



Project TransH2

Training Course Material for TTE Activities and Joint Educational Scheme

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Abstract

This document presents the Training Course Material for Transnational Training and Educational (TTE) Activities and the Joint Educational Scheme (deliverable 3.2.1), developed within the Interreg Italy–Croatia TransH2 project. It provides a structured framework for capacity building aimed at supporting the transition towards zero-emission maritime transport through the adoption of hydrogen technologies and digital solutions. The document outlines the educational objectives, methodology, thematic training areas, expected learning outcomes and supporting resources, while compiling expert presentation materials, recommended publications and reference sources. It serves as a practical guide for implementing the Joint Educational Scheme and as a lasting educational resource for stakeholders across the Adriatic region.



Introduction

The transition towards zero-emission maritime transport represents one of the key priorities of the European Green Deal, requiring coordinated action from public authorities, industry, research organizations and transport stakeholders. Achieving climate-neutral maritime transport in the Adriatic Sea demands not only technological innovation, but also the development of knowledge, skills, and cross-border cooperation necessary to support the deployment of sustainable solutions. In this context, hydrogen technologies, digitalization, and integrated planning are emerging as essential enablers of the decarbonization of the maritime sector.

Within the TransH2 project, capacity building is a fundamental prerequisite for accelerating the adoption of green hydrogen and other zero-emission technologies in maritime transport. While significant technological advancements are being made across Europe, their successful implementation depends on increasing awareness, strengthening technical competencies, and facilitating knowledge exchange among all relevant stakeholders. Addressing these needs requires structured educational activities that combine scientific knowledge, practical experience, policy perspectives, and real-life use cases.

Project Overview

TransH2 (Transition to Hydrogen Fuelled Cross-Border Sea-Mobility) project brings together partners from Croatia and Italy with the common objective of accelerating the transition towards sustainable, climate-resilient and zero-emission maritime transport in the Adriatic Sea by promoting the use of green hydrogen as an alternative marine fuel. The project addresses one of the major challenges of the Adriatic programme area, the need to



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decarbonize maritime transport and modernize port infrastructure while maintaining efficient cross-border connectivity.

Project activities focus on analyzing and identifying suitable maritime routes for hydrogen deployment, developing conceptual designs for hydrogen-powered passenger vessels, preparing feasibility studies for hydrogen refueling infrastructure in ports, and creating a joint cross-border strategy and investment framework for the long-term adoption of zero-emission maritime transport. In parallel, the project establishes a cross-border collaboration network that brings together public authorities, ports, transport operators, research organizations, industry representatives and other stakeholders to facilitate knowledge exchange and future cooperation.

An important component of the project is capacity building through the implementation of Transnational Training and Educational (TTE) activities and a Joint Educational Scheme, aimed at strengthening stakeholders' knowledge of hydrogen technologies, digital solutions, regulatory developments and practical implementation approaches. By combining research results, pilot activities and educational actions, TransH2 contributes to increasing regional readiness for the deployment of zero-emission maritime transport while supporting the wider objectives of the European Green Deal.

Purpose of This Document

This document presents the training course materials developed jointly by the project partners and experts to support the implementation of the Transnational Training and Educational (TTE) activities and the Joint Educational Scheme within the TransH2 project. The materials have been prepared collaboratively by Croatian and Italian partners and experts, reflecting the cross-border character of the project and ensuring that the educational content addresses the shared challenges and opportunities of the Adriatic maritime region.



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It aims to strengthen the knowledge and capacities of key maritime stakeholders by providing a structured overview of the regulatory framework, hydrogen technologies, digital solutions, industry best practices and practical experiences that support the transition towards sustainable, zero-emission maritime transport in the Adriatic Sea. It can also serve as a reference resource for the replication and wider dissemination of the project's educational outcomes beyond the project lifetime.

Objectives of the Educational Scheme

The Joint Educational Scheme aims to strengthen the knowledge, technical capacities and cross-border cooperation of key stakeholders involved in the transition towards zero-emission maritime transport in the Adriatic Sea. Through a series of transnational training and educational (TTE) events, 2 organized in Croatia and 2 organized in Italy, the programme should provide participants with a comprehensive understanding of hydrogen technologies, digital solutions, regulatory frameworks, industry developments and practical implementation approaches supporting the decarbonization of maritime transport. By combining scientific expertise, policy perspectives, industrial case studies and lessons learned from the project's pilot activities, the educational scheme aims to facilitate knowledge transfer, promote the uptake of innovative hydrogen-based solutions, encourage collaboration among Croatian and Italian stakeholders, and support the wider replication of good practices across the Adriatic region and beyond.

