid turnaround and connectivity to inland distribution routes matter for bunkering logistics.

The operator landscape at Trieste is diverse and competitive, with global shipping and logistics players such as DFDS, Grimaldi, HHLA PLT Italy, and Samer & Co. active in container and Ro-Ro services, alongside a network of freight forwarders, terminal operators, and rail partners shaping cargo flows. Given that short-sea operators often require dependable refuelling nodes that tie into broader supply chains, this existing critical mass of maritime and logistics activity could support pilot hydrogen bunkering operations, especially where environmental regulations and decarbonisation mandates (e.g., EU Green Deal standards) drive adoption.

Reference users and ecosystem

- AdSP Port Authority – includes Port of Trieste and Monfalcone
- Port terminals
- Connected logistic infrastructures – hydrogen production
- Connected logistic infrastructures – hydrogen distribution
- Industry actors in the H2 value chain
- Energy producers
- University and research
- Governmental and local governments

Hydrogen demand and price in the area

The hydrogen price on the Italian market is high, the cost of producing renewable hydrogen (RFNBO) in Italy is currently higher when compared with other EU countries, largely due to electricity costs around 110 €/MWh in 2024–2025. Estimates by industry analysts (AGICI) put the production cost at about: approximately 13 €/kg for hydrogen produced via electrolysis with renewable electricity in Italy. By contrast, EU Hydrogen Bank auction averages are significantly lower, typically between 5–9 €/kg[27]. The estimates elaborated within the project are witnessing an estimate on Trieste close to 10 – 11 €/kg. Similar studies focussing hydrogen storage and application for ship purposes in similar ports in Italy highlights how the green hydrogen price could progressively lower in a significant way in the upcoming decades. The reference for the North Tyrrhenian region is to move from 13.7€/kg in the 2023 towards 8.8€/kg in 2030, 4.7€/kg in 2040 and 2.5€/kg in 2050[28].

Overview – Hydrogen plan Trieste	**Quantity**
Daily hydrogen demand	1 200kg
Annual hydrogen demand	360 000kg
Refuelling profile (number of refuelling per day)	2
Flow rate	Aprox 4.5kg/min
Refuelling time	2h 15min
Supply mode	Tube trailer
Supply – distance to be covered	Aprox 35 km
Number of loading arms	2

Table 7 – Hydrogen plan Trieste

27 AGICI https://agici.it/rassegna-stampa-policy-e-strategie-per-il-presente-e-il-futuro-dellidrogeno-e-ora-di-agire/

28 Clean Hydrogen Partnership (2023), Study on hydrogen in ports and industrial coastal areas, Report 3, Case studies December 2023, www.clean-hydrogen.europa.eu ISBN 978-92-9246-428-8

3.3.3 CAPEX considerations on the Port of Trieste

For the Port of Trieste, the capital expenditure (CAPEX) of a gaseous hydrogen refuelling station would be driven mainly by the high-pressure "back-end" equipment required to deliver hydrogen at 350 bar, with port-specific constraints shaping both layout and cost. The overall costs can reconnect to the estimates provided in the use case definition. In Trieste, additional CAPEX drivers would likely include ATEX zoning and fire protection, gas detection and emergency shutdown systems, containerised modularisation (often preferred in ports for faster permitting and relocation), and civil works such as foundations, separation distances, fencing, and protected truck access lanes for tube-trailer unloading. Overall, the Trieste port environment—characterised by limited available space in operational areas, strict safety requirements, and the need for robust logistics interfaces—suggests that CAPEX will be dominated by the compression/storage block and site integration works, while modular container-based solutions can help reduce engineering complexity and support phased scaling as demand grows.

In relation to civil works, constraints and specifics could vary in relation to the area identified and targeted in the port, together with planning and safety requirements set by the port authority. With this regard the preliminary steps already taken at local level through the hydrogen valley and in connection with the cooperation projects can help and facilitate the adoption of a cost-effective solution.

3.3.4 OPEX considerations

For the Port of Trieste, the operational expenditure (OPEX) of a gaseous hydrogen refuelling station would be driven primarily by energy use, hydrogen supply logistics, maintenance, and staffing, with port-specific factors shaping their relative weight. Electricity consumption for compression and station auxiliaries is expected to represent a major recurring cost, and its impact will depend on Italian industrial electricity prices, grid tariffs, and the ability to optimise operations through off-peak usage or partial renewable sourcing. If hydrogen is supplied via tube trailers rather than produced on site, transport and delivery costs will add a significant variable OPEX component, influenced by distance to production sites, trailer utilisation rates, and port access logistics. The potential connection with new hydrogen production areas in Monfalcone and Trieste, could significantly reduce the transport cost (despite the current destination use of Monfalcone is dedicated to bus transport). Maintenance of compressors, high-pressure storage, dispensers, and safety systems, together with mandatory inspections and insurance for a high-risk industrial environment, will contribute a largely fixed annual cost that benefits from higher station utilisation. Labour costs for trained operators and safety personnel, as well as ancillary port expenses such as site services, security, and utilities, further affect OPEX. Overall, the Trieste context—characterised by an energy-intensive port environment, good logistics connectivity, and potentially growing hydrogen demand from maritime users—suggests that achieving sufficient throughput will be critical to diluting fixed OPEX components and maintaining competitive refuelling costs during the early market ramp-up phase.

Transport considerations

Academic and industry modeling studies (e.g., techno-economic hydrogen analyses) provide transport cost benchmarks for gaseous hydrogen delivered by tube trailer: approximately 2.65 €/kg as indicative transport cost by tube trailer per kg of H_2 (assuming central production, transport, compression, etc.). This is separate from production and station dispensing costs and represents only the logistics leg from a producer to a refueling site[29].

Delivery cost for hydrogen transported via diesel trailers, data referring from Italian Ministry of Infrastructure and Transport are mentioned with a connected cost per kilometre of travel

[29] Sgaramella A., Pastore L. M., Lo Basso G., De Santoli L. (2025), A techno-economic analysis of hydrogen refuelling and electric fast-charging stations: Effects on cost-competitiveness of zero-emission trucks. Elsevier, Energy 331 (2025) 137066.

for vehicle above 26 tons is assumed equal to 0.423 € / km. The leasing prices referred to the work of Caponi (2022) is of 2.150€ month.

Production

In relation to concrete measures implemented in the target area there is concrete hydrogen project realized in the Lisert area in Monfalcone (approximately 35km from Port of Trieste) that goes well beyond early concept work: it is a fully specified renewable hydrogen production and refuelling station integrated with greening of local public transport. At the core of this initiative is the local transport company - Azienda Provinciale Trasporti (APT) of Gorizia (part of the TPL FVG S.c.ar.l consortium, handling local road, rail and maritime transport services) with a project in the Lisert industrial area, which has received European NextGenerationEU (PNRR) and regional funding PREPM-TPL (approved with Approved by Regional Executive Resolution No. 588/2023) to build a complete hydrogen production and dispensing facility for buses. The planned installation includes a 1 MW electrolyser that will produce renewable hydrogen locally using electricity — in part supplied by an integrated 1.6 MW photovoltaic park — with an approximate production capacity of about 400 kg of hydrogen per day. This capacity is sized to ensure the full supply of the hydrogen bus fleet envisaged by the PREPM and, as a priority, any potential expansions thereof, as a functional infrastructure for public local transport (TPL) services. Any additional production surplus may also be allocated to support an initial fleet of low-emission buses (around eight hydrogen fuel-cell buses serving Monfalcone, Staranzano and Ronchi dei Legionari) and also to support light- and heavy-duty vehicles thanks to multiple dispensing points. The station's hydrogen handling system is designed for typical transport pressures: two hydrogen dispensers operating at 350 bar (for heavy-duty vehicles) and one at 700 bar (for lighter vehicles), which reflects industry standards for vehicle refuelling and allows flexibility for different vehicle classes[30].

The project's financing and delivery parameters are also well defined: the overall implementation is backed by around €9.4 million–€11.2 million in EU and regional co-funding. Construction works and deployment are performed, making it one of the first fully integrated green hydrogen refuelling stations in the Friuli-Venezia Giulia region and a potentially a best practice in hydrogen applied to transport nodes.

The technical terms are summarized below:

- Electrolyser power: ~1 MW (renewable hydrogen production);
- Production capacity: ~400 kg of H_2 per day;
- Dispensers: 2 × 350 bar + 1 × 700 bar;
- Renewable energy integration: 1.6 MW photovoltaic park;
- Primary target users: hydrogen buses for local public transport.

Furthermore, there is a defined hydrogen production site planned in the Port of Trieste as part of the North Adriatic Hydrogen Valley (NAHV) initiative. At the core of this development is the Hydrogen Hub Trieste, a renewable hydrogen production, storage and distribution facility being realised under the leadership of AcegasApsAmga (part of the Hera Group) with support from Italy's National Recovery and Resilience Plan (PNRR) and the Horizon Europe Clean Hydrogen Partnership. This hydrogen hub will be constructed on an industrial site adjacent to the HestAmbiente waste-to-energy plant made available by the Port System Authority of the Eastern Adriatic Sea — a location chosen specifically for industrial symbiosis, utilising water from the adjacent plant for electrolysis to enhance resource efficiency. The facility is designed with a 5 MW electrolyser powered in part by a 4.8 MW photovoltaic park, with the renewable electricity from the solar installation directly feeding the electrolysis

[30] https://www.aptgorizia.it/apt-news/presentato-ecomove-il-progetto-di-green-mobility-di-apt-gorizia/

process that splits water into hydrogen and oxygen. When fully operational, expected around 2026, the Hydrogen Hub Trieste is projected to produce approximately 370 tonnes of green hydrogen per year (equivalent to about 1.000 kg per day) from renewable sources. The hub is meant to cover multiple parts of the hydrogen value chain — from production and storage to distribution — laying the foundation for a local renewable hydrogen market serving transport operators (road, rail, and logistics), industrial end-users, and potentially port activities that could include refuelling for short-sea shipping in the longer term. The initiative is one of the flagship pilot projects within the NAHV, which is a transnational European hydrogen valley spanning Italy (Friuli-Venezia Giulia), Slovenia, and Croatia and involving partners across pilot projects. This broader valley aims to produce over 5.000 tonnes of renewable hydrogen annually by 2029 and to establish an integrated ecosystem of production, storage, distribution and use that can support decarbonisation across multiple sectors.

The Hydrogen Hub Trieste project in the Port of Trieste is characterised by:

- Renewable hydrogen production via a 5 MW electrolyser and supporting 4.8 MW photovoltaic park;
- Annual green hydrogen output of about 370 tonnes;
- Industrial symbiosis with an adjacent waste-to-energy plant, recycling process water;
- Part of the North Adriatic Hydrogen Valley (NAHV) cross-border project targeting 5.000 tonnes/year by 2029;
- Funding from PNRR (€15.8 M) and Horizon Europe (€1.5 M), totalling over €20M;
- Timeline targeting operational readiness by 2026.

This site therefore establishes a strategic renewable hydrogen production node in Trieste's port area that could serve as an anchor for future hydrogen refuelling infrastructure for transport and logistics, including maritime users if additional distribution and bunkering systems are connected to the hub's output.

3.4 Use case - Port of Split

This section applies the economic assessment framework established in Sections 3.1–3.2 to the Port of Split pilot case, providing context on the port's role in Croatian maritime transport, hydrogen demand scenarios, CAPEX and OPEX considerations, and supply chain constraints that differentiate Split from the Trieste case.

3.4.1 Context and maritime traffic profile–

Port of Split is best understood as Croatia's leading passenger hub and one of the most active ferry ports in the Adriatic, rather than a heavy cargo gateway. It sits on the central Dalmatian coast and functions as the main maritime node connecting the mainland city of Split with the islands (Brač, Hvar, Vis, Šolta, Korčula, etc.), while also serving international ferry routes and seasonal cruise traffic. Operationally, the port handles a mix of Ro-Pax ferries, fast catamarans, cruise ships, yachts and small craft, fishing vessels, and a limited amount of general cargo activity. Compared with Rijeka (Croatia's primary cargo and container port), Split's cargo role is smaller and more local, but its passenger throughput is nationally strategic due to tourism and island connectivity.

Split's port area is organised around several functional zones. The central harbour contains the main passenger terminal and ferry berths, where most domestic and international passenger flows are concentrated. This zone is built for fast embarkation/disembarkation, vehicle queuing for Ro-Ro ramps, and pedestrian access from the city. The port also includes dedicated or semi-dedicated areas for cruise berthing, typically close to the urban waterfront (which is commercially attractive but operationally tight). On the cargo side, Split has limited cargo quays and storage, supporting smaller consignments and regional supply needs rather than large distribution logistics. There are also berths for fishing and service craft, plus nautical berths connected to the wider Split marina ecosystem. Split has 28 berths and can accommodate vessels up to roughly 250 m LOA with draft around 7.9 m is consistent with its positioning: capable for medium cruise ships and major ferries, but not designed as a deep-draft bulk or mega-container port. These constraints naturally shape the vessel mix and keep the port's cargo profile modest.

Split benefits from strong road access through the national motorway and trunk road network (often referenced via the E65/E71 corridors), which is critical for passenger vehicles, tourist coaches, and regional distribution. The port also has a rail connection, but the line is operationally limited for modern freight logistics: capacity, geometry, and service patterns mean that rail plays a minor role in cargo flows compared with road transport. As a result, Split's port logistics are generally road-dominant, which fits its passenger and Ro-Pax character but is less competitive for heavy cargo growth

3.4.2 Demand estimation and refuelling scenarios

The port's activity is dominated by passenger transport, with high seasonality: summer peaks are driven by tourism, island travel, and cruise calls, while winter traffic is sustained mainly by essential island services. The ferry segment includes both conventional Ro-Pax ferries (car + passenger) and high-speed passenger craft. Split is also a visible cruise destination on Adriatic itineraries, typically handling medium-sized cruise vessels rather than the very largest ships, reflecting local berth and draft constraints. In addition, the port supports nautical tourism through yacht and marina activity, and it has a role in the local fishing economy, including berthing and landing support. Cargo exists mainly as small-scale coastal/general cargo, often linked to local construction supply chains and island provisioning, rather than large-scale container throughput.

Hydrogen demand and price in the area

Split's passenger ferry and cruise traffic make it a promising site for hydrogen refuelling or hydrogen-powered vessel support, especially for shorter ferry routes and coastal shipping. A smaller hydrogen station capable of about 1 200 kg/day could serve ferries and coastal ships that return frequently, aligning with demand cycles and shorter-range needs.

Hydrogen bunkering could also support emerging low-emission initiatives for passenger vessels in the Adriatic region.

Drivers for hydrogen demand:

TransH2 route analysis and pilot models could help define fleet schedules where hydrogen propulsion or hybrid solutions are feasible. Split's strong traffic in passenger ferry and cruise segments means operators may explore hydrogen to meet upcoming fuel decarbonisation targets.

Overview – Hydrogen plan Split	**Quantity**
Daily hydrogen demand	1.200kg
Annual hydrogen demand	360.000kg
Refuelling profile (number of refuelling per day)	2
Flow rate	Aprox 4.5kg/min
Refuelling time	2h 15min
Supply mode	Tube trailer
Supply – distance to be covered	Aprox 150km Zadar and 400km Rijeka
Number of loading arms	2

Table 8 - Hydrogen plan Split

3.4.3 CAPEX considerations

For a hydrogen refuelling station (HRS) in Split supplied by gaseous hydrogen tube trailers, the CAPEX is primarily driven by the station hardware needed to receive, compress, store and dispense hydrogen. The station requires a robust unloading interface, compression to 350 bar, high-pressure storage, dispensing equipment, and the associated safety and control systems. In practice, the station CAPEX in Split would be similar to other Adriatic ports, although local factors such as available space, civil works, and safety separation distances may increase costs depending on where the HRS can be installed within the port.

3.4.4 OPEX considerations

By contrast, the OPEX in Split is much more sensitive to the trailer-based supply chain, because long-distance delivery tends to become a dominant recurring cost. If hydrogen must be loaded from other distant production hubs, the delivered cost will increase due to truck mileage, driver hours, ferry/ro-ro logistics where applicable, trailer utilisation rates, and the low payload efficiency of gaseous hydrogen transport. In addition to transport, Split's OPEX would include electricity for compression and auxiliaries, maintenance of compressors/storage/dispensers, periodic inspections and insurance, and staffing. Overall, compared with a port located closer to hydrogen production (e.g., North Adriatic), Split faces a structural disadvantage on OPEX because tube-trailer delivery over long distances can materially increase the €/kg cost of hydrogen during the early ramp-up phase, making throughput and logistics optimisation critical for economic viability.

For the Port of Split, a potential gaseous hydrogen refuelling station would incur various operational cost impacts shaped by local hydrogen infrastructure development and supply logistics. Croatia has recently launched funding schemes to support hydrogen refuelling stations along major transport corridors, including east-west connections that may affect Split's urban and port mobility network, with at least six publicly accessible HRS planned by 2026 with minimum capacities of about 100 kg/day under national subsidy programmes. Because hydrogen supply in Croatia is still emerging — with no large commercial production yet in place and plans for electrolyser rollout only beginning (e.g., a 10 MW green hydrogen plant planned near Rijeka for 2026) — the cost of hydrogen delivery (likely by truck trailers in the near term) would form a significant portion of OPEX, driven by delivery distance, trailer utilisation, and logistics coordination with local producers or suppliers. Taken together, these factors suggest that while fixed operational costs (maintenance, labour, safety compliance) are scalable with utilisation, hydrogen procurement and transport costs for a nascent supply chain around Split will be key drivers of OPEX in the early phases of station operation, particularly until on-site or nearby renewable production becomes established.

Cost of energy labour

Labour is a relevant fixed cost because safe operation typically requires trained personnel for trailer reception, connection/disconnection, monitoring of dispensing operations, emergency readiness, and routine inspections; even if the station is partially automated, staffing cannot be eliminated in a port environment. Compared with Northern Europe, Croatian labour costs are generally lower, which can help reduce fixed OPEX, but the need for qualified operators (and potentially 24/7 coverage if aligned with ferry schedules) can still make staffing a material annual cost.