The Transnational Training and Educational (TTE) Scheme represents a key capacity-building output of the TransH2 project (output 3.1). By jointly developing and delivering a series of four interconnected training events, two scheduled to take place in Zagreb and organized by Croatian Chamber of Economy and Urbanex, and two in Trieste, organized by University of Trieste and MARE FVG, the project enables the transfer of knowledge on zero-emission maritime transport, green hydrogen applications and the open-source TransH2 solution to a broad range of stakeholders from Croatia, Italy and beyond through the participation of at



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least 50 representatives from public authorities, ports, transport operators, research institutions, industry and other relevant organizations.

Target Audience

The Joint Educational Scheme is intended for a broad range of stakeholders involved in the planning, regulation, operation and development of sustainable maritime transport in the Adriatic region. Its primary target groups include port authorities, maritime and public transport operators, shipbuilders, technology providers, classification societies, regional and national public authorities, development agencies, research and higher education institutions, and organizations involved in innovation, energy and transport planning. The programme is also relevant for industry representatives, policy makers and other organizations interested in the deployment of hydrogen technologies and digital solutions for maritime decarbonization.

Although mainly aimed at stakeholders from the Italy–Croatia Programme area, the Transnational Training and Educational (TTE) activities are also open to participants from neighbouring Adriatic and other European countries to facilitate wider knowledge exchange, promote the transferability of project results, and encourage the replication of zero-emission maritime transport solutions beyond the programme area.



Methodology

The educational methodology adopted within the TransH2 project is based on an interdisciplinary and collaborative learning approach that combines theoretical knowledge with practical experience and cross-border knowledge exchange. Rather than focusing solely on the technical aspects of hydrogen technologies, the training programme is designed to provide participants with a comprehensive understanding of the policy, regulatory, technological, environmental and economic dimensions of the transition towards zero-emission maritime transport. This integrated approach enables stakeholders from different sectors to understand not only the individual components of the hydrogen value chain, but also the interactions between technology, infrastructure, legislation, investment and market development.

The Joint Educational Scheme will be implemented through a series of Transnational Training and Educational (TTE) events jointly organized by Croatian and Italian project partners. Each training session will combine expert presentations, thematic lectures, practical case studies, demonstrations of innovative technologies, and interactive discussions. The participation of representatives from public authorities, ports, research institutions, universities, industry, technology providers and maritime organizations should ensure that the educational content reflects both scientific developments and real-world implementation experiences. This multidisciplinary environment will foster dialogue among stakeholders, encourage the exchange of perspectives and facilitate the identification of common challenges and opportunities across the Adriatic region.

Through the analysis of existing projects, emerging technologies and implementation experiences, participants will gain insights into successful approaches, potential barriers and lessons learned that can support future deployment activities. Interactive discussions and question-and-answer sessions will further encourage participants to share their own experiences, discuss local challenges and explore opportunities for cooperation and replication.



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The educational methodology should also promote continuous knowledge transfer beyond the duration of the training events. The developed training materials are intended to serve as a long-term reference resource that can be reused by project partners and other organizations for future educational activities, awareness-raising initiatives and capacity-building programmes. In this way, the Joint Educational Scheme contributes not only to strengthening the competencies of individual participants but also to building a sustainable knowledge base that supports the wider adoption of hydrogen technologies and zero-emission maritime transport solutions throughout the Adriatic region and beyond.



Suggested Thematic Areas

The Joint Educational Scheme is organized around a series of interconnected thematic areas that collectively address the key aspects of the transition towards zero-emission maritime transport. The selected topics provide participants with a balanced understanding of the policy framework, technological developments, industry perspectives and practical implementation approaches required for the deployment of hydrogen-powered maritime solutions in the Adriatic Sea. Together, these thematic areas create a progressive learning pathway, moving from fundamental concepts and the current state of the sector towards future developments, innovative technologies and practical applications that support the decarbonization of maritime transport.

1. Introduction to Zero-Emission Maritime Transport in the Adriatic Sea

This thematic area introduces the concept of zero-emission maritime transport and its importance in achieving European and national climate objectives. It provides an overview of the environmental impacts of conventional maritime transport, the policy drivers behind decarbonization, and the role of alternative fuels in reducing greenhouse gas emissions.

Participants are introduced to the European Green Deal, the Sustainable and Smart Mobility Strategy, FuelEU Maritime, the Alternative Fuels Infrastructure Regulation (AFIR), and other relevant policy initiatives shaping the future of maritime transport. The module also explains why the Adriatic Sea represents a strategic region for demonstrating zero-emission solutions, considering its intensive passenger traffic, island connectivity, tourism and cross-border transport links.

2. Current State of Zero-Emission Maritime Transport in the Adriatic Sea

This thematic area examines the current level of development and deployment of zero-emission technologies in the maritime sector, with particular emphasis on the Adriatic



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region. Presentation could include ongoing European and national initiatives, existing hydrogen and alternative fuel projects, infrastructure readiness, technological maturity and market developments.

Other subject matters could include the current barriers affecting implementation, including infrastructure limitations, investment needs, regulatory uncertainty, technological challenges and stakeholder readiness. By analyzing the existing landscape, participants should gain a realistic understanding of both the opportunities and constraints influencing the transition towards zero-emission shipping.