Energy costs are also critical because electricity is needed for compression to 350 bar, cooling/temperature compensation, and station auxiliaries; in Split, the impact will depend on Croatian industrial electricity prices, network charges, and whether the operator can use off-peak operation strategies. When combined with the long-distance trailer supply (potentially from Northern Italy or other distant hubs), these OPEX factors mean that Split's refuelling cost is likely to be particularly sensitive to utilisation rate: high throughput is essential to dilute fixed labour and maintenance costs and to reduce the €/kg impact of transport and electricity consumption per unit of hydrogen dispensed. In terms of energy costs, Croatia has among the higher industrial electricity prices in the EU, with non-household electricity averaging around €0.20–0.24 per kWh for business and industrial consumers in recent data, a level above many other EU peers and reflecting high non-commodity and network charges

Production

From a production and policy perspective, Croatia's national hydrogen strategy (*Hrvatska Strategija za Vodik do 2050*) aims to develop a domestic low-carbon hydrogen economy through phased electrolysis roll-out and renewable integration. The strategy targets roughly 70 MW of electrolyser capacity by 2030 to support mobility and industrial demand, with further expansion planned toward 2050, and includes provisions for production, storage, transport and application of hydrogen.

Constraints

Port of Split's main constraint for developing a hydrogen refuelling station is that it is fundamentally a dense, space-limited passenger port embedded in the city waterfront, rather than an industrial logistics port, meaning hydrogen infrastructure must be fitted into an area already dominated by Ro-Pax ferry ramps, vehicle staging, pedestrian passenger flows, cruise operations, and urban access. While hydrogen is technically feasible, the port's high public exposure (tourists, commuters, cruise crowds) raises the consequence profile of any hazardous installation, making regulators and the port authority likely to require conservative safety zones, separation distances, controlled access, and hazardous-area zoning, which are difficult to achieve close to the main terminals. In addition, Split's constrained hinterland access and peak-season congestion complicate hydrogen supply logistics (especially if delivered by tube trailers or liquid hydrogen trucks), while on-site electrolysis would shift the burden to electric grid capacity and utility upgrades, which may already be pressured by summer demand and port electrical loads. These factors point toward a phased approach in Split—starting with small-scale, modular systems (potentially truck-to-ship or remote storage feeding a controlled dispensing point) located away from the busiest passenger areas—because large, permanent hydrogen storage and compression facilities near the central harbour would face significant permitting, space, operational, and public-acceptance barriers.

3.5 Use case - Port of Zadar

This section applies the economic assessment framework established in Sections 3.1–3.2 to the Port of Zadar pilot case, providing context on the port's role in Croatian maritime transport, hydrogen demand scenarios, CAPEX and OPEX considerations, and supply chain constraints that differentiate the port.

3.5.1 Context and operational profile – maritime traffic, cargo traffic, hydrogen ecosystem and related stakeholders

Zadar County is framed in project strategy as a strong pilot region for hydrogen-powered maritime routes connecting the Croatian mainland and islands due to its geographic position along the Adriatic and its role as a domestic and international connector. According to the Croatian Ministry of Sea, Transport and Infrastructure, the Port of Zadar records approximately 2.7 million passengers and 430,000 vehicles per year and more than 300,000 tonnes of cargo, of which about two-thirds is liquid petroleum products. The same source notes that passenger and vehicle traffic growth intensified with the start of operations of the new passenger port in Gaženica. Within this context, the Port of Zadar (Gaženica) is a major passenger and ferry port developed to relocate ferry traffic from the historic city port area; it supports island, coastal and international ferry traffic, cruise calls and RO-RO operations. The port authority reports that the terminal started operating in April 2015 (international ferry traffic from July 2015) and that approximately 1,420 m of coastline was built to provide 12 berths within an approximately 13.5 ha port area; the passenger terminal building was ceremonially opened in 2019..

This positioning is important because it anchors Gaženica's pilot relevance not only in abstract decarbonisation ambitions, but also in the operational reality of passenger and island connectivity that defines the regional maritime system. Island connectivity is served through frequent local ferry services, including routes departing from the Gaženica ferry terminal (e.g., Gaženica–Ošljak–Preko), while some passenger-ship services to the same destination depart from the city port (Zadar–Preko), indicating a split operational pattern across the Zadar port system

Although Gaženica's primary functional role is domestic and regional passenger transport, the TRANS H2 framework requires that pilot use cases contribute to a coherent cross-border feasibility narrative. In that sense, Gaženica provides a reference case for how hydrogen refuelling readiness can be developed in a port with strong passenger flows, high seasonality, and strict operational constraints. Operational constraints relevant for any future alternative-fuel logistics are reflected in port operating rules, including mandatory pilotage for vessels above 500 GT and advance ETA notification requirements (24 hours before arrival, and at least 48 hours when arriving with dangerous cargo). This has direct value for interoperability, because early hydrogen bunkering concepts must be designed so they can be compared across ports and transferred to similar Adriatic contexts where passenger operations and public interfaces shape what is feasible in early deployment stages.

At use-case level, the Gaženica system should be understood as a functional cluster comprising the passenger terminal and ferry berths handling intensive vehicle loading and unloading cycles, dedicated or shared berthing capability for cruise calls, and an adjacent cargo port area with storage and tank capacities. The multipurpose terminal concept described by the port authority is located between the old cargo port and the New Passenger Port in Gaženica, which underlines the importance of maintaining clear separation and controlled interfaces between passenger operations and any emerging fuel logistics activities during early hydrogen deployment phases.

The cargo port area in Gaženica includes extensive logistics and storage interfaces: a port authority document describing the multipurpose terminal highlights open storage areas of 150,000 m², covered warehouse space of 30,600 m², and a liquid cargo tank capacity of 75,000 m³. In addition, port operating instructions define operational parameters for cargo berths (e.g., cargo berth/berths and gats) and associated safety and service requirements. . These parameters are important for hydrogen infrastructure feasibility because they indicate the presence of industrial interfaces and potential space for staged installations, the existence of logistics patterns compatible with periodic deliveries, and the need to manage interfaces between passenger operations and any fuel handling area through clear zoning and access control.

Possible users and market analysis

Port of Gaženica is the main passenger and ferry terminal within the Port of Zadar system, serving island, coastal and international ferry traffic, cruise calls, and RO-RO traffic, and it is located next to the cargo port area (Teretna luka Gaženica). The passenger terminal was developed to relocate ferry operations from the historic city centre, and it started operating in April 2015 for domestic ferry services and cruise vessels, and from early July 2015 it also handles international ferry traffic.. In practical terms, the use-case is characterised by high-frequency passenger and vehicle flows linked to mainland-island connectivity, combined with a seasonal cruise profile that concentrates large passenger peaks in limited time windows. Port authority traffic statistics indicate sustained high-volume passenger and vehicle flows in the Zadar passenger port system over 2017–2022 (e.g., total passengers rising from 2,525,107 in 2017 to 2,581,746 in 2022; total vehicles from 437,437 to 574,801). Cruise traffic monitoring published by the port authority shows that Gaženica accounts for the dominant share of cruise passengers within the Zadar port areas (e.g., by 31 August 2025: 163,693 passengers on 82 cruise calls in Gaženica).

Annual cargo throughput in Teretna luka Gaženica provides a quantitative indicator of cargo activity relevant for SIMOPS, safety zoning and traffic windows. Port authority statistics for 2017–2022 report an increase from 313,160 t (2017) to 542,187 t (2022), with intermediate values 324,491 t (2018), 426,170 t (2019), 407,810 t (2020) and 429,947 t (2021). This baseline is useful for assessing the potential operational interfaces (SIMOPS constraints, safety zoning and traffic windows) relevant to siting and phasing of hydrogen bunkering/refuelling infrastructure in proximity to cargo handling areas.

Hydrogen demand and price in the area

In addition to the broader European/global benchmark, the perceived need for a hydrogen filling/bunkering solution in the Port of Gaženica should be supported by national and local pipeline signals as well as by the regulatory baseline that sets minimum infrastructure coverage and capacity requirements. At EU level, the Alternative Fuels Infrastructure

Regulation (AFIR) sets minimum requirements for publicly accessible hydrogen refuelling stations along the TEN-T core road network by 2030, including maximum spacing and minimum daily capacity, and requires at least 700-bar dispensing for interoperability. At national level, the implementation summary of the Croatian Hydrogen Strategy reports NRRP funding for six hydrogen refuelling stations by 2026 and proposes a wider roll-out concept (e.g., 16 stations along TEN-T routes and urban hubs), which provides a policy pipeline signal even though maritime supply chains remain to be defined site-specifically. At local level, the City of Zadar's 2025–2027 Energy Efficiency Action Plan includes the preparation of a feasibility study for installing a hydrogen refuelling station in the Gaženica port area, primarily intended for hydrogen-powered vessels; it also references Interreg Italy–Croatia (TransH2) as the foreseen co-financing framework and lists an indicative investment of EUR 10,000 for the feasibility study. Such evidence helps bridge strategy and implementation by showing whether Croatia has dedicated funding and rollout plans, what minimum capacities and timelines are mandated at EU level, and whether there is a local policy measure explicitly preparing the ground for a station in Gaženica (e.g., a planned feasibility study).

For the Gaženica use case, the most credible near-term hydrogen demand driver is the domestic passenger service system that connects Zadar with the surrounding islands, where Gaženica functions as the principal passenger and ferry port for island connectivity. Within this system, the Zadar–Preko connection is used as the demand reference because it is well documented and provides an operational rhythm that can be translated into refuelling frequency and port-stay windows; publicly available schedules distinguish a boat service departing from the city port of Zadar and a ferry service departing from the Gaženica ferry terminal. . The ship feasibility study for the Croatian pilot routes provides route geometry, sailing time, voyage counts by season, and a baseline profile of the currently operating ship, and these data are summarised in Table 9 and in Table 10.

Parameter	Value	Unit	Comment
Route distance (port-to-port)	3.3	NM	Zadar to Preko (Ugljan Island).
Voyage time (port-to-port)	26	min	Includes manoeuvring and berthing steps in the reference breakdown.
Annual number of voyages (one-way)	6 802	voyages/year	Sum of off-season, low season and high season in the 2023 schedule dataset.
Peak weekday voyages (high season)	22	voyages/day	Monday-Friday in high season.
Maximum daily sailed distance	72.6	NM/day	High season Monday-Friday maximum reported in the feasibility study.

Table 9 – Operational characteristics of the passenger line Zadar-Preko (Line 409) used as a demand reference for the Gaženica use case[31]

For sizing an early-phase port-side solution, the peak weekday in high season provides an indicative upper bound for daily refuelling service capacity. Based on the reported high-season weekday utilisation (22 voyages and 9 hours 10 minutes of navigation time), the implied peak-day diesel consumption is approximately 4,501 litres. Under the same conversion assumptions, this corresponds to an indicative hydrogen requirement of about 0.67 to 1.34 tonnes per day, depending on the adopted propulsion efficiency assumption. These values are not intended to replace detailed ship design calculations, but they provide a defensible range for feasibility-level storage buffering and delivery logistics.

[31] Source: ZEAS Project. (2024). D2.1 Ship feasibility study (project deliverable). Provided as supporting input: "D2.1_Ship_feasibility_study.pdf".

Overview – Hydrogen plan Zadar	Quantity	Details
Daily hydrogen demand	1 240 kg/day	Calculated from the annual demand assuming 360 operational days
Annual hydrogen demand	432 000kg	
Refuelling profile (number of refuelling per day)	2	Implies app. 600 kg per refuelling event
Flow rate	3.6–7.2 kg/min	Up to 3.6 kg/min for standard fueling protocols, while 7.2 kg/min corresponds to high-flow cases where both vehicle and station are designed for higher flow
Refuelling time	app. 83–167 min	Calculated for app. 600 kg/event: 600/7.2 = 83 min to 600/3.6 = 167 min
Supply mode	Tube trailer (CGH_2)	Typical payloads: conventional tube trailer 300 kg; high-pressure (e.g., 500 bar); tube trailer up to 1,000 kg per delivery. For 1,200 kg/day, this implies roughly 2 deliveries/day (1,000 kg case) or 4 deliveries/day (300 kg case).
Supply – distance to be covered	App 232 km one-way (Rijeka scenario)	Supply from the Rijeka direction. Driving distance Rijeka–Zadar is reported at app. 232 km (one-way)
Number of loading arms	2	Consistent with 2 refuelling events/day

Table 10 – Overview of Hydrogen plan Zadar

3.5.2 CAPEX considerations

Capital expenditures (CAPEX) and OPEX at Zadar are also shaped by its relative isolation from hydrogen production hubs. Zadar faces high logistics costs due to long delivery routes, while elevated electricity prices increase compression expenses. Labour costs are lower than in Western Europe, which partially offsets staffing costs, but the lack of nearby hydrogen production underscores the importance of operational strategies to improve economics. These include maximizing throughput utilisation and securing long-term supply agreements or eventually integrating local electrolysis projects in Dalmatia.

In Croatia, hydrogen is presently produced and utilised predominantly within the Rijeka Oil Refinery and for ammonia production at Petrokemija Kutina, while the national implementation study also outlines the deployment of hydrogen refuelling stations along TEN-T routes and in urban nodes, including NRRP-supported investments for six hydrogen refuelling stations by 2026. In parallel, the Zadar local action framework foresees the preparation of a feasibility study for a hydrogen refuelling station in the port area of Gaženica, which strengthens the local pipeline signal for early-phase implementation.

The analysis carried out for the Gaženica port highlights that deploying a hydrogen refuelling station requires balancing CAPEX, operational complexity, logistics, safety, and scalability. Mobile GH2 trailers offer low-to-medium upfront investment with limited civil works, making them ideal for early pilot phases, but they generate a high number of daily deliveries due to low payload, increasing traffic and operational constraints in a passenger-dense port. LH2 trailers require higher capital and specialized cryogenic handling but reduce delivery frequency and operational conflicts, offering a flexible intermediate solution. Fixed installations demand the highest upfront CAPEX for permanent storage, compression, and integrated systems, but they provide a scalable platform with lower marginal costs per refuelling event once established. Safety and operational governance are critical across all options: mobile units must maintain strict segregation from passenger flows and adhere to high-pressure handling protocols, while cryogenic or fixed systems require complex permitting, authorisations, and ongoing compliance procedures. A phased deployment strategy would be recommended, beginning with GH2 trailers, potentially transitioning to LH2 units, and ultimately moving to fixed infrastructure as demand stabilizes and supply chains mature. Financial modelling should reflect staged CAPEX, OPEX per delivery, staffing, downtime risk, and upgrade triggers based on hydrogen throughput and delivery cadence, allowing the port to optimise investment while respecting safety and operational constraints.

Scaling beyond the reference route should be treated as conditional and triggered only when there is credible confirmation of recurring demand. In the Gaženica context, the wider ferry passenger throughput exceeds 1.5 million passengers per year in the published port statistics for recent pre- and post-COVID years, which suggests that a larger fleet base exists for medium-term conversion. However, for the purposes of the joint investment plan, the recommended approach is to use the reference-route demand range as the minimum viable throughput case for Phase 1, and to define Phase 2 and Phase 3 triggers in terms of additional vessels committed to hydrogen operation, confirmed operational procedures in the port environment, and a sufficiently stable regulatory and authorisation pathway for fixed assets.

3.5.3 OPEX consideration

For the Port of Zadar, operating expenses (OPEX) for a hydrogen refueling station (HRS) are heavily shaped by hydrogen logistics, energy costs, maintenance, and regulatory obligations. In Croatia, hydrogen production and use is currently concentrated in a limited number of industrial sites (e.g., Rijeka Oil Refinery and Petrokemija Kutina), therefore an early Gaženica HRS concept is expected to rely on off-site supply and road delivery logistics until a local supply chain is established. A major recurring cost stems from hydrogen delivery via tube trailers, as local production capacity in Croatia remains limited. A Rijeka-based delivery scenario implies an approximate driving distance of 232 km one-way, which affects trailer utilisation, driver time, and delivery scheduling and raise per kilogram delivery costs compared with Northern Adriatic ports. Electricity for hydrogen compression is another significant variable, with Croatian industrial rates (€0.20–0.24/kWh) increasing energy-related OPEX. Additional expenses include routine maintenance of compressors, storage vessels, dispensers, and mandatory inspections, alongside salaries for trained hydrogen-handling personnel. Port-specific costs, such as insurance, land use fees, safety compliance, and emergency preparedness, further add to the station's annual operating budget. Also, port operating rules include advance ETA notification requirements, with stricter notice (at least 48 hours) when arriving with dangerous cargo, which may affect delivery planning and standby/availability costs for hydrogen logistics.

Constraints, production and plans

The principal uncertainty for demand in the Gaženica use case is the timing and technical configuration of hydrogen vessel deployment. For financial calculations in the joint feasibility study, it is nevertheless useful to provide an indicative throughput range derived from the existing diesel baseline, clearly labelled as an interim modelling input that must be revised once the propulsion concept and efficiency are confirmed. The reference ship operating line 409 route is reported with a diesel consumption of 491 litres per hour and a voyage time of 26 minutes. Using standard net calorific values to convert fuel volume to energy and to an equivalent hydrogen mass, the analysis carried out provides annual and peak-day indicative hydrogen demand ranges for two bounding cases: an efficiency-improved fuel cell configuration and a conservative case with limited or no efficiency gain.

The Port of Gaženica phased hydrogen refuelling plan translates quantified demand and concept options into a structured, conservative investment pathway that balances operational feasibility, safety, and capital efficiency. The approach could be organised into three phases—Pilot/Demonstration, Early Deployment, and Scale-Up—allowing the port to progressively integrate hydrogen logistics into its day-to-day operations while mitigating risks associated with space, passenger flows, and regulatory compliance. In Phase 1, mobile GH2 trailers establish a minimum viable capability, providing operational learning, validating procedures, and generating investment-grade data with low upfront CAPEX and minimal civil works. Phase 2 consolidates early operations into repeatable, semi-permanent infrastructure, optimising delivery logistics, scheduling, and access control, and introducing LH2 supply where operational benefits justify the transition. Phase 3 scales to permanent port-side installations, including larger on-site storage, compression, and integrated transfer systems, once demand, permitting, and governance conditions support higher-capital assets. The plan explicitly considers constraints at Gaženica, including limited quayside space, high passenger and ferry traffic and seasonal congestion, urban waterfront interfaces, and the need for controlled scheduling and compliance procedures for any dangerous-goods deliveries (e.g., advance notice requirements). Safety and operational governance remain central throughout, with incremental implementation of emergency shutdowns, exclusion zones, monitoring, and staff training to align with maritime and urban regulatory frameworks. By structuring investments into modular CAPEX building blocks and linking each phase to evidence-based decision gates, the plan provides flexibility to adapt to evolving demand, minimise risk, and integrate Gaženica into the broader Joint Investment Plan for TRANS H2, enabling a phased, scalable, and financially disciplined hydrogen refuelling solution that can be replicated or compared across other Adriatic ports.

4 Investment feasibility and funding pathways

An evaluation about the investment feasibility of the three TransH2 pilot cases should combine EU instruments, national/regional funding, and private capital in configurations tailored to each site's specific characteristics, supply chain readiness, and institutional context. These configurations are illustrative and should be refined based on actual funding call eligibility, project scale, and stakeholder agreements.

This chapter provides a structured overview of available financing mechanisms for hydrogen refuelling station deployment in port environments that could be applied to both TRANSH2 countries, spanning EU-level instruments, national frameworks, and private capital sources. Section 4.1 establishes the overall financing landscape. Section 4.2 details European funding instruments including the Innovation Fund, AFIF, and IPCEI schemes. Section 4.3 examines national and regional funding frameworks in Italy and Croatia. Section 4.4 reviews private finance options and public-private partnership structures. A specific detail is provided at national and local level when deepening the specific use cases applied to the sides identified for HRS location.

Public funding for hydrogen technologies is increasingly moving from broad headline announcements to committed project allocations, signalling a maturation of policy support for the hydrogen economy. According to the Global Hydrogen Review 2025 by the International Energy Agency, total announced public funding for hydrogen has declined from nearly USD 100 billion in the previous reporting period to around USD 38 billion in 2025, not because support is waning but because much of the earlier announced funding has now been allocated to specific projects and programmes. Investment in hydrogen production alone reached USD 4.3 billion in 2024, reflecting active capital deployment on the ground. A large part of the prior year's higher figure was due to multiyear initiatives such as the Important Projects of Common European Interest (IPCEI) in the European Union, Carbon Contracts for Difference (CCfD) schemes for industrial use in Germany, and contracts for difference (CfD) for hydrogen production in Japan, which collectively accounted for nearly USD 35 billion of previously announced funding. While no major new funding rounds for these programmes were announced in 2025, all have progressed: Germany has disclosed results from its first CCfD round and obtained European Commission approval for a second round in March 2025; Japan and France initiated their first CfD rounds; and Finland, Italy and Spain have begun allocating IPCEI funds to specific hydrogen projects. Advanced economies account for almost 90 % of the USD 38 billion in funding announced or updated since the previous review, reflecting the predominance of instruments such as grants, auctions and CfDs in these markets. By contrast, emerging economies more commonly deploy tax incentives, fixed premiums, or simplified administrative procedures to support hydrogen deployment; India's Strategic Interventions for Green Hydrogen Transition (SIGHT) programme — targeting electrolyser manufacturing and ammonia production — is a key example of public funding from emerging markets.

In 2026 Hydrogen Europe Assumes that to meet the regulatory demand of 2.8 Mt of clean hydrogen by 2030, the hydrogen sector will require investments of at least €263 billion. While national and EU-wide funding are both increasing, public support remains insufficient:

- IPCEI: only 22% of Important Projects of Common European Interest have reached FID. Delays in the EU notification process and slow allocation of funding by national authorities are the main reasons behind the numbers.
- Innovation Fund: grants have allocated €4.3 billion to 65 projects, but so far only one is operational and 7 are in construction.
- EU Hydrogen Bank: waiting for a first FID; operations of the winners of the first auction should start in 2029.
- Connecting Europe Facility: CEF funding for hydrogen projects is increasing, focusing on infrastructure development. Since 2021, €352 million were allocated to hydrogen refuelling stations.

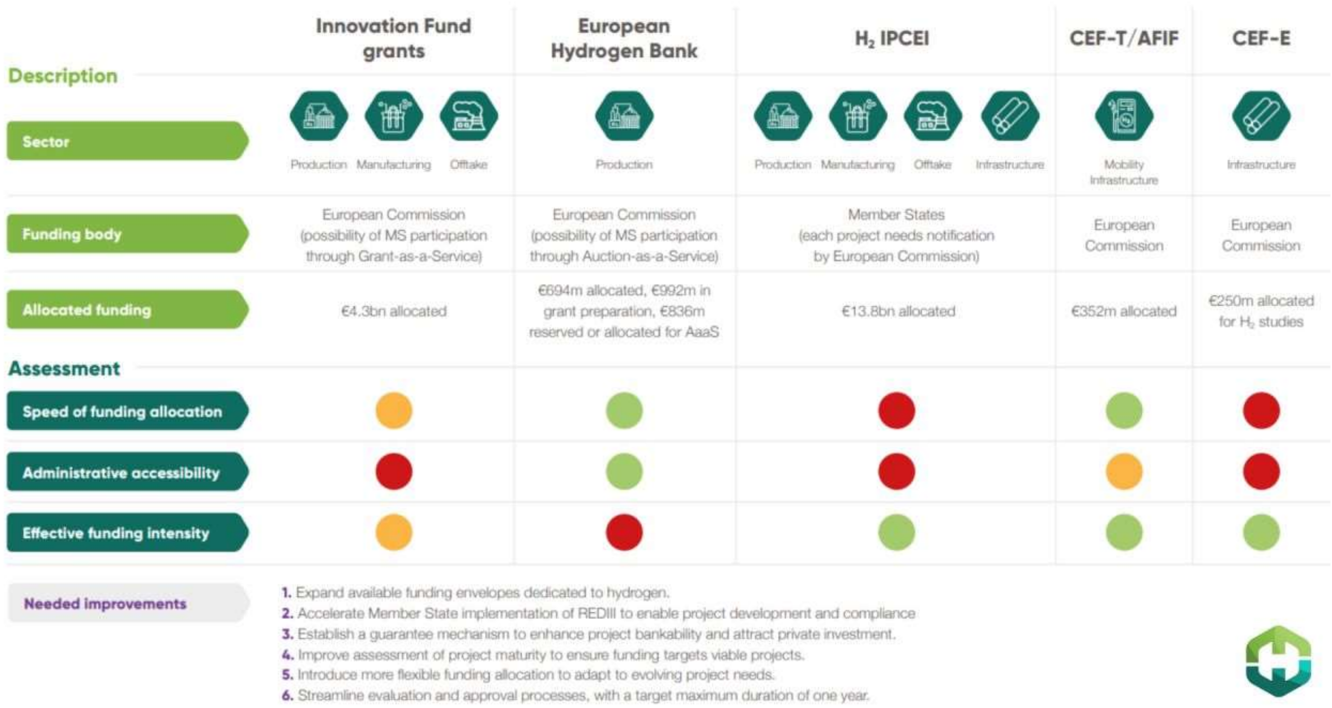

Figure 6 - Funding perspective on investments at EU level. Source Hydrogen Europe

4.1 Overview of financing

Low-emissions hydrogen projects are being financed through a mix of corporate balance sheet funding and project finance structures, with the choice depending on the project's scale and maturity, and its developers. In both cases, public support – such as via grants, tax incentives, or concessional finance – remains a key component of overall funding.

Established industrial companies may opt to fund projects directly using internal cash reserves or retained earnings, which is commonly referred to as balance sheet financing. This allows them to avoid external debt or equity issuance but means that financial risk is concentrated on their own books. While financing details are often undisclosed, it is likely that smaller projects backed by major industrial players use balance sheet funding.

For capital-intensive or large-scale projects, developers often establish joint ventures (JVs) and may create special purpose vehicles (SPVs) or project companies to pool resources, share risks, and isolate liabilities from corporate balance sheets. JV partners typically provide initial equity contributions, while the JV itself or a designated SPV may also secure public grants, concessional finance, or external debt to meet total investment requirements (IEA 2025).

Each low-emissions hydrogen project is still unique, as the market is maturing, and financing typically relies on a combination of public grants, equity contributions from public or private entities, and debt financing, including both concessional and commercial sources. Project developers and SPVs typically adopt project finance structures that raise capital at the project level through a mix of debt and equity from multiple investors. This approach facilitates risk-sharing and can attract external capital, though it often requires long-term offtake agreements.

4.1.1 Development finance institutions (DFIs) and multilateral funding

IEA witnesses that development finance institutions (DFIs) account for only around 1% of total energy sector financing, but their role in shaping clean energy transitions in emerging markets and developing economies (EMDEs) is far greater than that share suggests. By supporting early-stage, high-risk projects that may not yet attract commercial funding, DFIs play a critical role in enabling investment, de-risking technologies, and laying the groundwork for long-term, transformative development. Their support often extends beyond capital, including sector-specific policy engagement and technical assistance to build local capacity. Around 30% of the production from announced low-emissions hydrogen projects, and more specifically nearly 40% of electrolytic hydrogen production, comes from projects that are planned in EMDEs other than China, where successful deployment could support industrial development and export-oriented growth. With FIDs in hydrogen projects still limited in most EMDEs (5% compared with a global average of 11%), DFIs could play a critical role in filling early-stage funding gaps and enabling the project pipeline to mature.

DFI funding in low-emissions hydrogen rose sharply between 2022 and 2025, from virtually zero to USD 4.6 billion in committed funding, with an additional USD 2.1 billion announced and pending final approval. In 2023, announcements reached a historic high of USD 4.8 billion, though only USD 1.2 billion was committed that year. While announcements slowed in 2024 and 2025, commitments increased, rising to USD 1.6 billion in 2024 and USD 1.8 billion by mid-2025, partly consolidating earlier announcements. For context, DFIs disbursed an average of USD 24 billion annually to energy-related projects between 2019 and 2022. If they are eventually disbursed, recent hydrogen-related announcements could account for a notable share of broader energy financing by DFIs (IEA 2025).

4.1.2 Financing mechanisms for port-based hydrogen infrastructure

The development of hydrogen infrastructure, including hydrogen refueling stations (HRS), is increasingly recognized as a cornerstone of Europe's transition to a low-carbon economy. The European Union supports this transition through multiple funding instruments, combining public infrastructure investment and innovation grants with production-scale incentives. Key mechanisms include the Alternative Fuels Infrastructure Facility (AFIF), which finances HRS deployment along trans-European transport corridors, and the European Hydrogen Bank, providing premium support to scale up renewable hydrogen production. Complementary programs, such as the Innovation Fund, further channel grants toward hydrogen R&D and demonstration projects, while cross-border infrastructure funding ensures the integration of hydrogen into energy and transport systems. Beyond public financing, private investors are playing an increasingly significant role, particularly in higher-throughput projects and industrial applications, attracted by long-term hydrogen demand forecasts and the EU's regulatory support frameworks. Together, these public and private funding flows aim to reduce early-stage investment risks, accelerate hydrogen market development, and ensure that hydrogen refueling infrastructure becomes widely accessible across European ports, urban centers, and transport corridors.

H2Global

H2Global is an international initiative and market-creation mechanism designed to accelerate the global deployment of clean hydrogen and other low-carbon fuels by addressing early market barriers and stimulating supply and demand simultaneously. It operates through a contract-for-difference auction model—managed by the non-profit H2Global Foundation and its trading subsidiary Hintco—to secure long-term purchase agreements for renewable hydrogen and derivatives from producers abroad and resell these into European and global markets, bridging the price gap and de-risking early-stage hydrogen projects. The overarching objective is to support the ramp-up of renewable hydrogen markets, reduce costs, and strengthen global supply chains for decarbonised energy carriers, aligning with broader climate and clean-energy goals. Governments including Germany, the Netherlands, Canada and Australia have collectively committed around €6 billion in funding for H2Global tenders as of late 2025, and subsequent auction rounds under the programme can total several billion euros more, making H2Global a major instrument for scaling clean hydrogen internationally[32].

Tax incentives

The European Commission has issued recommendations for tax incentives to accelerate investment in clean industrial technologies, including hydrogen production and storage. These include provisions like accelerated depreciation or immediate expensing of eligible clean technology investments, designed to stimulate corporate capital expenditure in low-carbon projects. Member States are encouraged to adopt these tax measures (e.g., accelerated tax write-offs) to support clean technology deployment, with alignment to State aid rules under the EU's Clean Industrial Deal framework[33].

4.2 European funding instruments

4.2.1 Innovation Fund and revenue support

European Hydrogen Bank (EHB) [34]

Launched in 2022 by the European Commission, the European Hydrogen Bank is a strategic financing instrument designed to accelerate the development of renewable hydrogen production across Europe and globally. Unlike a physical bank, the EHB functions as an EU-managed investment platform, operated internally by Commission services, aimed at creating investment certainty and stimulating private-sector engagement in the hydrogen value chain. Its primary objective is to unlock private investments by bridging the gap

[32] https://h2-global.org/

[33] https://observatory.clean-hydrogen.europa.eu/eu-policy/state-aid?utm_source=chatgpt.com

[34] European Hydrogen Bank https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen/european-hydrogen-bank_en

between renewable electricity generation and hydrogen demand, thereby addressing the early-stage financial and market risks that can impede project deployment.

The EHB operates primarily through auction mechanisms, where renewable hydrogen producers can secure long-term offtake contracts at pre-agreed prices, effectively reducing revenue risk and improving bankability. This model encourages investment in large-scale electrolyser projects, hydrogen infrastructure, and related applications, while aligning with EU climate and energy policy goals. By connecting hydrogen supply with European demand, the EHB not only supports domestic decarbonization efforts but also positions the EU as a leader in renewable hydrogen markets, facilitating industrial competitiveness and global export opportunities. The European Hydrogen Bank complements other EU initiatives, such as the Innovation Fund and CEF-E, by providing targeted financial support to projects that might otherwise struggle to attract private capital due to market or technology risk

Innovation Fund

The EU Innovation Fund is one of the largest funding programmes for clean technologies, financed by revenues from the EU Emissions Trading System (ETS). It supports highly innovative projects with significant greenhouse gas (GHG) reduction potential, including clean hydrogen production and related technologies. It supports up to 60% of relevant costs (CAPEX + OPEX) linked to implementation during the first 10 years of operation for regular grants. For competitive hydrogen auctions (bid price' mechanism), support can cover up to 100% of relevant costs via a fixed premium per kg of hydrogen produced over up to 10 years. Eligible costs include capital expenditure and operating costs, less revenue, using either a reference plant or no-reference plant method depending on call rules. Projects must demonstrate GHG emission avoidance, maturity, scalability and cost efficiency.

The program has issued specific Innovation Fund 2025 Hydrogen Calls (IF25).

IF25 Hydrogen Auction

Objective: Support renewable hydrogen (RFNBO) and low-emission electrolytic hydrogen production to accelerate market deployment and reduce production costs.

- Scope of Topics:
- Topic 1: Renewable fuels of non-biological origin (RFNBO) hydrogen production — approx. €600M.
- Topic 2: RFNBO & low-emission hydrogen production — approx. €400M.
- Topic 3: RFNBO & low-emission hydrogen for maritime and aviation sectors — approx. €300M.

Total budget (auction): ~€1.3 billion.

Mechanism (Offtake/Revenue Support): projects compete by bidding a fixed premium per kg of hydrogen produced — this "bid price" bridges the gap between levelised cost of hydrogen (LCOH) and expected revenue from market sales. The premium is paid annually for verified hydrogen production for up to 10 years. This approach effectively underwrites hydrogen production revenue, supporting bankability and offtake economics in early markets.

Net-Zero Technologies Call (IF25–Net Zero)

Objective: Support large-, medium- and small-scale projects that deliver deep decarbonisation — eligible technologies include clean hydrogen production, storage, utilisation and related components (e.g., electrolysers).

Funding Structure: Grants covering up to 60% of relevant costs (CAPEX + OPEX), calculated over a typical 10-year period of project operation.

Expected project categories include: Large-scale projects (CAPEX > €100M), Medium-scale projects (€20M–€100M), Small-scale projects (< €20M), Clean-tech manufacturing (including electrolyser manufacturing), Pilot and disruptive technology projects

CAPEX/OPEX Treatment:

CAPEX: Eligible costs tied to construction, equipment, industrial installation and integration, net of reference plant cost.

OPEX: Operating costs up to 10 years, including maintenance, monitoring, and verified climate benefits tracking.

Offtake/Revenue Aspect: unlike the hydrogen auction, this grant call does not use a per-kg premium; instead, financial viability is demonstrated via cost reduction, GHG savings and technology scalability, and revenue projections factors into the relevant costs calculation against baseline scenario

4.2.2 Alternative Fuels Infrastructure Facility (AFIF)

The Alternative Fuels Infrastructure Facility (AFIF) is a key EU funding instrument under the Connecting Europe Facility (CEF-Transport) that plays a strategic role in enabling the deployment of hydrogen infrastructure across Europe, particularly along the TEN-T transport network. Its main objective is to accelerate the roll-out of alternative fuels infrastructure, including hydrogen refuelling stations (HRS) and associated supply systems, in order to support the transition to zero-emission transport and to implement EU regulations such as AFIR, FuelEU Maritime and ReFuelEU Aviation. AFIF operates through rolling calls for proposals managed by CINEA, allowing projects to be submitted at multiple cut-off dates, and focuses on mature, ready deployment infrastructure rather than early-stage R&D. In terms of funding, AFIF combines non-repayable EU grants with blended finance, leveraging private and institutional capital (e.g. EIB or national promotional banks), with a total budget of around €1 billion for the 2024–2025 period (approximately €780 million from the general CEF envelope and €220 million from the cohesion envelope). Co-funding rates typically range from 30% to 50%, depending on project type and location, and supported actions include networks of hydrogen refueling stations, integrated hydrogen production via electrolysers at transport hubs, and cross-border infrastructure projects, making AFIF a cornerstone instrument for scaling up hydrogen mobility and infrastructure deployment in Europe.