3. Future of Zero-Emission Maritime Transport in the Adriatic Sea

Building upon the assessment of the current situation, this thematic area explores future pathways for achieving climate-neutral maritime transport. It examines expected technological advancements, policy developments, funding opportunities and investment priorities that will shape the next generation of sustainable maritime transport solutions.

The module discusses the future role of hydrogen and other renewable fuels, the evolution of maritime infrastructure, emerging vessel technologies and the importance of cross-border cooperation in accelerating market uptake. Participants are encouraged to consider long-term scenarios and identify actions needed to facilitate the widespread adoption of zero-emission maritime transport throughout the Adriatic region.

4. Role of the Adriatic Maritime Industry in the Transition to Zero-Emission Shipping

This thematic area explores the roles and responsibilities of shipbuilders, ports, transport operators, technology providers, classification societies, public authorities and research institutions in supporting the deployment of hydrogen-powered maritime solutions.



The module should explore the importance of innovation, industrial cooperation, investment and workforce development, while emphasizing the need for coordinated action among public and private stakeholders. Practical examples demonstrate how collaboration across sectors can accelerate technology adoption and strengthen regional competitiveness.

5. How Digital Technologies Can Be Used to Achieve Zero-Emission Maritime Transport in the Adriatic Sea

Digitalization is recognized as a key enabler of the green transition in maritime transport. This thematic area presents the role of digital technologies in improving operational efficiency, supporting infrastructure planning and optimizing the integration of hydrogen technologies into maritime transport systems.

Topics include digital twins, smart port solutions, artificial intelligence, big data analytics, predictive maintenance, energy management systems and decision-support tools. Participants gain insight into how digital innovation complements alternative fuels by increasing safety, reducing operational costs and enabling data-driven decision-making throughout the maritime ecosystem.

6. Hydrogen as a Source of Power for Zero-Emission Maritime Transport in the Adriatic Sea

Hydrogen is considered one of the most promising alternative fuels for achieving zero-emission maritime transport. This thematic area provides participants with a comprehensive overview of hydrogen technologies and their application within the maritime sector.

The module covers the hydrogen value chain, including renewable hydrogen production, storage, distribution, bunkering infrastructure, propulsion technologies, fuel cells, safety considerations and regulatory requirements. It also presents practical examples of



hydrogen-powered vessels, pilot projects and demonstration initiatives, illustrating the technological potential, implementation challenges and future opportunities for hydrogen deployment in the Adriatic maritime sector.

Lessons Learned and Main Expected Outcomes

The Joint Educational Scheme is designed not only to transfer knowledge but also to strengthen the long-term capacity of stakeholders to actively contribute to the transition towards zero-emission maritime transport. By bringing together expertise from academia, industry, public authorities and research organizations, the training programme promotes a shared understanding of the challenges and opportunities associated with hydrogen technologies and sustainable maritime mobility. The educational activities encourage interdisciplinary dialogue, facilitate the exchange of experiences and support the development of practical solutions that can be replicated across the Adriatic region.

Lessons Learned

The implementation of the educational programme is expected to demonstrate that the successful transition towards zero-emission maritime transport requires coordinated action across multiple sectors and governance levels. While technological innovation plays a central role, its deployment depends equally on supportive regulatory frameworks, adequate infrastructure, strategic investment planning and continuous stakeholder engagement.

The training activities should also highlight the importance of cross-border cooperation in addressing common challenges within the Adriatic Sea. Knowledge exchange between Croatian and Italian partners enables participants to compare national approaches, identify



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common priorities and develop a shared vision for the future deployment of hydrogen technologies in maritime transport.

The role of digitalization as an essential complement to alternative fuels should also be highlighted. Digital technologies, including digital twins, smart port systems and data-driven decision-support tools, significantly improve planning, operational efficiency and infrastructure management, increasing the feasibility and effectiveness of zero-emission maritime solutions.

Finally, the programme demonstrates that capacity building is a key enabler of innovation. Increasing the knowledge and competencies of stakeholders helps reduce uncertainty, supports informed decision-making and creates favourable conditions for the wider adoption of hydrogen technologies within the maritime sector.

Key Expected Outcomes

The educational programme is expected to deliver the following key outcomes:

- Increased knowledge and awareness of zero-emission maritime transport concepts, hydrogen technologies and digital solutions among maritime stakeholders.
- Better understanding of European and national regulatory frameworks supporting maritime decarbonization.
- Improved capacity of stakeholders to plan, evaluate and implement hydrogen-based maritime transport solutions.
- Strengthened cross-border cooperation and knowledge exchange between Croatian and Italian stakeholders, while fostering engagement with participants from countries beyond the programme area.
- Greater dissemination of good practices, pilot experiences and innovative approaches supporting the replication of zero-emission maritime transport solutions.



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- Establishment of reusable training materials that continue to support education, awareness-raising and capacity building beyond the duration of the TransH2 project.
- Increased readiness of ports, transport operators and public authorities to contribute to the development of a hydrogen-based maritime ecosystem in the Adriatic region.



Training Resources

The following resources support the delivery of the Joint Educational Scheme and provide reliable sources of information for the training activities. They include presentation materials, key publications, relevant legislation, technical standards and online resources covering hydrogen technologies, zero-emission maritime transport and the broader policy framework for maritime decarbonization.

Presentation Materials

The following presentation materials, available in appendix, support the delivery of the Joint Educational Scheme and the TTE activities:

- Alternative Fuels – With Focus on Maritime Transport, by Vesna Kučan Polak of Croatian Hydrocarbon Agency
- Hydrogen in Maritime: State of the Art and Perspectives, by assoc. prof. Ankica Kovač, PhD of Faculty of Mechanical Engineering and Naval Architecture (University of Zagreb)
- Analysis of the Applicability, Relevance, and Challenges of Implementing Hydrogen as an Energy Source/Carrier in Croatian and Regional Mobility, by Dražen Vrhovski, EERING Consultancy
- Contribution of the Interreg Framework to the Operational Use of Hydrogen in the Adriatic Maritime Transport Sector, by Dražen Vrhovski, EERING Consultancy
- sHYps-Viking Hydrogen, by Stefano Quattrini, R&D, Viking Newbuilding and Viking Hydrogen – Viking Cruises
- Unlocking hydrogen in the maritime industry, by Marco Molica Colella, Funding Team Manager, Hydrogen Europe
- Onboard utilization of liquid hydrogen: an overview, by prof. Rodolfo Taccani, University of Trieste



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- Designing Digital Twins for Energy Transitions: The H₂Smart Lab Approach, by Alberto Soraci, Technologist – Area Science Park
- Zero emissions maritime propulsion: alt-fuels & digitalization, by Fabrizio Cadenaro, Lead Specialist Alternative Fuels – Lloyd's Register
- DIGITal Twin applications for the PORT of Trieste, by Giacomo Morassutti, Strategic Planning and Innovation Department – Port Authority of the Eastern Adriatic Sea
- Hydrogen Hub Trieste, by Massimo Giacomini, New Vectors Development Facilities – AcegasApsAmga

The presentation materials included in Appendix 1 form the core educational resources used during the Transnational Training and Educational (TTE) activities. Prepared and delivered by experts from academia, public institutions, industry and research organizations, these presentations provide participants with a comprehensive overview of the key topics addressed within the Joint Educational Scheme. Covering policy and regulatory frameworks, hydrogen technologies, maritime applications, digitalization, industrial case studies and practical implementation experiences, the materials combine scientific knowledge with real-world examples to support capacity building and facilitate knowledge transfer. As such, they serve both as reference materials for the training sessions and as a lasting educational resource for stakeholders interested in the transition towards zero-emission maritime transport.

Recommended Publications

European Commission

Publication	Source
A European Green Deal	European Commission – <i>The European Green Deal</i> https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en



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Sustainable and Smart Mobility Strategy	European Commission – <i>Sustainable and Smart Mobility Strategy</i> https://transport.ec.europa.eu/transport-themes/mobility-strategy_en
EU Hydrogen Strategy	European Commission – <i>A Hydrogen Strategy for a Climate-Neutral Europe</i> https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en
REPowerEU Plan	European Commission – <i>REPowerEU Plan</i> https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en
Industrial Action Plan for the European Automotive Sector	European Commission – <i>Automotive Package – For a Clean and Competitive Automotive Sector</i> https://transport.ec.europa.eu/transport-themes/action-plan-future-automotive-sector/automotive-package_en
FuelEU Maritime Regulation	European Commission – Decarbonising maritime transport – FuelEU Maritime https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime_en
Alternative Fuels Infrastructure Regulation (AFIR)	European Commission - Alternative Fuels Infrastructure Regulation https://transport.ec.europa.eu/transport-themes/clean-transport/alternative-fuels-sustainable-mobility-europe/alternative-fuels-infrastructure_en

European Maritime Safety Agency (EMSA)

Publication	Source
Potential of Hydrogen as Fuel for Shipping	European Maritime Safety Agency (EMSA). <i>Potential of Hydrogen as Fuel for Shipping</i> (Technical Report, 2023). https://www.emsa.europa.eu/publications/reports/item/5062-potential-of-hydrogen-as-fuel-for-shipping.html



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Alternative Fuels and Sustainable Shipping Resources	European Maritime Safety Agency (EMSA). <i>Alternative Sources of Power for Shipping</i> . https://www.emsa.europa.eu/sustainable-shipping/alternative-fuels.html
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Hydrogen Europe