The second phase of AFIF (2024-2025) supported objectives regarding publicly accessible electric recharging pools and hydrogen refuelling stations across the European Union's main transport corridors and hubs, as well as the objectives set in the ReFuelEU aviation and the FuelEU maritime Regulations.

Link: https://cinea.ec.europa.eu/funding-opportunities/calls-proposals/cef-transport-alternative-fuels-infrastructure-facility-afif-call-proposal_en

Since 2021, AFIF has provided funding to 208 projects, supporting a combined €1.3 billion in EU contributions. These investments are devoted to unlocking more than €3.5 billion in total funding. The funding will help roll out large-scale alternative fuel infrastructure in line with Europe’s Green Deal and Fit for 55 goals. The round of hydrogen station projects will complement existing national strategies to scale up hydrogen mobility — especially for commercial transport.

Figure 7 presents the criteria that determine which projects and applicants can receive AFIF funding.

Eligibility matrix

	ELIGIBILTY BY TOPIC & LOCATION (amounts in K€ & %)	Topic		Financial Support per location (*) (**)								Synergetic Element				Associated eligible costs				
		Unit Cost	Co-funding rate	TEN-T road network	Safe & Secure Parkings	Urban nodes	TEN-T Airports	TEN-T Maritime ports	TEN-T Inland ports	TEN-T Rail network under specific conditions	Railway Shunting terminals	Grid connection	On-site electricity storage	On-site Electricity production (Solar panels, ...)	On-site Hydrogen prodcution by Electrolyser	Grid connection	Battery charging system	Short Sea Shipping vessels	Port operation vessels	Zero emission transhipment equipement
Electricity	Road: HPC 150kW - LDV (CCS)	x		20-30 K€																
	Road: HPC 150kW - HDV (CCS)	x			20-30 K€															
	Road: HPC 350kW - HDV (CCS)	x		40-60 K€	40-60 K€	40-60 K€														
	Road: HPC 1MW only (MCS)		x	30-50%	30-50%	30-50%						x	x	x						
	Road: HPC 1MW mixed with 350kW/150kW (***)		x	30-50%	30-50%	30-50%						x	x	x						
	Road: Recharging points for public transport		x			30-50%								x		x	x			
	Waterborne: OPS IWW & maritime vessels		x					30-50%	30-50%					x		x	x	x		
	Waterborne: OPS for Port operation vessels		x					30-50%	30-50%					x		x	x		x	
	Waterborne: Recharging stations for port services		x					30-50%	30-50%					x		x	x			x
	Air: Electricity for stationary aircrafts & airships		x				30-50%							x		x	x			
	Air: Electricity for airport ground operations		x				30-50%							x		x	x			
H2 Hydrogen	Road: HRS 1T supply at 700 bar for road LDV/HDV		x	30-50%		30-50%									x					
	Road: HRS 350/700 bar for Public Transport		x			30-50%									x					
	Waterborne: HRS for waterborne transport		x					30-50%	30-50%						x			x	x	x
	Air: HRS supplying airports		x				30-50%								x	x				
	Railway: HRS for railway transport		x							30-50%	30-50%				x					
NH3 Ammonia	Waterborne: Shore-based ammonia stations		x					30-50%	30-50%									x	x	
	Waterborne: Bunkering barges/vessels (10,000m³)		x					30-50%	30-50%									x	x	
CH_3OH Methanol	Waterborne: Shore-based methanol stationst		x					30-50%	30-50%									x	x	
	Waterborne: Bunkering barges/vessels (10,000m³)		x					30-50%	30-50%									x	x	

(*) for HPC, ony on eligible sections with a bufer of 3km from the nearest exit of the TEN-T network / For Hydrogen locations a buffer of 10km is accepted
(**) Minimum applies to the General Call, maximum to the Cohesion Call. For outermost regions, co-funding rate is 70%
(***) for "mixed" pools the grant for 350kW & /150kW is capped at the maximum provided in the Unit Contribution topic

Figure 7 - Criteria that determine which projects and applicants can receive funding, source AFIF

Reference call – example given

<u>Demonstration and deployment of multi-purpose Hydrogen Refuelling Stations combining road and airport, railway, and/or harbour applications. HORIZON-JTI-CLEANH2-2024-02-05</u>[35]

Project results are expected to contribute to the following objectives and KPIs of the Clean Hydrogen JU SRIA:

- *Reduction of CAPEX: 1.5–4k€/(kg/d) (700bars), 0.65-2.5k€/(kg/d) (350bars), 1.5-4k€/(kg/d) (LH2);*

35 https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-jti-cleanh2-2024-02-05

- *Increased availability: 98% (700bars), 98% (350bars), 97% (LH2);*
- *Hydrogen price: 3€/kg (700bars), 2€/kg (350bars), 3€/kg (LH2);*
- *Annual maintenance cost: 0.5€/kg (700bars), 0.35€/kg (350bars), 0.5€/kg (LH2) ;*
- *Increased reliability (mean time between failures): 72 days (700 bars), 144 days (350 bars), 216 days (LH2).*

Public funding for hydrogen technologies is now showing signs of maturation. Total announced funding has decreased by nearly two-thirds compared to what was reported in GHR-24 from almost USD 100 billion to USD 38 billion, but a lot of the funding has moved from announcements to allocation to specific projects.

For reference, investment in hydrogen production was USD 4.3 billion in 2024. In large part, the difference with last year is explained by multiyear programmes that were announced in 2024. These included the Important Projects of Common European Interest (IPCEI) in the European Union, Carbon Contracts for Difference (CCfD) for industrial use in Germany, and the contracts for difference (CfD) for hydrogen production in Japan, which together represented nearly USD 35 billion of last year's total. In all those cases, no new funding has been announced in 2025, but the programmes have progressed. In Germany, results from the first round of the CCfD scheme were announced, and its second round was approved by the European Commission in March 2025, Japan and France both opened the first round of their CfD schemes, and Finland, Italy and Spain have allocated IPCEI funds to specific projects.

Almost 90% of the USD 38 billion of funding under policies announced or updated since GHR-24 is from advanced economies . This is a reflection of funding in the form of grants, auctions and CfDs being more common in advanced economies, whereas emerging economies tend to use other instruments, such as tax incentives, fixed premiums or simplified administrative procedures. Most of the funding from emerging economies is from India, through the Strategic Interventions for Green Hydrogen Transition (SIGHT) programme targeted to electrolyser manufacturing and ammonia production.

Connecting Europe Facility – Energy (CEF-E) for Hydrogen

The Connecting Europe Facility for Energy (CEF-E) is the European Union's dedicated financial instrument for accelerating the development of cross-border energy infrastructure under the Trans-European Networks for Energy (TEN-E) policy framework. With a total budget of about €5.84 billion for 2021–2027, CEF-E co-finances strategic projects of common interest (PCIs) and projects of mutual interest (PMIs) that enhance the integration, resilience, and sustainability of Europe's energy systems. While traditionally focused on electricity grids, smart networks, and CO_2 transport, recent calls have expanded to explicitly support hydrogen infrastructure, including feasibility studies and preparatory work for pipeline networks, storage, and electrolyser linkages that will form the backbone of a European hydrogen market.

Under the 2024–2026 CEF-E calls, hydrogen-related projects receiving support include major preparatory and engineering studies for backbone corridors such as the Spanish Hydrogen Backbone and H2Med, feasibility work for the Italian H2 Backbone, and readiness studies for retrofitting existing networks for hydrogen transport. These actions are designed to bridge planning and permitting phases and help projects move toward final investment decisions, thereby enabling large-scale renewable hydrogen transport and cross-border energy integration. CEF-E funding also covers hydrogen infrastructure as part of PCI/PMI selection, allowing projects to access accelerated permitting advantages and streamlined regulatory treatment, reinforcing the EU's decarbonization and energy security goals.

4.2.3 IPCEI schemes and transnational initiatives

IPCEI Funding Scheme

IPCEI (Important Projects of Common European Interest) initiative, which includes a specific section dedicated to hydrogen (IPCEI Hydrogen). The IPCEI Hydrogen targets the innovation, demonstration and deployment of hydrogen technologies. It comprises four clusters of projects covering the entire value chain: production, import, transportation and end use.

IPCEI Hy2Tech (€5.4 billion public support)[36]

Involved 41 projects from 35 companies at the time the project was approved by the European Commission. Projects were submitted by 15 Member States: Austria, Belgium, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Italy, the Netherlands, Poland, Portugal, Slovakia and Spain. IPCEI Hy2Tech operates in the field of relevant technologies in the areas of hydrogen production, infrastructure and utilization for commercial and economic exploitation. Focus of IPCEI Hy2Tech is the development of innovative technologies to produce renewable and low-carbon hydrogen using mainly electrolysis. Further focus points are storage, transportation and distribution of hydrogen followed by the end use of hydrogen in industry and transport with a clear emphasis of the mobility sector.

The following list provides details on the Italian companies involved:

- Hydrogen generation technology: Ansaldo, De Nora and Enel;
- Fuel cells technology: Ansaldo, De Nora and Fincantieri;
- Storage, transportation and distribution technology: Enel;
- End-user technology: Alstom (railway sector), Fincantieri (maritime and shipping industry) and Iveco (heavy-duty trucks).

IPCEI Hy2Use (5,2 billion of public support)[37]

IPCEI Hy2Use involves 37 projects. These projects were submitted by 13 Member States plus Norway: Austria, Belgium, Denmark, Finland, France, Greece, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain and Sweden. The project is structured to cover a wide part of the hydrogen value chain by supporting (i) the construction of hydrogen-related

[36] IPCEI Hy2Tech https://ipcei.observatory.clean-hydrogen.europa.eu/hy2tech

[37] IPCEI Hy2Use https://ipcei.observatory.clean-hydrogen.europa.eu/hy2use

infrastructure, notably large-scale electrolysers and transport infrastructure, for the production, storage and transport of renewable and low-carbon hydrogen; and (ii) the development of innovative and more sustainable technologies for the integration of hydrogen into the industrial processes of multiple sectors, especially those that are more challenging to decarbonise, such as steel, cement and glass.

The companies involved within this cluster include Nextchem (green chemistry), RINA-CSM (materials development), SardHy Green Hydrogen (potentially associated with the decarbonisation of a refinery in Sardinia) and South Italy Green Hydrogen (likely involved in the decarbonisation of some refineries in Sicily.

IPCEI Hyfra (6,9 billion of public support)[38]

Hy2Infra involves 34 projects. These projects were submitted by 7 Member States: France, Germany, Italy, Netherlands, Poland, Portugal and Slovakia. Hy2Infra is focused on building the foundation for a cross-border hydrogen infrastructure in Europe. It brings together 34 companies to accelerate the ramp-up of renewable and low-carbon hydrogen in Europe. The initiative includes the development of up to 3.2 GW of electrolysis capacity, the construction and repurposing of around 2,700 km of hydrogen pipelines, and the creation of large-scale underground storage facilities with a capacity of about 372 GWh. Additionally, port infrastructure in Rotterdam will enable the import and handling of hydrogen via innovative carriers like LOHC.

IPCEI Hy2Move[39]

Hy2Move involves 10 projects and one associated partner. These projects were submitted by 8 Member States: Belgium (Associated Partner), Estonia, France, Germany, Italy,

[38] IPCEI Hyfra https://ipcei.observatory.clean-hydrogen.europa.eu/hy2infra

[39] IPCEI Hy2Move https://ipcei.observatory.clean-hydrogen.europa.eu/hy2move

Netherlands, Slovakia and Spain. IPCEI Hy2Move will cover a wide part of the hydrogen value chain by supporting (i) the development of innovative hydrogen-powered mobility solutions across road, rail, maritime, and air sectors, focusing on system integration, interoperability, and cross-sector synergies; (ii) the advance in high-performance, durable, and sustainable fuel cell technologies for mobility, including efforts to reduce critical materials and improve production efficiency; (iii) the focus on next-generation hydrogen storage systems with enhanced durability, safety, weight reduction, and optimised design for vehicles and aircraft; and (iv) the development of decentralised or centralised, efficient, and sustainable hydrogen production technologies tailored to mobility needs, including electrolysis and ammonia cracking systems.

4.2.4 Other funding initiatives

Green bonds and blue bonds

Hydrogen bunkering infrastructure in ports represents a highly suitable asset class for both green and blue bond financing, as it directly combines climate mitigation with maritime and ocean sustainability objectives. From a green bond perspective, hydrogen bunkering enables the decarbonisation of shipping and port operations, qualifies under the EU Taxonomy as renewable hydrogen and clean transport infrastructure, and involves long-lived, capital-intensive assets such as electrolysers, compression, storage and quay-side bunkering systems that are well aligned with bond tenors and institutional investor expectations. From a blue bond perspective, ports are coastal and marine assets, and hydrogen bunkering contributes to improved air quality, reduced marine pollution and the development of zero-emission shipping corridors, fitting squarely within sustainable blue economy and ocean protection frameworks. The bankability of hydrogen bunkering is further strengthened by predictable revenue structures, including long-term maritime offtake agreements and policy-backed support mechanisms such as Innovation Fund hydrogen auction premiums, which reduce market and operating risk. When combined, green or blue bonds can efficiently finance the upfront CAPEX of port hydrogen bunkering infrastructure, while public support mechanisms and contracted demand stabilise cash flows, creating a credible, scalable and investor-ready financing model for the decarbonisation of maritime transport

Collaboration between the public and private sector – Public Private Partnerships

Public–private partnerships (PPPs) are particularly well suited to the deployment of hydrogen bunkering infrastructure in ports, as they allow the alignment of public policy objectives with private-sector delivery, financing and operational expertise in a capital-intensive and early-stage market. In this model, port authorities or public entities typically provide land access, permitting, regulatory coordination and strategic demand aggregation, while private partners design, finance, build and operate hydrogen production, storage and bunkering assets. PPP structures help address the high upfront CAPEX and initial demand uncertainty by allocating construction, technology and operational risks to private operators, while public partners mitigate market and regulatory risks through long-term concessions, availability payments or policy-backed revenue support such as Innovation Fund hydrogen auction premiums. Overall, PPPs provide a scalable and replicable framework for accelerating hydrogen bunkering in ports, ensuring infrastructure is deployed in line with public decarbonisation goals while remaining financially sustainable and attractive to private investors.

Clean Hydrogen Partnership (formerly Fuel Cells and Hydrogen Joint Undertaking – FCH JU)

The Clean Hydrogen Partnership (CHP) is a public–private partnership (PPP) under Horizon Europe that brings together the European Commission, industry leaders, and research organizations to accelerate the development, demonstration, and deployment of clean hydrogen technologies across Europe. Launched in 2021 as the successor to the FCH JU, the partnership pools EU research and innovation funding with private-sector contributions, creating a blended finance model that leverages public investment to attract substantial private capital.

The CHP focuses on the entire hydrogen value chain, from production (electrolysis and renewable hydrogen generation) and storage to transport, distribution, and end-use applications such as mobility, industry, and maritime decarbonization. Its objectives include reducing costs, increasing efficiency, and demonstrating the commercial viability of hydrogen technologies at scale. Funding is primarily provided through competitive Horizon Europe calls, which co-finance research, demonstration projects, and pilot facilities, with industry partners contributing matching resources, in-kind support, or operational expertise.

For maritime decarbonization, the partnership supports projects that develop hydrogen-fueled ships, port infrastructure, and hydrogen supply chains for shipping and logistics. By coordinating EU research priorities, standardization efforts, and industry collaboration, the CHP plays a central role in scaling hydrogen solutions, enabling industrial adoption, and facilitating market integration, complementing other EU initiatives such as the European Hydrogen Bank, CEF-E, and AFIF for hydrogen infrastructure.

Role of Private Finance Funds in Hydrogen and Maritime Decarbonization

Private finance funds—including venture capital, private equity, infrastructure, and blended finance vehicles—play a critical role in scaling hydrogen technologies and supporting the decarbonization of maritime transport. These funds primarily provide risk capital, growth financing, and investment scale that public programs alone cannot deliver. By investing in projects across the hydrogen value chain—such as electrolyser manufacturing, hydrogen storage, fuel cell development, and hydrogen refueling stations (HRS)—private funds help bridge the gap between demonstration-scale innovation and commercial deployment. In maritime decarbonization, private finance contributes to the adoption of hydrogen-powered ships, port infrastructure, and supply chains for zero-emission fuels. For example, funds like Hy24 and Copenhagen Infrastructure Partners' Energy Transition Funds mobilize billions of euros to support industrial-scale hydrogen production projects, HRS at ports, and related technologies, often structured to deliver long-term, predictable returns for institutional investors. These funds de-risk projects by providing upfront capital, technical advisory, and sometimes co-investment alongside industrial partners, which makes projects bankable and more attractive to additional investors. Some examples and brief descriptions of funds are provided below.

CIP – CI Energy Transition Fund I & Related Strategies

Copenhagen Infrastructure Partners (CIP) is a major Danish private infrastructure fund manager with a strong focus on energy transition. Its CI Energy Transition Fund I (CI ETF I) is one of the largest dedicated clean hydrogen and Power-to-X (PtX) funds globally, with a €3 billion hard cap and commitments from institutional investors. The fund invests in industrial-scale PtX projects that will produce green hydrogen, ammonia, methanol, and related products to decarbonize sectors like shipping and heavy industry, helping to bridge the investment gap in sustainable fuels and infrastructure across Europe and other regions. CIP also manages related strategies and funds (e.g., advanced bioenergy funds, green credit/debt vehicles) that support decarbonization infrastructure, offering private investors exposure to long-term energy transition assets.

CIP Global Energy Transition (GET)

As part of its broader strategy, CIP launched the Global Energy Transition (GET) evergreen fund to give eligible private investors access to its infrastructure platform. This fund taps into energy transition trends, including clean fuels and hydrogen value chains, allowing institutional and private capital to invest alongside CIP's large-scale projects. While not hydrogen-specific, GET broadens the investor base supporting decarbonization infrastructure and complements targeted funds like CI ETF I.