Publication	Source
Hydrogen Europe (Official Website)	https://hydrogeneurope.eu/ – Official website, providing policy updates, news, publications and information on the European hydrogen ecosystem.
Reports	https://hydrogeneurope.eu/reports/ – Collection of technical reports, market analyses and policy studies.
Position Papers	https://hydrogeneurope.eu/policy-priorities/position-papers/ – Position papers and policy recommendations on hydrogen deployment, transport, infrastructure and industrial decarbonisation.
Quarterly Magazine (H2 Talks)	https://hydrogeneurope.eu/h2-talks/quarterly-magazine/ – Quarterly publication featuring analyses, interviews and updates on hydrogen technologies, policy and market developments

Clean Hydrogen Partnership

Publication	Source
Clean Hydrogen Partnership – Official Website	https://www.clean-hydrogen.europa.eu/ – Official portal with information on EU-funded hydrogen research and innovation, projects, funding opportunities and knowledge resources
Strategic Research and Innovation Agenda (SRIA) 2021–2027	https://www.clean-hydrogen.europa.eu/about-us/key-documents/strategic-research-and-innovation-agenda_en – The Partnership's flagship strategic document outlining research priorities, technology roadmaps and innovation objectives under Horizon Europe



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Technical Standards

Publication	Source
ISO – Hydrogen Standards Portal	https://www.iso.org/sectors/energy/hydrogen – Official ISO portal covering standards for hydrogen production, storage, transport, fuelling, fuel quality and safety
IEC – Technical Committee 105: Fuel Cell Technologies	https://www.iec.ch/dyn/www/f?p=103:7:0:::FSP_ORG_ID:1316 – Official IEC Technical Committee responsible for the IEC 62282 series on fuel cell technologies
IMO – International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code)	https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.391(95).pdf Official IMO page for the IGF Code governing the safe design and operation of ships using alternative fuels.
CEN- CENELEC – Hydrogen Standardization	https://www.cenelec.eu/areas-of-work/cenelec-sectors/energy-and-utilities-cenelec/hydrogen/ – European standardisation activities for hydrogen, including technical committees, the Hydrogen Standardization Landscape and links to the European Clean Hydrogen Alliance Roadmap



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European Hydrogen Observatory – Codes and Standards Database	https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/policies-and-standards/codes-and-standards – Searchable database of European and international hydrogen-related standards (ISO, IEC, EN and others)
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Useful Websites

	Website	Description
European Commission – Mobility and Transport (DG MOVE)	https://transport.ec.europa.eu	EU transport policies, sustainable mobility initiatives, FuelEU Maritime, AFIR and maritime decarbonisation.
European Commission – Energy (DG ENER)	https://energy.ec.europa.eu	EU energy policy, hydrogen strategy, renewable energy and energy system integration.
European Commission – Climate Action (DG CLIMA)	https://climate.ec.europa.eu	Climate policy, European Green Deal, Fit for 55 and EU climate legislation.
Clean Hydrogen Partnership	https://www.clean-hydrogen.europa.eu	EU public-private partnership supporting research, innovation and deployment of hydrogen technologies through Horizon Europe
European Hydrogen Observatory	https://observatory.clean-hydrogen.europa.eu	Comprehensive platform providing data, market intelligence, policies, standards, projects and statistics on the European hydrogen sector.



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Hydrogen Europe	https://hydrogeneurope.eu	European industry association representing the hydrogen sector, offering publications, policy updates, reports and technical resources.
Hydrogen Europe Research	https://hydrogeneuroperesearch.eu	European network of universities and research organisations supporting hydrogen research and innovation
European Maritime Safety Agency (EMSA)	https://www.emsa.europa.eu	Technical guidance, studies and resources on sustainable shipping, alternative fuels and maritime safety.
International Maritime Organization (IMO)	https://www.imo.org	International regulations, conventions, codes and guidance related to maritime safety, environmental protection and shipping decarbonisation.
European Alternative Fuels Observatory (EAFO)	https://alternative-fuels-observatory.ec.europa.eu	European database on alternative fuels infrastructure, policies, market developments and statistics.
CORDIS – EU Research Results	https://cordis.europa.eu	Repository of EU-funded research and innovation projects, including hydrogen, maritime transport and energy transition initiatives.
CEN-CENELEC Hydrogen Standardization	https://www.cenelec.eu/areas-of-work/cenelec-sectors/energy-and-utilities-cenelec/hydrogen/	European standardisation activities, technical committees and guidance related to hydrogen technologies.
ISO – Hydrogen Standards	https://www.iso.org/sectors/energy/hydrogen	Official ISO portal providing information on hydrogen-related international standards.



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National and Regional Hydrogen Initiatives

In addition to the European policy framework, several national and regional initiatives play a significant role in accelerating the deployment of hydrogen technologies and supporting the transition towards zero-emission transport. These initiatives provide strategic guidance, promote research and innovation, facilitate cross-sector cooperation, and support the development of hydrogen infrastructure and regional hydrogen ecosystems.