Climate Investor Three (CI3) feeder fund

Climate Investor Three (CI3) is a blended finance fund structured to mobilize public and private capital across the energy transition and green hydrogen value chains, balancing risk to attract institutional investors. It functions as a "feeder" fund that can both invest directly and allocate capital into country-specific underlying funds targeted at green hydrogen and decarbonization markets in emerging economies. Its initial commitments target projects across the development continuum and support the incubation and scaling of hydrogen-related infrastructure and production capabilities.

Copenhagen Infrastructure Growth Markets Fund II

The Copenhagen Infrastructure Growth Markets Fund II (GMF II) is a large-scale infrastructure investment fund targeting greenfield energy projects in high-growth, middle-income markets, including renewable energy generation and associated technologies that can integrate hydrogen and PtX infrastructure. With an estimated target size of around USD 3 billion, CI GMF II mobilizes institutional capital into emerging renewables markets across Asia, Latin America, and Africa, helping to de-risk and scale projects that contribute to decarbonization and energy transition goals

Green Climate Fund (GCF)

The Green Climate Fund is the largest multilateral climate finance fund under the UN Framework Convention on Climate Change (UNFCCC) tasked with supporting low-emission, climate-resilient development in developing countries. It finances a broad range of mitigation and adaptation activities, including energy system transformation and grid modernization that can enable renewable hydrogen deployment. While not hydrogen-specific, GCF's investments help catalyze innovation and infrastructure improvements that underpin hydrogen markets, often with co-financing from public and private partners.

Green Hydrogen Fund

A Green Hydrogen Fund—as referenced in EU/German funding frameworks—typically denotes financing vehicles (such as those associated with the European Investment Bank and PtX platform) that provide investment grants and risk-sharing instruments to support green hydrogen production projects in developing countries and emerging markets. These funds help bridge financing gaps for electrolytic hydrogen production, improve bankability, and attract private investors by reducing early-stage risks.

Green Private Credit (EIF-Anchored Fund of Funds)

The Green Private Credit initiative, launched by the European Investment Fund with French institutional partners, is a private debt fund of funds aimed at scaling climate and environmental financing solutions in Europe. Although not exclusively hydrogen-focused, this fund is designed to unlock billions in green financing for climate tech and decarbonization ventures—including renewable energy, sustainable mobility, and infrastructure technologies—that could indirectly support hydrogen ecosystem growth and maritime decarbonization.

Hy24 – Clean Hydrogen Infrastructure Fund

Hy24 is the world's first private equity asset manager focused exclusively on the hydrogen economy, created by a 50/50 joint venture between Ardian (a major private investment house) and FiveT Hydrogen. The Clean Hydrogen Infrastructure Fund has raised around €2 billion and attracted over 50 investors from industrial and financial sectors, including energy majors, institutional investors, pension funds, and corporate partners. The fund deploys capital across the hydrogen value chain—covering production, supply infrastructure (including hydrogen refueling and mobility solutions), equipment and technologies—and supports developers such as H2 Mobility, HysetCo, Everfuel, Enagás Renovable, and others. It aims to accelerate commercial-scale hydrogen deployment and decarbonize hard-to-abate sectors such as heavy transport and maritime fuels.

IDC-KfW Green Hydrogen Fund (South Africa–Germany)

The IDC-KfW Green Hydrogen Fund combines South Africa's Industrial Development Corporation (IDC) with Germany's KfW development bank to support the growth of hydrogen value chains and connected industries. It finances green hydrogen production, downstream applications, and related infrastructure, leveraging concessional capital and technical cooperation to promote industrial decarbonization and the creation of export-oriented hydrogen economies in South Africa and beyond. KfW's broader PtX Development Fund work also supports local value chains in hydrogen and derivative fuels in emerging countries.

PtX Development Fund (Germany)

The Power-to-X (PtX) Development Fund—supported by the German government and implemented through KfW—aims to accelerate the establishment of local PtX and green hydrogen value chains in developing and emerging economies. It provides non-reimbursable grants and risk-mitigating support to projects along the hydrogen and derivative fuels value chain, from renewable electricity generation to hydrogen production and export, thereby closing financing gaps that hinder bankability in early-stage markets.

SA-H2 Fund (South Africa)

The SA-H2 Fund (also referred to as CI3 South Africa) is a blended finance initiative aimed at accelerating South Africa's energy transition and green hydrogen market development. Backed by Climate Fund Managers in partnership with Invest International and South African financial institutions, the fund deploys early-stage capital into hydrogen and related PtX projects, including support for large-scale green ammonia production. By de-risking development and attracting co-investment from public and private investors, SA-H2 builds project pipelines and enhances export-oriented hydrogen production capacity.

SDG Namibia One Fund

The SDG Namibia One Fund, also associated with CI3, is a blended finance vehicle focused on developing Namibia's green hydrogen sector and related infrastructure. Managed by Namibia Hydrogen Fund Managers in partnership with Climate Fund Managers and Invest International, the fund aims to catalyze investment in electrolytic hydrogen production and downstream markets, supporting the establishment of a green hydrogen economy and contributing to economic diversification and industrial growth in Namibia.

4.3 National funding frameworks

This Chapter describes the policies supporting hydrogen technologies in Italy and Croatia.

4.3.1 Italian policies and financial support initiatives

In November 2024, Italy published its final hydrogen strategy (*Strategia Nazionale Idrogeno*). The strategy is structured around a framework that considers three possible scenarios developed over a long-term horizon, up to 2050. For 2030, it estimates a moderate demand for renewable hydrogen of around 250 000 tonnes driven mainly by European policies, while for 2050, renewable hydrogen demand is estimated between 2.2 and 4.2 million tonnes, depending on the scenario. In terms of hydrogen supply, the strategy re-iterates the scenario of the NECP in which 70% of hydrogen is produced domestically. While the final version of the strategy does not mention specific targets on electrolyser capacity, it refers to a potential need for 15 GW to 30 GW capacity, considering the NECP scenario. To account for limitations in developing the necessary RES supplying the electrolysers domestically, an alternative scenario considers that around 80% of the demand would come from imports mainly from North Africa via the Southern Hydrogen Corridor, but also via ammonia and methanol shipments from other parts of the world. While the strategy reiterates the vision of connected hydrogen hubs and the strategic importance of the Southern Hydrogen Corridor, it refrains from quantifying the foreseen infrastructure needs (see ACER 2025).

Italian national hydrogen strategy

Italy's strategy confirms the 2030 targets from the National Energy and Climate Plan of 3 GW of electrolysis, 137 ktpa of demand from transport, 115 ktpa for industry, and at least 70% of demand met by domestic production. Total investment needs for 2050 are €29-57 billion. The strategy estimates 15-30 GW of electrolysis by 2050, requiring cumulative investments of €8-16 billion for electrolysis alone, creating 4 700 to 9 000 jobs. Investment needs for the demand side are €16-33 billion, with the bulk of this going to the transport sector. The strategy includes three scenarios with a hydrogen demand of between 2.2 Mtpa and 4.2

Mtpa in 2050, with nearly 45-55% used for aviation and trucks. Most of the difference between scenarios relates to hydrogen demand for industrial heat and trucks. As a point of reference, current hydrogen demand in Italy is about 525 ktpa.

PNRR and tax incentives

In relation to taxing, from 2020 Italy benefits from renewed tax credit schemes based on a new calculation method (from the incremental method used until FY 2019 to the volumetric calculation method). Tax credit is extended not only to R&D projects but also to technological innovation/ecological transition and a tax credit for Industry 4.0 for machinery and software.

The 2022 Italian Budget Law has renewed the tax credits until 2031 foreseeing a reduction in rates over the years. For FY2025, rates are 10% for R&D tax credit and 5% for Technological Innovation and Design tax credits. Compared to the previous regime, investments do not require a minimum expense to be eligible for tax credits. However, with the newly introduced measures, the tax credits' maximum amount is now capped at €5 million for R&D projects €4 million for ecological transition and 4.0 technological innovation and at €2 million for both for technological Innovation and Design ones.

The new method does not foresee an incremental calculation on a baseline. Rather, it is now based on a direct calculation on the total eligible costs in the fiscal year.

The new tax credit, by changing the calculation method, also encourages investment in skilled labour. In particular, it prises qualified personnel with subordinate employment contract (or in a self-employment relationship with the company) and, in particular, under-35s holding a PhD or a scientific degree. Furthermore, expenses relating to extra muros contracts with universities, research centres and innovative startups are also promoted.

Although no pre-approval is required, it is important that the company is able to provide in-depth technical and financial documentation in case of a tax authority inspection[40].

Italy's strategy[41] confirms the 2030 targets, investment needs for the demand side are €16-33 billion, with the bulk of this going to the transport sector. The strategy includes three scenarios with a hydrogen demand of between 2.2 Mtpa and 4.2 Mtpa in 2050, with nearly 45-55% used for aviation and trucks. Most of the difference between scenarios relates to hydrogen demand for industrial heat and trucks. As a point of reference, current hydrogen demand in Italy is about 525 ktpa. TCTF: RRF - Italy: Support for the development of hydrogen valleys (amendment of SA.106007 as prolonged by SA.110511).

The main and reference calls for hydrogen related activities in Italy can be categorized in following areas.

National Funding Scheme (PNRR)

Italy, in line with the European hydrogen strategy, intends to promote the production and use of hydrogen, in particular through the PNRR funding scheme. In this context, the development of flagship projects for the use of hydrogen in industrial hard-to-abate sectors was expected. The funding also intended to encourage creation of hydrogen supply chains (referred to as "*hydrogen valleys*" in the funding scheme), particularly leveraging areas with abandoned industrial sites (brownfield sites). The use of hydrogen in heavy transport and on non-electrifiable railway routes was be pursued through the installation of hydrogen refuelling stations (HRSs) along the main commercial routes. Finally, the funding scheme

[40] Ayming Institute (2025, The Benchmark 2025, Global R&D Incentives

[41] Piano Nazionale dell'Idrogeno – www.mase.gov.it

aimed to support research and development while establishing the necessary regulatory framework to facilitate the use, transport and distribution of hydrogen.

The total funding devoted to hydrogen development was divided into specific calls for proposals.

Hydrogen production in brownfield areas

Funding 500mEur. Call: January–February 2023 Grant. April–September 2023

This investment aimed to support the production and local utilization of green hydrogen in industry (especially in small- and medium-sized enterprises), as well as in local transportation, thereby promoting the establishment of new hydrogen valleys. €450 M was distributed among the regions for implementing the projects, while €50 M was designated for flagship projects.

Hydrogen Use in Hard-to-Abate Sectors

This investment aims to promote research, development and innovation in the field of industrial processes. The goal is to foster the use of hydrogen in industrial applications that, as an example, currently rely on methane as a source of thermal energy (such as cement, paper mills, ceramics, glass industries, etc.). The production of low-carbon hydrogen from renewable energy sources in accordance with Directive (EU) 2018/2001 or grid electricity was also supported within this funding. The call for proposals had a minimum funding request of €0.5 M per project and an overall budget availability of €1000 M (50% of the total funding available within this topic).

Hydrogen Refuelling Stations for Road Transport

Funding 230meuro. Call: November 2022. Grant: March 2023

The call for proposals for road hydrogen refuelling stations aimed to install at least 40 HRSs by 2026 (€230 M) along the road network . About €103.5 M for HRSs (36 projects) was allocated in the first call for projects in March 2023. The second call for projects was published in July 2023 and funded the other 12 HRSs with the goal of decarbonising connections to northern countries (such as the Brennero connection towards Munich, Germany), as well as western–eastern corridors and trans-European routes. This is visible also from the fact that 77% of the €103.5 M is invested in northern countries. Currently, in Italy, only two other HRSs are available and in operation, located in Bolzano and Mestre.

Hydrogen Refuelling Stations for Railway Transport

Funding 300meuro. Call: July - November 2022. Grant: April 2023

The €300 M dedicated to railway transportation was designated to convert regional or local services currently operated using diesel trains (non-electrified lines) or other fossil fuels. Decree 144/2023 distributed all of the available resources allocated for this area (€300M). In particular, €276M has been allocated for the construction of renewable hydrogen production, storage and refuelling stations and €24M for the purchase of hydrogen-powered trains. Only six regions were involved in this funding (Lombardia, Puglia, Campania, Calabria, Sardegna and Sicilia), covering a total number of 10 railway lines.

Research and development

Funding: 160meuro. Call: March 2022. Grant: June 2022

Research projects was assigned during 2022 with two calls for fundamental and industrial research, respectively. The detailed list of funded research projects is available in the Supplementary Materials. Seven fundamental research projects were financed, coordinated by universities, for a total funding of about €20M, focused on materials for catalyst, solid storage and hydrogen production. Another €30M was given to 15 projects on industrial research (typically coordinated by companies). Even in this case, the spectrum of topics covers hydrogen production (50% of the project, focused typically on the manufacturing/development of innovative large-size electrolysers), transport, storage and end-uses (propulsion systems, power generation and e-fuels production).

Hydrogen Industrial Value Chain

Devoted to the creation of an industrial value chain, with the goal of building one or more electrolyser manufacturing plants and reaching a manufacturing capacity of 1 GW/year. The *H2 Technology* initiative, which includes two projects by Ansaldo Energia S.p.A and De Nora Italy Hydrogen Technologies S.r.l., received formal authorization on July 2022 and will allow Italy to reach (and even exceed) the target production capacity of 1 GW/year by 2026. This funding is part of the IPCEI initiative.

Regulatory and administrative measures

In addition to direct funding, Italy has implemented several regulatory measures to facilitate hydrogen deployment:

- The revision of the existing regulation on hydrogen injection into the natural gas grid, with a new limit of maximum 2%vol. (Ministerial Decree No. 139, June 2022).
- Administrative simplification measures for the construction of small-scale (<10 MW) hydrogen production facilities, with authorization procedures managed by a single entity (Legislative Decree No. 199, November 2021).
- The inclusion of hydrogen production plants in grid-balancing services, through a directive by the Italian Energy Regulator (ARERA).
- The establishment of a system of guarantees of origin for renewable hydrogen, aimed at providing price signals to consumers, issued by the Italian Energy Regulator (ARERA) and the Energy Services Manager (GSE). This activity is not yet finalised.

Facilitating the construction of hydrogen refuelling stations at strategic locations such as highway service areas, logistics warehouses and ports. This effort involves the identification of selected refuelling areas along the local refuelling network to create hydrogen corridors spanning across Italy. The goal is the reduction in the grid electricity price to produce low-carbon hydrogen. To this aim, a decree-law was published in 2022. This decree foresees an exemption from the payment of the variable quota of the general costs (*oneri generali*) for the use of renewable electricity in electrolysis plants for the production of green hydrogen (defined as "green" when the lifecycle GHG emissions are lower than 3 tCO_2eq/tH_2). This benefit can be cumulated with other benefits of any nature. Furthermore, green hydrogen is not subjected to excise duty (*accise*), if not directly used in thermal engines as fuel.

Regional funding instruments

Hydrogen-related calls published by the Region of Friuli Venezia Giulia (FVG) in the last 10 years

Call for the creation and upgrading of research infrastructures in the renewable hydrogen sector (2024–2025)

The Region implemented a dedicated funding call under Law 13/2023, Article 7, targeting the creation and modernization of research infrastructures in the renewable hydrogen sector. The call closed on 23 September 2024, with 5 applications admitted for funding. Total allocation is €11.2 million at 100% funding rate, with an Advisory Board overseeing implementation.

The five funded infrastructure projects represent shared research facilities, with each infrastructure involving collaboration between at least two partner institutions:

- FUSE (OGS as lead partner)
- I-CAMPUS-H2 (CNR as lead partner; partners: Elettra Sincrotrone, Area Science Park)
- H2SmartLab (Area Science Park as lead partner; partners: SISSA, UNITS)
- E4H2 (UNITS as lead partner; partner: UNIUD)
- IMPACT-H2 (UNIUD as lead partner; partner: UNITS)

These infrastructures are diversified in focus: some concentrate on materials research, others on strengthening value chains through intelligent management systems based on digital twins, and others on chemical sciences, physics, and materials process engineering.

The emphasis on shared infrastructure encourages cross-institutional collaboration and avoids duplication of expensive equipment.

In summary:

- Publication year: 2024
- Objective: Support the creation or modernization of research infrastructures dedicated to the renewable hydrogen value chain (production, storage, fuel cells, smart systems).
- Budget: €11.2 million (regional funds).
- Beneficiaries: Universities, public research bodies, and research–industry partnerships based in FVG.
- Funding type: Non-repayable grants.
- Outcome: Financing of strategic infrastructures and other advanced facilities for hydrogen materials and processes.

Call for research projects in the renewable hydrogen sector (2025)

The Region implemented a further dedicated funding call under Regional Law 13/2023, Article 7, for research in the renewable hydrogen sector. The call closed on 26 September 2025 and resulted in 7 conventions with research institutions, with an expected generation of 37 new multi-year research contracts. Total resources allocated amount to €4.7 million, distributed as follows:

- Area di ricerca scientifica e tecnologica di Trieste – Area Science Park: €790 000
- Consiglio Nazionale delle Ricerche (CNR): €365 000
- Elettra – Sincrotrone Trieste S.C.p.A.: €320 000
- Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS): €410 000
- Scuola Internazionale Superiore di Studi Avanzati (SISSA): €185 000
- Università degli Studi di Trieste: €1 485 000
- Università degli Studi di Udine: €1 145 000

The seven funded research projects are: H2 Smart Campus (AREA), SURFACE (CNR IOM), i-CAMPUS-Op (Elettra Sincrotrone Trieste), IHOST (OGS), H2SmartLab (SISSA), RISE-H2 (UNITS), and Udine Hydrogen Research Center – UD-H2 (UNIUD).

This allocation demonstrates significant investment in the human capital dimension, addressing the need to build research capacity in an emerging sector. The presence of seven high-level research institutions with hydrogen competencies within a relatively small regional territory represents a distinctive territorial asset that differentiates Friuli Venezia Giulia from other European regions pursuing hydrogen strategies.

In summary:

- Publication year: 2025
- Objective: Finance applied and industrial research projects to be carried out using the hydrogen research infrastructures funded in 2024.
- Budget: Approx. €4.7 million.
- Beneficiaries: Universities, research institutes, and scientific centers operating in Friuli Venezia Giulia.
- Funding type: Non-repayable grants.
- Strategic role: Strengthening FVG as a regional and European hub for hydrogen research and innovation.

PNRR-related regional implementation measures for renewable hydrogen (2023–2025) & "Flagship projects" call for renewable hydrogen production in disused industrial areas (2025)

Region's first large-scale hydrogen production facility was funded through PNRR Investment 3.1 of Mission 2 Component 2 ("Implementation of renewable hydrogen production plants in disused industrial areas"). The call closed on 6 March 2023, with financed expenditure of 15.8 million €. One project was funded: "Hydrogen Hub Trieste," led by AcegasApsAmga S.p.A. (lead partner) and HestAmbiente S.r.l., with planned production capacity of 400 tonnes of hydrogen per year. The plant has been authorized and is currently under construction.

This project was complemented by the "Progetto Bandiera" (Flagship Project) initiative, governed by MASE Decree n. 235 of 27 November 2024 and Decree n. 404 of 18 November 2024, which allocated resources for flagship projects. Total funding is 10 million € from MASE plus 5 million € from the Autonomous Region of Friuli Venezia Giulia. The call closed on 27 October 2025, with two winning projects:

- SOLHX – Cantieri Navali di Monfalcone S.r.l.: 8.4 million € contribution
- ABS Produzione di idrogeno rinnovabile – Bertoli Safau S.p.A.: 6.5 million € contribution

These projects target innovative decarbonization of the production system through renewable hydrogen production in disused areas, representing the second and third major hydrogen production facilities in the Region.

ERDF programming (FESR FVG 21-27)

The Regional ERDF Programme FVG 2021-2027 is undergoing Mid-Term Review (MTR), with a flexibility quota totalling 54.8 million € to be allocated. A portion of this flexibility quota assigned to Specific Objectives A1, A6, and B2 will be dedicated to the renewable hydrogen sector:

- Objectives A1 and A6 ("Develop and strengthen research and innovation capacity and productive investments"): will support R&D projects and productive investments (STEP).
- Objective B2 ("Promote renewable energy in accordance with Directive (EU) 2018/2001"): will support industrial projects and renewable energy infrastructure.

This future funding allocation represents a significant programmatic commitment at regional level, though specific calls and allocation criteria are still under development through the MTR process.

Synthesis of FVG regional public resources activated

Total public resources activated in the Friuli Venezia Giulia territory for hydrogen initiatives amount to 333.5 million €, distributed as follows:

- PNRR (excluding IPCEI): 21 million €
- PNRR IPCEI: 240.5 million €
- EU resources (direct management): 12 million €
- Regional resources: 50 million €
- State – MASE (Flagship Project): 10 million €

This figure is likely conservative, as not all funding sources may have been captured. The 50 million € in regional resources represents direct regional budget commitment beyond leveraged European and national funding, demonstrating substantial financial commitment at subnational level. The IPCEI component (240.5 million €) indicates significant private sector engagement in large-scale industrial hydrogen projects that have qualified under Important Projects of Common European Interest frameworks, suggesting mature project pipelines beyond early-stage research and demonstration.

The regional funding strategy is characterized by simultaneous investment across the entire innovation chain: fundamental research (4.7 million €), research infrastructure (11.2 million €), production capacity (PNRR + Flagship projects), and end-use demonstrations (public transport). This comprehensive approach reduces the risk of bottlenecks at any single stage of the value chain and creates conditions for sustained ecosystem development beyond individual project timelines.

Hydrogen-related calls – Emilia-Romagna (last ~10 years)

Call for renewable hydrogen production plants in disused industrial areas (PNRR – Emilia-Romagna)

- Published: January 2023 (application period mid-Jan to 20 Feb 2023).

- Objective: Support the development and installation of renewable hydrogen production facilities located in disused industrial sites across Emilia-Romagna, to foster local decarbonisation and hydrogen uptake in industry and transport.
- Funding framework: PNRR Mission 2 *Green revolution and ecological transition*, Investment 3.1 (Energy, hydrogen, grid and sustainable mobility).
- Budget: approx. 19.5 million €.
- Beneficiaries: Companies of all sizes, individually or in consortium, implementing hydrogen production plants (electrolyzers + renewable energy sources, storage and auxiliary systems).
- Call status: Archived (completed), with projects selected including *IdrogeMO* by Hera and Snam in Modena.
- Key outcome: financing of a hydrogen production hub producing up to ~400 tonnes per year of green hydrogen powered by photovoltaics in a former landfill site in Modena.

IdrogeMO – Hydrogen Valley project supported by Emilia-Romagna (2023)

- Context: Implementation of the above mentioned call for hydrogen production plants.
- Funding: approx. €19.5 million allocated by the Regional Government (PNRR).
- Project: Joint Hera + Snam initiative creating a green hydrogen hub with a 6 MW photovoltaic field and electrolyzer, producing up to ~400 t/year of hydrogen destined for local public transport and industry use.
- Strategic role: Part of Emilia-Romagna's Hydrogen Valley strategy.
- Note: While not a separate call itself, this project resulted directly from winning the regional PNRR-linked tender.

Private Investors in Italy — Key Aggregations and Trends

In Italy, private capital has become increasingly active in hydrogen and energy transition initiatives, often in partnership with industrial and infrastructure players. Large domestic investment managers and asset owners are moving beyond pure financial returns to strategic decarbonisation projects, reflecting both market opportunity and supportive policy frameworks.

At national level, Associazione IBAN (Italian Business Angels Network), is the main national body representing business angel investing in Italy: founded in 1999, it operates as a non-profit association that connects individual angels, local Business Angels Networks (BANs), and investor clubs, with the goal of promoting early-stage private investment and acting as the Italian reference point at both national and European level (including links with the European confederation of angel associations). Alongside IBAN's "umbrella" role, Italy also has major national-scale operational angel aggregations such as Italian Angels for Growth (IAG) and Club degli Investitori, which run structured deal-flow activities (startup sourcing, screening, due diligence, syndication and mentoring) and represent two of the best-known organized communities of private investors in the country; in parallel, a broader layer of regional and thematic BANs—such as Business Angels. Network and other local groups—completes the national landscape by providing territorial access points for informal venture investment into startups and innovative SMEs.

An example operating in the hydrogen sector is Sosteneo SGR (part of the Generali Investments ecosystem), which has partnered with energy major Edison, engineering group Saipem, and state investment agency Invitalia to take a 40 % stake in the "Puglia Green Hydrogen Valley" project — a major photovoltaic-powered green hydrogen initiative aimed at decarbonising steel and industrial processes in southern Italy. Italian industrial groups are also investing directly in hydrogen technologies and decarbonisation partnerships. Snam, the country's leading gas infrastructure company, is leveraging its network and capital to become "hydrogen-ready," investing in electrolyser manufacturing (including a minority stake in Industrie De Nora) and positioning Italy as a potential hydrogen hub for European markets.

Strategic collaborations among corporates — such as the partnership between Eni, Fincantieri and RINA — illustrate how Italian corporations are pooling investment, engineering and shipbuilding expertise to enable maritime transport decarbonization pathways. This alliance also includes analysis and development of alternative fuels, infrastructure and logistics solutions for sustainable shipping.

In the Italian hydrogen production landscape, agreements like the ten-year renewable hydrogen project between Solvay and Sapio at Rosignano reflect corporate investment flowing into production at scale, supported by local regional funding aligned with national strategic goals. Italian private investors are further embedded in EU-wide green hydrogen infrastructure programmes, such as the Hy2Infra common interest project, where public funding (~€6.9 billion) is expected to unlock an additional ~€5.4 billion in private investment across participating companies, including Italian ones like Snam and Saipem. Companies such as Landi Renzo — a listed Italian group specialising in pressure management for mobility and hydrogen infrastructure — represent active Italian industrial investors aligned to hydrogen value chains.

Italy — Private Funds and Investment Vehicles

1. UFI Hydrogen / Hydrogen Tech Fund (with Aster Capital)

A newly launched Hydrogen Tech Fund, led by Aster Capital with participation from Italian firm UFI Hydrogen, represents one of the first private venture capital efforts in Europe dedicated to hydrogen technology development. This fund aims to raise roughly €150 million to invest in startups and scale-ups across the hydrogen value chain—from electrolysis technologies to storage, compression, and fuel cell innovations—supporting key components that underpin hydrogen deployment across sectors, including mobility and industrial applications. It is explicitly structured as a technology-oriented venture fund backed by private investors, focusing on early-stage to growth-stage companies that are enabling hydrogen systems and equipment.

2. CDP Equity / CDP Venture Capital & Co-Investment Funds

While not a pure private fund, CDP Equity S.p.A.—the investment arm of *Cassa Depositi e Prestiti (CDP)*—operates quasi-commercially in private equity and co-investment, alongside private institutional partners, to support strategic industrial champions. Its portfolio includes major Italian groups such as Fincantieri and is linked to CDP Venture Capital SGR, which manages climate and green transition capital. CDP's investment ecosystem can unlock growth capital for hydrogen-related technologies and infrastructure by co-investing with private funds and is positioned to leverage venture capital towards clean energy startups, including hydrogen and alternative fuels.

3. Primo Climate (Primo Ventures)

Primo Ventures—an Italian venture capital manager—has launched Primo Climate, a climate-tech venture fund targeting innovation across sustainable energy, mobility, and decarbonization technologies, with hydrogen identified among strategic verticals alongside renewables, energy efficiency, and clean mobility. This fund is structured to attract private capital into early-stage companies delivering technologies that can contribute to emissions reduction and support decarbonization pathways including hydrogen technologies that might intersect with maritime and port applications.

4. Green Transition Fund (GTF) via CDP Venture Capital SGR

Italian public-private initiatives like the Green Transition Fund (GTF) managed by CDP Venture Capital SGR aim to channel private risk capital toward climate tech and energy transition ventures, including hydrogen applications. Although funded with public support through the PNRR (Recovery and Resilience Plan), the GTF is geared toward engaging private investors in venture capital vehicles, stimulating investment into innovative technologies that can scale within Italy's green economy.

4.3.2 Croatian policies and financial support initiatives

Croatia has an official Hydrogen Strategy to 2050[42], which lays out the national vision for the hydrogen economy, including infrastructure, production, transport, R&D, and use in transport (road, rail, maritime). The strategy explicitly identifies the need to:

- develop hydrogen value chain infrastructure (including refuelling stations),
- promote research, innovation and commercialisation of hydrogen technologies,
- support education and innovation ecosystems that link academic, industrial and public actors.

This provides the policy basis for subsequent funding and incentive instruments

Funding

The Ministry of Economy and Sustainable Development launched a national subsidy programme (~€29.6 million) to support the construction of hydrogen filling stations and electric charging infrastructure for vehicles, with approximately €23 million earmarked for hydrogen stations over 2024-2026. Although this call is geared toward road transport stations (cars, buses, trucks), the subsidy mechanisms and experience could be relevant for port hydrogen refuelling infrastructure if extended or adapted to higher-capacity, mobility-oriented infrastructure[43]. Approximately €15 millions available in 2024 and €8 millions in 2026 targeted at hydrogen infrastructure. Per-station support ceilings exist (e.g., up to ~€2 millions for passenger vehicle stations; up to ~€ 3.5 millions for bus/heavy-duty). National calls expect placement along TEN-T corridors, potentially including ports.

[42] Ministry of Economy and Sustainable Development (2022), Hydrogen Strategy of the Republic of Croatia until 2025, Zagreb March 2022.

[43] https://balkangreenenergynews.com/croatia-earmarks-subsidies-for-its-first-hydrogen-filling-stations-for-vehicles/

Tax incentives for R&D and Innovation

Croatia offers corporate income tax relief and employment-related incentives for investment projects that include R&D and innovative activities — including:

- Reduced tax rate on profit from qualifying activities (50% to 100% reduction depending on investment scale and job creation);
- Eligibility for new or transformed business capabilities, often including advanced technology investment — which could encompass hydrogen infrastructure components.

This can support companies planning capital-intensive infrastructure like hydrogen refuelling stations, especially if coupled with R&D elements[44].

Transport & fuel tax regime

Croatian policy frameworks provide for environmental taxation that can indirectly improve the economics of low-carbon fuels (e.g., proportional fuel consumption tax based on emissions). While this is not a direct grant, it reduces the operating cost burden of lower-emission energy carriers like hydrogen relative to fossil fuels

Croatian Green Ports initiative

Subsidized loans and grants on green infrastructures. Fleet Modernization Grants for the Fishing Industry.

[44] https://investcroatia.gov.hr/poticaji-za-investicijske-projekte/

Green Shipping Fund (GSF)

Managed by PROW Capital, €420 million private debt fund providing tailored financing for new and existing vessels that meet environmental standards. It supports European shipowners, including those in Croatia, in adopting green technologies and reducing emissions.

Croatian Bank for Reconstruction and Development (HBOR)

HBOR - role in financing green projects. In collaboration with the European Investment Bank (EIB), it secured a €200 million loan to expand green financing for Croatian businesses, including those in the maritime sector.

Innovation Norway – Bilateral Cooperation Program

This program fosters long-term business cooperation between Croatia and Norway in green industry innovation. It offers grants ranging from €25 000 to €100 000 for projects in areas like renewable energy, circular economy, and zero-emission transport, including green shipping.

HAMAG-BICRO

The Croatian Agency for SMEs, Innovations, and Investments (HAMAG-BICRO) provides financial support to small and medium-sized enterprises for research and development. It plays a crucial role in funding innovative projects, including those aimed at advancing green shipping technologies.

The Croatian Agency for Small Business, Innovations and Investments (HAMAG BICRO) administers R&D support programmes including:

- grants for proof-of-concept and pilot projects related to emerging technologies,
- open calls for commercialisation of innovation,

- funding linked specifically to R&D projects in energy, mobility, and climate tech sectors.

Although not hydrogen-specific, these instruments can be used to partially fund R&D and pilot deployment of hydrogen technologies, and they are relevant for early-stage demonstrations of new hydrogen station designs, safety systems, monitoring, etc

Early Stage / Emerging Private Investment Activity

Venture Capital and Private Equity Ecosystem (general)

Croatia's private equity and venture capital landscape is smaller and less specialized in hydrogen or maritime decarbonization today compared with Western European markets. Private equity and VC funds in Croatia, such as Fil Rouge Capital (VC) and other generalist PE vehicles supported by institutions like HBOR (Croatian Bank for Reconstruction and Development), invest in early-stage and growth companies broadly—and while they are not currently dedicated to hydrogen or maritime decarbonization, these local funds could be mobilized toward cleantech segments as the market develops. This includes potential investment in companies serving hydrogen supply chains or port-related decarbonization technologies if market readiness improves.

At present, there are no widely publicised Croatian private equity funds solely focused on hydrogen or maritime decarbonization; most private capital in Croatia still targets general VC or mid-market buyouts.

4.4 Current initiatives and perspective in Italy and Croatia

An evaluation about the investment feasibility of the three TransH2 pilot cases should combine EU instruments, national/regional funding, and private capital in configurations tailored to each site's specific characteristics, supply chain readiness, and institutional context. These configurations are illustrative and should be refined based on actual funding call eligibility, project scale, and stakeholder agreements. This chapter outlines the most significant initiatives and viewpoints within the H2 value chain relevant to the area under study.

4.4.1 North Adriatic Hydrogen Valley (NAHV/ NACHIP / NASCHA)

The North Adriatic hydrogen ecosystem is supported by structured transnational cooperation platforms that complement national and regional funding instruments.

The North Adriatic Hydrogen Valley (NAHV) project, funded under Horizon Europe through the Clean Hydrogen Joint Undertaking, benefits from approximately €25 million in EU contribution within a broader investment framework exceeding €300 million including co-financing. Of this EU contribution (approximately €8.8 million are allocated to partners operating within the Friuli Venezia Giulia territory). It involves 37 partners, participating in test bed demonstrations advancing technologies from TRL 6 to TRL 8. The regulatory sandbox component, a milestone of the project, is particularly relevant for ports, as it could be able to create experimental regulatory environments that can accelerate approval processes for innovative hydrogen applications here. The establishment of an AISBL legal entity, as well a project milestone, provides long-term governance beyond the project period, potentially offering institutional continuity for cross-border hydrogen infrastructure development.

The NAHV project's main goal is the creation of a hydrogen-based economic, social and industrial ecosystem based on the capacity of the quadruple helix actors. This will drive economic growth, generating new job opportunities within the framework of both the green and digital transitions and, by creating the conditions for wider EU replicability, it will contribute to the creation of a European Hydrogen Economy. To fulfil these objectives, the NAHV project involves a well-rooted partnership of 37 organisations (of which two are in Hydrogen Europe, and three in Hydrogen Europe Research), covering the transnational Central European area of three territories – Slovenia, Croatia and the FVG Region, demonstrating cross-border integration of hydrogen production, distribution and consumption, and building up capacities for an annual hydrogen production of over 5000 tons of which over 20% is expected to be exchanged within the area of the NAHV. The project targets to activate 17 testbed applications in their related ecosystems, clustered in three main pillars – hard-to-abate industries and the energy and transport sectors. These will act as real-life cases for piloting global hydrogen markets, moving from Technology Readiness level (TRL) 6 at the beginning to TRL 8 by the end of the project. Four fuel cell applications in the energy and transport sectors will be demonstrated. Testbeds will then be scaled up to the industrial level as a replicable model, contributing to the decarbonisation of the three territories by harnessing renewables to improve system resilience, security of supply, and energy independence. Replicability will also be ensured for the whole NAHV model, with the uptake of at least five additional hydrogen valleys in Europe, particularly in Central and South-Eastern Europe.

Complementary initiatives include the North Adriatic Clean Hydrogen Investment Platform (NACHIP) supports hydrogen innovation clusters with cascade financing and innovation acceleration for SMEs, aiming at clean hydrogen solutions across value chains. NAHCIP is financed under the Interregional Innovation Investments (I3) instrument of the European Regional Development Fund. The project was financed and initiated in 2024, with total eligible costs of €10.5 million and EU funding of €7.6 million. It is led by the Jožef Stefan Institute (Slovenia) and involves 12 partners.