Initiative	Country/ Region	Official Website	Relevance
North Adriatic Hydrogen Valley (NAHV)	Croatia – Italy – Slovenia	https://www.nahv.eu	The first transnational Hydrogen Valley in the EU, integrating renewable hydrogen production, storage, distribution and end-use across industry, energy and transport. It serves as the most relevant strategic initiative for the deployment of hydrogen solutions in the Adriatic region and provides a valuable framework for the replication of TransH2 results
NACHIP – North Adriatic Clean Hydrogen Investment Platform	Croatia – Italy – Slovenia	https://www.nachip.eu	EU-funded initiative supporting the North Adriatic hydrogen ecosystem by accelerating hydrogen technologies, developing investment-ready pilot projects, supporting SMEs through cascade funding and strengthening cross-border hydrogen value chains.
H2IT – Italian Hydrogen and Fuel Cell Association	Italy	https://www.h2it.it	National association representing Italian companies, research organisations and institutions active in the hydrogen sector. It promotes hydrogen technologies through policy advocacy, technical working groups, market studies and stakeholder networking.



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Croatian Hydrogen Association (H2 Croatia)	Croatia	https://croh2.fesb.unist.hr/	National association promoting the development and application of hydrogen technologies through research, education, international cooperation and knowledge exchange among academia, industry and public authorities.
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Conclusion

The Joint Educational Scheme provides a structured framework for strengthening the knowledge and capacities of stakeholders involved in the transition towards zero-emission maritime transport in the Adriatic Sea. Through a combination of expert-led presentations, practical case studies and cross-border knowledge exchange, the programme enhances participants' understanding of hydrogen technologies, digital solutions, regulatory frameworks and implementation challenges. The training materials developed within the TransH2 project serve as a lasting educational resource, supporting the continued dissemination of project results, fostering cooperation among maritime stakeholders and facilitating the wider adoption and replication of hydrogen-based solutions in the Adriatic region.



Appendix 1

Presentation Material



Interreg



Co-funded by
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Croatian Hydrocarbon Agency

Vesna Kučan Polak

PROJECT TransH2

TRANSITION TO HYDROGEN FUELLED
CROSS-BORDER SEA-MOBILITY

Alternative Fuels – with Focus on Maritime Transport

TTE event | 22nd May 2026

**Production and Use of Hydrogen in Croatia
Today,
Goals for Croatia**

1

Key findings of the “*Study for the Development and Implementation Plan of the Croatian Hydrogen Strategy until 2050*”

**Regulatory Framework for Maritime
Decarbonisation**

2

Framework overview and
examples of implementation in
Member States

**Alternative Fuels in Maritime
Transport**

3

Overview of fuel types, and
applications in maritime
transport





- 2020.  The **European Hydrogen Strategy** for a Climate-Neutral Europe, adopted in July 2020, highlights the significance of scaling-up hydrogen applications as essential for the comprehensive decarbonisation of the economy, particularly within the energy sector, to meet the 2050 climate neutrality goals.
- 2021.  The “Fit-for-55 Package”, presented in July 2021 and subsequently adopted, puts forward several legislative proposals that translate, among others, the European Hydrogen Strategy into a concrete European hydrogen policy framework. This includes proposals to set targets for the uptake of renewable hydrogen in industry and transport by 2030.
- 2022.  **Repower EU Plan** accelerated hydrogen deployment by setting a target of domestic production of 10 million tonnes of hydrogen per year by 2030, importing another 10 million tonnes per year, and distributing the combined quantities throughout Europe.
-  **Croatia adopted the Hydrogen Strategy of the Republic of Croatia Until 2050** , outlining a national framework for hydrogen production and use, focusing on renewable and low-carbon hydrogen as alternatives to fossil fuels.
- 2023.  **Croatian Hydrocarbon Agency (CHA)** becomes the national coordinating body for hydrogen (Official Gazette 83/23)
- 2024.  *A **Study for the Development and Implementation Plan of the Croatian Hydrogen Strategy until 2050** has been prepared*

1. Potential for the Production and use of Renewable Hydrogen

Hydrogen: energy storage, feedstock, chemical

- The hydrogen value chain comprises production, distribution, storage, and application
- **Industrial applications** of hydrogen include chemical production and refining, reducing fossil fuel dependency and CO2 emissions.
- In the **energy sector**, hydrogen plays a crucial role as an energy carrier to balance seasonal fluctuations of renewable energies and to stabilize the electricity grid.
- In the **transport sector**, hydrogen is crucial for decarbonisation, particularly where electrification is challenging.



*“Alternative fuels” means fuels or power sources that serve, at least partly, as a substitute for fossil oil sources in the energy supply to transport and which have the potential to contribute to its decarbonisation and enhance the environmental performance of the transport sector: **electricity, hydrogen, biofuels, synthetic and paraffinic fuels**, natural gas, including biomethane, in gaseous form (compressed natural gas (CNG), liquefied natural gas (liquefied natural gas (LNG), liquefied petroleum gas (LPG).*

The **RED III Directive** sets ambitious targets to increase the share of **renewable energy** in the European Union's total energy consumption, supporting the transition towards a net-zero emissions economy by 2050.