The project focuses on validation and demonstration of clean hydrogen technologies across three value chains: manufacturing, urban areas, and mobility. NACHIP implements 5 pilot projects for hydrogen-related technologies at TRL 6 or higher, ensuring near-market readiness of demonstrated solutions.

A key innovation is the development of "local hydrogen alliances" around each pilot project, creating stakeholder networks that support further value chain development beyond the project timeline. The project includes an acceleration programme to support technology maturation and provides cascade financing with targeted support for less developed territories.

Finally, NASCHA is a further project born in the NAHV context, financed under I3 financing initiative and initiated in 2025 with EU funding of €7.9 million. Led by Area Science Park (Friuli Venezia Giulia), it involves 23 partners, representing the largest consortium of the three transnational initiatives.

The project strengthens hydrogen value chains across three sectors: transport and mobility, urban areas, and sustainable irrigation. A distinctive feature is cascade financing for approximately 18 SMEs, with each eligible to receive up to €60 000, addressing capital access barriers for smaller actors in the hydrogen value chain.

NASCHA implements 5 pilot actions: three based on "Smart Communities of Practice" focused on hydrogen use in urban areas and minor islands (directly relevant to Croatian island connectivity challenges), and two vertical projects targeting innovative products and processes. This dual approach addresses both systemic integration and specific technological bottlenecks.

Integration into the broader NAHV ecosystem is a core design principle, ensuring continuity across funding cycles and reinforcing transnational governance structures. For port hydrogen infrastructure, NASCHA provides accessible SME funding, stakeholder engagement models applicable to port contexts, and demonstration of island connectivity scenarios relevant to the Split and Zadar use cases.

4.4.2 Other relevant initiatives in Italy

Italy has allocated € 500 million from its Recovery and Resilience Plan to hubs. So far, 52 hubs have been supported. Even though these are for relatively small electrolysers (1-5 MW), they can be useful to build experience across different project configurations. Italy allocated €994 million from the Hy2Infra IPCEI to specific companies.

NatPower H – Green Hydrogen Refuelling Network for Recreational Boating

One of the most ambitious hydrogen HRS initiatives in Italy is led by NatPower H, a subsidiary of the NatPower Group focused on renewable hydrogen production, storage, and refuelling infrastructure. This project plans to build the world's first dedicated hydrogen refuelling infrastructure for recreational boating, with an investment of approximately €100 million and a network of about 100 hydrogen refuelling stations for marinas and ports by 2030. The first installation is expected by summer 2024, starting in locations such as Venice, and the network already has commitments from around 25 Italian marinas and ports. Stations are designed in collaboration with Zaha Hadid Architects to fit maritime environments and support the acceleration of hydrogen-powered vessels and yachts, helping reduce emissions from boating across the Mediterranean.

Eni (Enilive) – Venice Mestre Hydrogen Refuelling Station

Although not a maritime-specific hydrogen fueling station, Eni's hydrogen refuelling facility in Venice Mestre represents an early commercial hydrogen refuelling point in Italy, originally developed as part of Eni Sustainable Mobility (now Enilive). This station, inaugurated in June 2022, is equipped with dispensing points capable of refuelling light vehicles and buses with hydrogen and forms part of broader decarbonization efforts in the Veneto region. It signals private sector deployment of hydrogen refuelling infrastructure within urban and transport contexts that could potentially support future expansion toward maritime uses in port cities.

Hydrogen Refuelling and Production Project — Port of La Spezia

The Port System Authority of the Eastern Ligurian Sea (*Autorità di Sistema Portuale del Mar Ligure Orientale*) has initiated a hydrogen production and distribution project at the Port of La Spezia aimed at enabling refuelling for multiple transport modes, including vessels, rail shunting locomotives, and other port vehicles. A project financing procedure was launched in late 2025 after a positive evaluation of a proposal by Bluenergy of Genoa, which responded to the Authority's expression of interest for designing, realising, and managing the infrastructure. The facility is planned to have an installed capacity of around 56 kW and produce renewable hydrogen on site, which will be stored in cylinders mounted on a mobile trailer equipped with a dispenser and a motorised unit for distribution to refuelling points within the port area and at nearby Marina di Carrara. This "mobile refuelling" concept is intended to provide flexible hydrogen delivery to locomotives, vessels, and other port equipment. The total investment is around €2.2 million, financed through a mix of PNRR Green Ports funds (40%), private capital (28%), and port authority funds (32%). The procedure will lead to a competitive tender to select the final developer and operator for the installation and operation of the hydrogen refuelling infrastructure.

4.4.3 Relevant initiatives in Croatia

National R&D & Strategy Alignment

The national strategy explicitly states support for education, research, innovation, science–industry collaboration and technology development in hydrogen production, transport and use — giving strategic backing for any coordinated funding applications that include infrastructure R&D or demonstration elements.

Initiatives in the context of the North Adriatic Hydrogen Valley

Croatian oil and gas company INA received €15 million from the Government of Croatia for its project for the production and distribution of hydrogen in transport. The total value of the first project for the commercial production of green hydrogen in Croatia is estimated at €45.5 million, according to the Ministry of Economy. The ministry approved the grant to INA, owned by Hungary-based MOL Group, for investment in the project for the production and distribution of hydrogen in transport. It provided the funds from the National Recovery and Resilience Plan (NRRP), under the European Union's Recovery and Resilience Facility (RSF). In April last year, INA signed a contract with the selected contractor for the construction of a green hydrogen plant at its refinery in Rijeka.

The hydrogen production and distribution project envisages the installation of a 10 MW electrolyzer and an 11 MW solar power plant, which would provide part of the electricity for electrolyzer operation, the ministry specified in its decision. The investments in the electrolyzer and photovoltaic plant are estimated at an overall €40.2 million.

Though not a pure financial investor, Lürssen Design Center Kvarner (based in Rijeka) coordinates the ZEAS (Zero Emission Adriatic Ship) project—a Horizon Europe-funded consortium designing and building a hydrogen-powered passenger vessel for the Adriatic. Croatian partners include Jadrolinija, Gitone Kvarner, the University of Rijeka Maritime Faculty, the Maritime Center of Excellence, Scan Projekt, and the Croatian Hydrogen Association. These private and semi-private entities contribute expertise, co-financing, and in-kind investment capacity toward hydrogen propulsion and associated infrastructure demonstration.

5 Investment and economic feasibility

This Chapter provides site-specific investment insights for the three TransH2 pilot cases, applying the general financing frameworks documented in Chapter 4 to the particular contexts of Trieste, Split, and Zadar. While Chapter 4 described available funding instruments and their operational mechanisms (Innovation Fund, AFIF, IPCEI, national programmes, private finance vehicles), this chapter addresses how to combine these instruments strategically based on each location's documented supply chain positioning, institutional readiness, and project-specific requirements established in Chapter 3.

The investment strategies presented here combine established facts from preceding analysis with reasoned deductions and strategic hypotheses. Where this chapter proposes specific financing allocations or approaches, these should be understood as indicative frameworks requiring validation through actual funding call outcomes, stakeholder negotiations, and market conditions at time of implementation

5.1 Overview on funding and investment mix in Italy

The financing strategy for Trieste is informed by several documented characteristics established in Chapters 3.3 and 4.3.1: proximity to hydrogen production facilities (Monfalcone at approximately 35 km, Hydrogen Hub Trieste in port area, both operational 2025-2026 per Section 3.3.4), existence of PNRR-funded hydrogen infrastructure (€15.8M Hydrogen Hub Trieste allocation per Section 4.3.1), TEN-T core network status (Ch. 3.3), and availability of regional funding mechanisms (Friuli Venezia Giulia allocations documented in Ch. 4.3.1). Based on the cost analysis in Ch. 3.3, Trieste's delivered hydrogen cost is estimated at €7-9/kg compared to €9-13/kg for supply-constrained scenarios, suggesting a structural OPEX advantage of approximately €0.7M-€1.4M annually at reference throughput (360 000 kg/year). This cost positioning, combined with institutional capacity demonstrated through active PNRR implementation, provides a foundation for constructing a financing strategy that leverages both EU and national instruments while attracting private capital through improved project economics.

5.1.1 EU funding & grants (non-dilutive support)

Innovation Fund (Hydrogen Auction Premiums)

Use the Innovation Fund hydrogen auction mechanism to secure output-based premiums (€/kg H_2 produced/bunkered) over up to 10 years. This directly supports revenue and improves bankability for early operations. While specific winners are finalized case-by-case, Italy has been active and Innovation Fund continues to invest heavily in hydrogen technologies across Europe.

The mechanism is detailed in Ch. 4.2.1; for Trieste, the delivered hydrogen costs (€7-9/kg as estimated in Section 3.3.2) suggest that competitive bid pricing may be achievable, though actual auction outcomes depend on competing project economics and available budget at time of call. The premium may bridge the gap between levelized cost of hydrogen and market price, with revenue support potentially equivalent to 20-30% of project IRR contribution based on typical auction outcomes documented in Ch. 4.2.1.

Alternative Fuels Infrastructure Facility (AFIF) — CEF Transport

Apply for AFIF funding under the Alternative Fuels Infrastructure Facility to support the construction of alternative fuels infrastructure (including hydrogen refuelling stations and related bunkering), ideally in combination with private finance for blended capital. The AFIF budget is significant and can be open for proposals with cut-off dates (e.g., 11 June 2025 and future rounds). As documented in Ch. 4.2.2, AFIF provides grants covering 30-50% of eligible CAPEX, with higher co-financing rates potentially available for projects demonstrating strategic TEN-T alignment or multimodal integration. Use AFIF to co-finance CAPEX up to 50% (or more where relevant), blended with private debt/equity and complement AFIF with Innovation Fund premium for revenue support.

TEN-T / CEF Synergies

Trieste as a key Trans-European Transport Network (TEN-T) node qualifies strategically for connecting hydrogen infrastructure with multimodal freight and maritime corridors; projects aligned with CEF climate transition goals are more competitive.

5.1.2 National funding (Italy)

PNRR (National Recovery and Resilience Plan)

Trieste already benefits from a Hydrogen Hub project funded through PNRR (€15.8M) plus Horizon Europe contributions, including electrolysis and PV capacity, demonstrating Italy's commitment to regional hydrogen value chains.

National grants / incentives for clean fuels

• Italy's Ministry of Infrastructure and Transport may support alternative fuel stations under broader transport decarbonisation calls (e.g., AFIR-aligned investments).

• Complementary national funds may be available for energy transition infrastructure and industrial decarbonisation.

5.1.3 Regional funding (Friuli Venezia Giulia)

Regional grants & innovation programs

The Friuli Venezia Giulia region has allocated millions in regional funds to hydrogen research infrastructure and pilot projects (see Ch.4.3.1 - par. *Regional funding instruments*)

PSC and LR 13/2023, *art. 7 – Ricerca nel settore idrogeno rinnovabile*

- Application deadline 26.09.2025
- N. 7 Agreements
- N. 37 new research contracts planned

Research bodies and financial allocation:

- Trieste Scientific and Technological Research Area – Area Science Park: € 790 000
- Consiglio Nazionale delle Ricerche (CNR): € 365 000
- Elettra – Sincrotrone Trieste S.C.p.A.: € 320 000
- Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS): € 410 000
- Scuola Internazionale Superiore di Studi Avanzati (SISSA): € 185 000
- Università degli Studi di Trieste: € 1 485 000
- Università degli Studi di Udine: € 1 145 000

Total resources: €4 700 000

Funded projects:

- H2 Smart Campus (AREA)
- SURFACE (CNR IOM)
- i-CAMPUS-Op (Elettra Sincrotrone Trieste)
- IHOST (OGS)
- H2SmartLab (SISSA)
- RISE-H2 (UNITS)
- Udine Hydrogen Research Center – UD-H2 (UNIUD)

These demonstrate a regional focus on developing hydrogen ecosystem capabilities that can underpin infrastructure deployment.

More recently, as documented in Chapter 4.3.1 (par. *PNRR-related regional implementation measures for renewable hydrogen (2023–2025) & "Flagship projects" call for renewable hydrogen production in disused industrial areas (2025)*), FVG allocated approximately €15M for flagship renewable hydrogen production projects in brownfield areas (2025) and €10M for research infrastructures (2024).

Interregional & Cross-Border Initiatives

Transnational hydrogen initiatives in the North Adriatic area constitute an important driver for joint innovation and may create synergies with EU programmes that involve multi-regional or multi-state consortia; for further details on the specific investments, see Chapter 4.4.1.

5.1.4 Public-Private Partnerships (PPPs)

Port Authority + Private Developer Concession

Structure the HRS as a concession with the Port Authority of Trieste, where: the port authority contributes land, permitting support, infrastructure interfaces, and facilitation of maritime customers, while the private partner provides equity and operational expertise (often via special purpose vehicle).

This allocation of responsibilities is consistent with PPP structures described in Section 4.4.1, where public entities typically provide land and regulatory coordination while private operators assume technology and operational performance risk. For Trieste, the Port Authority (AdSP) could contribute land concession within the port area, coordinate permitting processes with fire services and maritime authorities, and potentially aggregate demand through commitment to convert port-owned vessel fleet (tugs, pilot boats, service vessels) to hydrogen, providing baseline utilization guarantees that de-risk private investment. The private partner, potentially an energy company, a maritime operator, or a specialized hydrogen infrastructure developer, would provide equity capital, procure HRS equipment, manage construction, and operate the facility under a long-term concession agreement.

Risk Sharing & Availability Payments

PPP may include availability payments or minimum revenue guarantees from the public side tied to service availability, further de-risking debt service.

Such mechanisms are particularly relevant in early-stage hydrogen markets where utilization ramp-up creates cash flow uncertainty.

Integration into Broader Infrastructure Projects

The HRS rollout into broader multimodal energy transition investments (shore power, electrification services), making the PPP more attractive and complex.

Co-location with shore power infrastructure, for example, may allow shared electrical grid connection, transformer capacity, and potentially civil works, reducing incremental HRS infrastructure costs. Integration with port electrification strategy (electric cranes, charging infrastructure for port equipment and trucks) could create economies of scope in planning, permitting, and operations. This bundled approach may be more attractive to private infrastructure investors seeking larger-scale, diversified port energy transition portfolios, and could facilitate green bond issuance (discussed in Ch. 5.1.5) at viable scale.

5.1.5 5. Green / Blue Bonds & Thematic Capital Markets Instruments

Green Bonds

This instrument could be activated through the Port Authority (sub-sovereign issuer), or a special purpose joint venture with private sponsor and institutional partner. Use proceeds to fund the CAPEX of hydrogen bunkering infrastructure, aligned with the EU Taxonomy's clean fuels and transport infrastructure categories.

Blue Bonds

Leverage port's maritime decarbonisation and coastal ecosystem benefits to attract blue bond investors by highlighting maritime emission reductions, cleaner air quality in coastal zones and alignment with Sustainable Blue Economy objectives.

Green/blue bonds can attract pension funds and ESG-oriented capital, reducing WACC and extending tenor beyond what typical project finance alone can achieve.

The blue bond framing emphasizes not only climate benefits but also air quality improvements in port and urban coastal areas (reduction of NOx, SOx, particulate matter from shipping), marine ecosystem protection through zero-emission shipping corridors, and sustainable blue economy development aligned with EU Blue Economy objectives. However, the blue bond market remains smaller and less mature than the broader green bond market, and certification frameworks are still evolving, which may limit immediate applicability pending market development.

5.1.6 Commercial Debt & Institutional Investors

Senior Project Finance Debt

Secure long-term loans (up to 15–20 years) from commercial banks and/or the European Investment Bank (EIB) or national promotional banks — possibly with public guarantees or partial credit enhancements.

For Trieste, potential debt providers include EIB (which has mandate for climate infrastructure and TEN-T projects), CDP (Cassa Depositi e Prestiti, Italian promotional bank with favorable pricing for strategic infrastructure), and commercial banks with project finance capabilities. Debt structuring would typically target loan-to-value ratios of 60-70% of total CAPEX, with tenor of 15 years matched to operational cash flow profile. Given the estimated CAPEX of €7.0M for reference HRS capacity (Ch. 3.3.3), and assuming grant coverage of 60-70% (€4.2M-€4.9M from AFIF, PNRR, and regional sources), the remaining €2.1M-€2.8M could be financed through a combination of debt (€1.1M-€1.5M) and equity (€0.7M-€1.0M). Bankability depends on operational cash flow projections, which in turn depend critically on Innovation Fund revenue support (as hydrogen sales revenue alone at uncertain market prices may be insufficient for debt service in early operational years) and ferry operator offtake commitments providing volume certainty. Credit enhancement through public guarantees (SACE, Italian export credit agency, or InvestEU instruments) could improve pricing and enable higher leverage, but would require specific negotiation with guarantee providers.

Institutional Equity / Co-Investment Funds

Attract equity from energy transition funds, hydrogen tech funds (such as emerging European hydrogen tech investment funds), or strategic partners in energy/maritime sectors.

Table 11 shows an indicative financing structure combining the documented funding instrument parameters from Ch. 4 with Trieste-specific strategic context established in Ch. 3.3 and 5.1. The allocations represent typical share ranges observed in comparable hydrogen infrastructure projects and should be understood as targets subject to refinement based on actual call outcomes, competitive evaluation results, stakeholder negotiations, and market conditions at time of financial close.

Source	Role	Typical Share
Innovation Fund Premium (€/kg)	Revenue support bridging gap	20–30% of IRR support
AFIF (CEF Transport)	CAPEX Co-financing	30–50% of eligible CAPEX
PNRR / National Grants	Strategic build-out	15–25%
Regional FVG Funds	Innovation, R&D complement	5–10%
Port Authority PPP Equity	Equity anchor	10–20%
Green/Blue Bonds	Medium/long debt, low cost	30–50%
Commercial/Promotional Bank Debt	Project finance	30–40%

Table 11 - Example Optimal Mix (Indicative)

5.2 Overview on funding and investment mix in Croatia

The financing strategy for Croatian pilot cases is based on the supply chain and institutional characteristics described in Ch. 3.4, 3.5, and 4.3.2. Both Split and Zadar face the constraint of no confirmed local hydrogen production, with potential supply distances of 150-400+ km from Zagreb region, cross-border suppliers, or future coastal facilities (Ch 3.4.4, 3.5.4), resulting in estimated delivered hydrogen costs of €9-13/kg for Split and €8.5-13.5/kg for Zadar compared to €7-9/kg for Trieste. This cost differential of approximately €2-4/kg translates to roughly €0.7M-€1.4M/year higher OPEX at reference throughput (360,000 kg/year), which materially impacts project economics and necessitates higher public co-financing to compensate for elevated operational risk. Croatia's hydrogen market is nascent, with the National Hydrogen Programme allocating ~€29.6M for HRS deployment (Ch. 4.3.2) and precedents like the INA Rijeka project (€45.5M total, €15M RRP grant) demonstrating emerging institutional capacity but limited operational experience with maritime hydrogen infrastructure. These factors suggest that Croatian cases require financing structures with higher grant shares (60-70% or above for demonstration-focused approaches) and a strong fund revenue support to bridge the cost gap and attract private capital. The analysis below examines how to combine Croatian national programmes, EU instruments, and private finance to address these constraints while managing investment risk through phased deployment where appropriate.

5.2.1 National Support for Hydrogen Refuelling Stations (HRS)

Croatian Ministry Funding Programme

Croatia has launched a dedicated subsidy programme targeted at constructing hydrogen refuelling stations for vehicles (cars, buses, trucks) as part of accelerating decarbonisation of transport, including hydrogen uptake in mobility infrastructure. The programme allocates a total of about €29.6 million, of which aprox €23 million is earmarked for hydrogen refuelling infrastructure deployment over the next few years, with around 65 % of funding expected to be rolled out in the first year.

It aims to install at least six hydrogen stations by 2026 on key transport corridors, potentially expandable depending on project proposals and planning.

This call is managed at the national level via the Ministry of Economy and Sustainable Development and could be leveraged for a Split or Zadar HRS if that location aligns with Croatia's broader alternative fuels deployment strategy.

As mentioned in Ch. 4.3.2, the programme currently targets road transport applications with per-station support ceilings of up to approximately €2M for passenger vehicle stations and up to €3.5M for bus/heavy-duty applications. Maritime HRS are not explicitly included in the programme scope as currently defined, which creates an eligibility uncertainty that requires resolution through proactive stakeholder engagement with the Ministry of Economy and Ministry of Sea, Transport and Infrastructure. Given that Split and Zadar are TEN-T comprehensive network nodes with significant maritime transport functions (Ch. 3.4.1, 3.5.1), there is a reasonable basis for advocating that port-based HRS serving ferry operations should be accommodated within the programme's TEN-T corridor deployment logic. If maritime HRS eligibility is confirmed, it would be reasonable to target the upper end of documented support ranges (€2.5M-€3.5M per station) given higher technical complexity and larger daily capacity requirements compared to road HRS. For a €7.0M CAPEX station, this would represent 36-50% public co-financing from the national programme alone, providing a substantial anchor for overall financing structure. However, absent ministerial confirmation of eligibility, this funding source remains contingent and alternative scenarios must be maintained

5.2.2 EU Funds & CEF/AFIF (Alternative Fuels Infrastructure Facility)

AFIF / CEF Transport for Split and Zadar HRS or Bunkering

The Alternative Fuels Infrastructure Facility (AFIF), under the Connecting Europe Facility (CEF) – Transport programme, finances infrastructure rollouts for alternative fuels including hydrogen refuelling and, importantly, supply to ports and maritime applications. This means projects at or near the Port of Zadar could qualify, especially if integrated with broader TEN-T network goals or linked multimodal transport infrastructure. As detailed in Ch. 4.2.2, AFIF operates through rolling calls with co-financing rates typically in the range of 30-50% of eligible CAPEX, with potential for higher rates for cohesion country projects (Croatia qualifies) or demonstration/lighthouse initiatives. The total AFIF budget for 2024-2025 was approximately €1B, with 208 projects funded since 2021 representing €1.3B in EU contributions.

Infrastructure may include hydrogen refuelling stations for vehicles and vessels, plus relevant supply systems at port locations. Eligible projects must be mature and often supported by implementing partners or financial institutions (e.g., EIB, national promotional banks). Infrastructure may include hydrogen refuelling stations for vehicles and vessels, plus relevant supply systems at port locations. Eligible projects must be mature and often supported by implementing partners or financial institutions (e.g., EIB, national promotional banks)

AFIF is ideal for CAPEX co-financing, helping reduce upfront investment costs when blended with national or regional co-financing and private capital. For Croatian maritime HRS, application strategy should emphasize lighthouse/demonstration value (first Croatian maritime hydrogen infrastructure, knowledge creation for broader Adriatic replication), cohesion country status, TEN-T alignment, and island connectivity social/environmental benefits. A coordinated approach presenting Split and Zadar as an integrated Croatian maritime hydrogen corridor demonstration could strengthen competitiveness relative to standalone applications. Based on documented AFIF parameters and strategic positioning, it is reasonable to target co-financing at 40-50% of eligible CAPEX (€2.8M-€3.5M for €7.0M project), though actual outcomes depend on competitive evaluation against other European projects and available budget at call cut-off dates. Technical assistance from EIB via JASPERS (Joint Assistance to Support Projects in European Regions) programme could support application preparation and improve quality, particularly given an ascent institutional experience with hydrogen project development in Croatian context.

EU Innovation Fund (Revenue Support)

Although not Croatia-specific, the EU Innovation Fund offers output-based support (e.g., premiums per kg of hydrogen produced/sold) for advanced clean hydrogen projects in Member States. This could support a hydrogen production + refuelling hub concept in Split or Zadar by bridging revenue gaps, especially for green hydrogen supply that ties into broader maritime and mobility decarbonisation.

This aligns with EU climate and industrial policy priorities and supports commercial sustainability through revenue incentives.

As documented in Ch. 4.2.1, the Innovation Fund operates through competitive auctions where projects bid a fixed premium per kg of hydrogen that bridges the gap between levelized cost and expected market price. For Croatian cases, given the elevated delivered hydrogen costs documented in Sections 3.4.2 and 3.5.2 (€9-13/kg range), the premium required to achieve commercial viability would be in the range of €3-9/kg depending on market price assumptions (€4-6/kg market price based on FuelEU Maritime compliance economics, though this is uncertain). This represents a higher bid price than lower-cost supply regions, which could reduce competitiveness in EU-wide auctions. However, bids can emphasize demonstration value for supply-constrained regions (a common scenario across much of Europe where production infrastructure is not yet proximate to demand centres), island connectivity social benefits, and knowledge creation for replicability. Without Innovation Fund revenue support, the operational economics of Croatian cases are fundamentally challenged, as hydrogen procurement costs alone (€9-13/kg) plus operational overhead would exceed likely market revenue, making the premium not merely beneficial but essential for project viability. This creates significant dependency on auction outcomes, which cannot be guaranteed ex-ante and introduce material execution risk that must be acknowledged in financing planning

Interregional & Collaborative Platforms: North Adriatic Clean Hydrogen Investment Platform (NACHIP)

Split and Zadar, as part of Croatia's North Adriatic region, are connected to the NACHIP initiative, which supports hydrogen value-chain innovation across Croatia, Slovenia, and Italy. A €7.6 million ERDF grant was awarded to support hydrogen projects and SME integration in hydrogen value chains. While this is more innovation and acceleration focused, it provides a cascade financing opportunity at TRL 6–9 and can help integrate smaller partners or technology pilots into broader infrastructure work.

As discussed in Ch. 4.3.2, NACHIP's primary role is complementary funding for innovation/demonstration components rather than core infrastructure CAPEX. Potential applications for Split and Zadar HRS include advanced monitoring and digitalization systems (real-time hydrogen quality sensors, predictive maintenance platforms), enhanced safety innovations (beyond standard requirements), SME integration funding for Croatian equipment suppliers or service providers participating in HRS supply chain, and workforce training programmes. Beyond direct financing, NACHIP provides access to transnational knowledge networks connecting Croatian projects to Italian and Slovenian hydrogen initiatives, which could facilitate technical assistance, regulatory best practice sharing, and capacity building to address institutional learning curve constraints documented in the strategic context above.

Environmental and Energy Efficiency Fund (FZOEU)

The Croatian Environmental Protection and Energy Efficiency Fund runs grant schemes that can co-finance development of hydrogen fuelling (charging) stations alongside electric charging infrastructure: grants at ~40 % co-financing were provided along in last presented calls, although relatively small, which can complement larger funding packages for demonstration projects or smaller hydrogen refueling components linked to broader Zadar sustainable mobility plans.

Given the modest scale of FZOEU grants relative to total HRS CAPEX requirements, this funding source should be positioned as gap-filling rather than foundational. Target allocation might be €0.3M-€0.5M for specific components such as grid connection, electrical infrastructure (transformers, backup power), civil works (site preparation, foundations), or safety equipment (fire suppression, ventilation systems). Application approach could involve municipal or county co-applicants (City of Split/Zadar, Splitsko-dalmatinska županija / Zadarska županija) and framing as part of integrated port green transition encompassing HRS alongside shore power and electrification initiatives, which may strengthen eligibility within FZOEU programme objectives.

Broader National Mobility Strategy

Croatia's National Recovery and Resilience Plan (RRP) and national policy frameworks support hydrogen refuelling stations development by 2026 across the country, financially supported by the Ministry of Economy and the Ministry of Sea, Transport and Infrastructure.

CEF-linked support for hydrogen stations along TEN-T and strategic routes to expand alternative fuel infrastructure. This points to policy alignment and funding prioritisation that a Split or Zadar project could tap into by aligning with national decarbonisation strategy and TEN-T network planning.

The Croatian Hydrogen Strategy to 2050 (see Ch. 4.3.2) provides strategic policy backing for hydrogen infrastructure development, though specific implementation mechanisms and funding allocations are still being established. The INA Rijeka green hydrogen project (€45.5M total value, €15M RRP grant as per Ch. 4.3.2) demonstrates that Croatian RRP resources can support hydrogen infrastructure, with approximately 33% public co-financing in that case. While INA Rijeka focuses on production rather than refuelling infrastructure, the precedent suggests that RRP or sectoral maritime decarbonization budgets could potentially contribute 10-20% of HRS CAPEX (~€0.7M-€1.4M) if the project is positioned as integral to Croatian maritime decarbonization strategy and FuelEU Maritime compliance for state-subsidized island ferry services (Jadrolinija operations).

Local / Regional Context — Zadar & EU Funds Awareness

Currently there is no evidence about specific Zadar-only funding call for hydrogen infrastructure, local actors (City of Zadar, Zadarska županija, development agencies) are actively engaged in EU fund promotion and capacity building events to help stakeholders access EU programmes. This includes information campaigns and partnerships to increase project readiness for EU calls. This institutional engagement, while not translating to dedicated local funding at present, indicates capacity building trajectory and stakeholder awareness that can support project preparation and application processes. Local actors' familiarity with EU funding mechanisms may facilitate coordination for AFIF applications, national programme engagement, and PPP structuring, even absent direct municipal or county financial contribution. Should future regional or local funding opportunities emerge (analogous to FVG regional hydrogen calls documented in Section 4.3.1), the existing engagement infrastructure could enable rapid mobilization.

Source	Instrument / Programme	Role in Project	Typical Share	Key Notes for Zadar
EU Innovation Fund	Hydrogen Auction (€/kg premium)	Revenue support to bridge LCOH–market gap (covers OPEX + risk)	*Revenue support equivalent to* **20–30% of project IRR uplift**	Particularly relevant if linked to green hydrogen production and maritime offtake; improves bankability but does not fund upfront CAPEX
CEF – AFIF (EU)	Grant + Blended finance	CAPEX co-financing for refuelling/ bunkering infrastructure	**30–50% of eligible CAPEX**	Strong fit for port-based infrastructure and TEN-T alignment; can be combined with national co-financing
Croatian National Hydrogen Programme	Direct national grants	Deployment of hydrogen refuelling stations	**15–25% of CAPEX**	National budget (~€29.6m) explicitly targets hydrogen stations; key anchor for Croatia-based HRS
Croatian RRP / Sectoral Funds	Recovery & resilience funding	Strategic infrastructure and clean mobility	**10–20% of CAPEX**	Best used if integrated into wider transport or port decarbonisation plans
Regional / Interregional (ERDF, NACHIP)	Cascade or complementary grants	Innovation, pilots, SME integration	**5–10%**	Useful for early deployment, digitalisation, safety systems, or cross-border Adriatic cooperation
Public Partner (PPP)	Port authority / municipality contribution	Land, permits, basic infrastructure, equity	**5–15% (in-kind + equity)**	Port of Zadar can contribute land, grid access, demand aggregation, lowering project risk
Green / Blue Bonds	Thematic bond issuance	Long-term CAPEX financing	**25–40% of total CAPEX**	Attractive for port-related assets with long lifetimes; blue bond angle strengthens maritime narrative
Senior Debt (EIB / Banks)	Project finance loans	Remaining CAPEX financing	**20–35%**	Credit enhanced by grants, PPP structure and Innovation Fund revenue support

Source	Instrument / Programme	Role in Project	Typical Share	Key Notes for Zadar
Private Equity	Sponsor / strategic investor	Risk capital, development and operations	**10–20%**	Typically energy, port services or hydrogen infrastructure operators

Table 12 - Example Optimal Financing Mix – Hydrogen Refuelling / Bunkering Station (Zadar)

5.2.3 Local / Regional Context - Trieste Public investment already mobilised (risk mitigation context)

The Friuli Venezia Giulia area, where Trieste is located, benefits from public investment already mobilised at EU, national and regional level, including the amounts described in the former chapters, Chapter 4.3.1 and 5.3.1:

- 8.8 million € (out of the total amount of 25 million €) EU contribution under NAHV (Horizon Europe – Clean Hydrogen Joint Undertaking);
- €15.8 million PNRR funding for renewable hydrogen production in Trieste;
- €11.2 million for hydrogen-related research infrastructures;
- €4.7 million for hydrogen R&D projects;
- approximately €15 million for flagship renewable hydrogen production projects.

These investments primarily reduce technology risk, strengthen production capacity and consolidate ecosystem maturity. They do not directly finance maritime hydrogen refuelling stations but contribute to lowering systemic and coordination risk.

5.2.4 Forward-looking EU and national funding opportunities

Beyond funding already allocated, several instruments remain potentially accessible for future hydrogen refuelling infrastructure projects:

- Clean Hydrogen Joint Undertaking (Horizon Europe): annual calls supporting demonstration projects (TRL 6–8), including infrastructure-related topics;

- Connecting Europe Facility (Alternative Fuels Infrastructure Facility – AFIF): blending facility combining grants with financial institution support;
- Innovation Fund: support for large-scale industrial decarbonisation projects involving renewable hydrogen;
- ERDF (FESR) mid-term reprogramming at regional level (Friuli Venezia Giulai): announced allocation to renewable energy infrastructure and industrial hydrogen projects;
- National alternative fuels infrastructure schemes aligned with AFIR implementation.

Access to such instruments is competitive and subject to call conditions; however, their existence reduces the likelihood that refuelling infrastructure would rely exclusively on private capital.

5.2.5 Indicative structuring considerations

Hydrogen refuelling infrastructure in port environments may be structured through a combination of public grants and private capital. An indicative (non-binding) structuring logic could include:

- Grant component (EU or national): partial CAPEX coverage;
- Regional co-financing: complementary support for infrastructure integration;
- Private equity: risk-bearing capital absorbing initial market uncertainty;
- debt financing: subject to revenue visibility and demand stability.

In such a structure, public funding primarily reduces capital intensity and mitigates early-stage technology and market risk, while private actors retain exposure to demand evolution and operational performance.

The feasibility of any specific structure would depend on project scale, offtake agreements, regulatory clarity and eligibility under applicable funding calls.

6 Summary of key findings

The potential implementation of hydrogen refuelling stations across selected port-related use cases within the Adriatic Sea basin has been assessed from an economic point of view. The analysis considers the current state of the art in terms of hydrogen demand, pricing dynamics, and the availability of supporting infrastructure at different territorial scales.

From a broader perspective, the analysis highlights a recognised need to further enhance and deploy dedicated hydrogen infrastructure, a condition that is closely linked to the establishment of an enabling framework for the uptake of hydrogen in transport applications, with particular reference to the maritime sector.

Within this context, a set of actions and pilot initiatives has been outlined. While Croatia is currently progressing towards the development of its first pilot installations, Italy is characterised by a more advanced level of engagement, reflecting a longer-standing involvement in hydrogen-related initiatives.

The architecture of the hydrogen refuelling station is connected to the most suitable form and the connected transport and logistic aspect. With this regard, the gaseous form supplied via tube trailers/trucks is the most realistic solution, even if it is not the cheapest in the long term compared to other solutions (e.g. pipelines, which require structured investment).

The topic of hydrogen propulsion is still under an intense research, development and innovation phase and availability of data and economic estimates are often fragmented and not available for all the use cases available. In these terms, the report integrates an aggregation of the most recent inputs and explains the significant impact of CAPEX costs on the equipment necessary for structuring the station. On the other side, OPEX are strictly related to the distance from the production point. In this regard, the Trieste use case could be facilitated by the availability of hydrogen production sites in the area, whereas the Zadar and Split use cases should consider the significant cost implications. In parallel, producing hydrogen on site would incur additional operating costs for Croatian use cases (production is not analysed in this report).

With regard to funding instruments that may support investment processes at the dedicated sites, several relevant measures have been implemented at European level, notably through the Innovation Fund, the CEF and IPCEI funding schemes - within which Italy has participated in dedicated project initiatives -. In addition, National initiatives under the National Resilience Plan, together with Regional funding instruments (e.g. those of the Friuli Venezia Giulia Region), have supported specific segments of investment and deployment plans for hydrogen infrastructure and related activities, thereby contributing to the development of local hydrogen ecosystems.

Finally, private investment and financial instruments are increasingly engaging with hydrogen-related projects, primarily in response to decarbonisation priorities. However, such investments are required to carefully account for the significant impact of CAPEX on both investment decisions and scaling dynamics. In this context, particularly for capital-intensive deployments, public–private partnerships may play a central role in enabling project implementation and risk-sharing.

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