The Renewable Energy Directive (RED) and its amendments define:

- “**renewable fuels**” means biofuels, bioliquids, biomass fuels and renewable fuels of non-biological origin (**RFNBO**)
- “**renewable fuels of non-biological origin**” means liquid and gaseous fuels the energy content of which is derived from renewable sources other than biomass; i.e. hydrogen produced from renewable electricity

EU regulations affecting the use of RFNBOs



Sector	INDUSTRY	TRANSPORT	MARITIME	MARITIME	AVIATION
Regulation	RED III	RED III	RED III	FuelEU Maritime	ReFuelEU Aviation
RFNBO Targets	2030: 42% RFNBO 2035: 60% RFNBO of H2 energy and non-energy consumption	2030: 5.5% of fuels must be advanced biofuels or RFNBO, Minimum share of 1% RFNBO	2030: RFNBO: 1.2% of the total amount of energy supplied to maritime transport section	<ul style="list-style-type: none"> • Incentives for RFNBO use until 2031 • mandatory share of 2% from 2034 if RFNBO < 1% in 2031 	Synthetic fuel share: 2030: > 0.7% 2040: > 8% 2050: > 28%
	↓	↓	↓		↓
Minimum Hydrogen Demand for Croatia to meet the RFNBO targets 2030	21.5 kt	3.81 kt	0.13 kt	-	0.017 kt
TOTAL Minimum Demand 2030: ~ 25.5 kt					

Reduction of CO2-eq emissions (tCO2)through the use of renewable hydrogen in **maritime transport**, compared to fossil fuel consumption:



2030: 4.538
2040: 8.233
2050: 12.602

Fit for 55

FuelEU Maritime

- promotes the use of renewable and low-carbon fuels
- Sets limits on GHG intensity of energy used by ships (>5,000 GT) – reaches up to 80% by 2050
- Requires shore-side electricity supply (OPS) or zero-emission tech at berth (passenger & container ships)

The Alternative Fuels Infrastructure Regulation (AFIR)

- main EU ports (TEN-T ports) – minimum OPS for ships
- availability of LNG refuelling infrastructure by 2025, with future planning for hydrogen, methanol and ammonia

The Renewable Energy Directive (RED III)

- includes maritime targets for the first time (1,2% RFNBO in shipping energy use by 2030)

The EU Emissions Trading System (EU ETS)

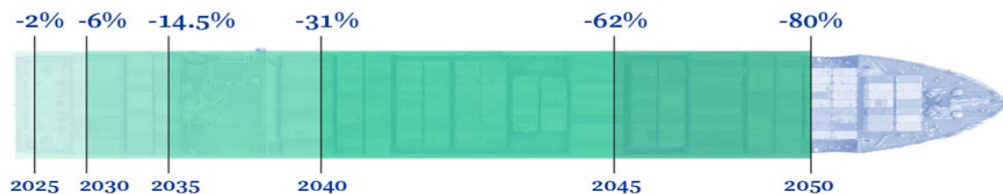
- The Fit for 55 package extends the existing ETS to new sectors, including shipping

The Energy Taxation Directive (ETD)

- Higher taxation for fossil fuel electricity and energy products used or sold on voyages within the EU

2. Regulatory Framework for Maritime Decarbonisation

Annual average carbon intensity reduction compared to the average in 2020



Croatian legislation

Law on the establishment of infrastructure for alternative fuels + AFIR

- Minimum requirements for the deployment of alternative fuels infrastructure

Law on the biofuels for transport

- Renewable fuels used in maritime sector are not included in the national transport target, but they can contribute to its achievement through a multiplier (1,2x), acting as an incentive

Law on climate change and ozone layer protection

- Includes maritime transport in EU ETS; applies to ships >5000 GT

Decarbonisation Technologies for the Transport Sector

Transport Sector

	Road Transport	Cars
		Delivery vehicles, vans
		Trucks & trailers
		City buses
		Construction vehicles
		Specialised vehicles, garbage trucks
	Rail	Passenger trains
		Freight trains
		Shunting locomotives
	Maritime / River	Ferries
		Passenger ships/small cruisers
		Cargo ships
		Tugboat
		Recreational vessels/yachts
	Air	Aircraft

Decarbonisation Technologies

Battery Electric Vehicle (BEV)
Electric with Overhead Wires
Internal Combustion Engine Vehicle (biofuels)
Hydrogen Internal Combustion Engine (ICEH2)
Hydrogen Fuel Cell Electric Vehicle (FCEV)
Jet Engine (hydrogen)
Methanol Fuel Cells
Internal Combustion Engine (e-fuels)
Internal Combustion Engine (ammonia)
Ammonia Fuel Cells
Jet Engine (e-fuels)

(Hydrogen-based technologies marked in blue)



Although hydrogen plays an important role, it is not a universal solution - especially in maritime transport.



EU regulatory framework does not prescribe a single fuel, but rather sets targets that can be met through different technologies.



Non-renewable alternative fuels and transitional fossil fuels

- Liquefied natural gas (LNG)
- Liquefied petroleum gas (LPG)
- Methanol

Renewable fuels

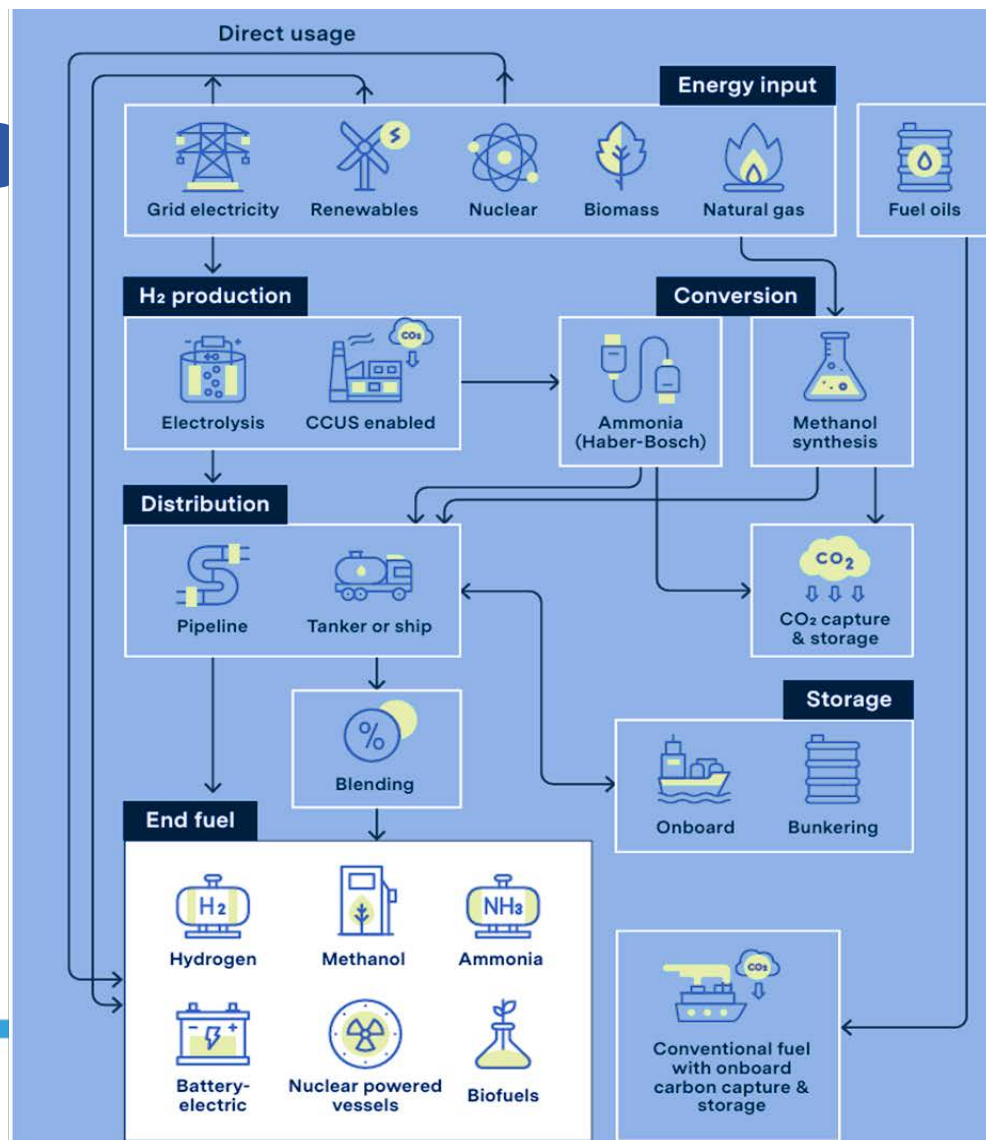
- Biofuels (biodiesel, biomethane, biomethanol)
- Synthetic fuels (e-diesel, e-methane, e-methanol)

Zero emission fuels

- Hydrogen
- Ammonia
- Electricity

Nuclear Energy*

3. Alternative Fuels in Maritime Transport



Shipping is a large consumer of fossil fuels, so the potential for the use of hydrogen as a fuel is high.

In the Republic of Croatia, about 310 vessels larger than 100 GT participate in maritime traffic.

Around 85% of these vessels are passenger ships and the rest are used for the transport of goods.

The potential for the use of hydrogen in Croatia's maritime sector, including ferries, small ships, and boats, presents a unique opportunity to both decarbonisation of the commercial shipping sector and enhancement of green tourism.

Maritime Transport

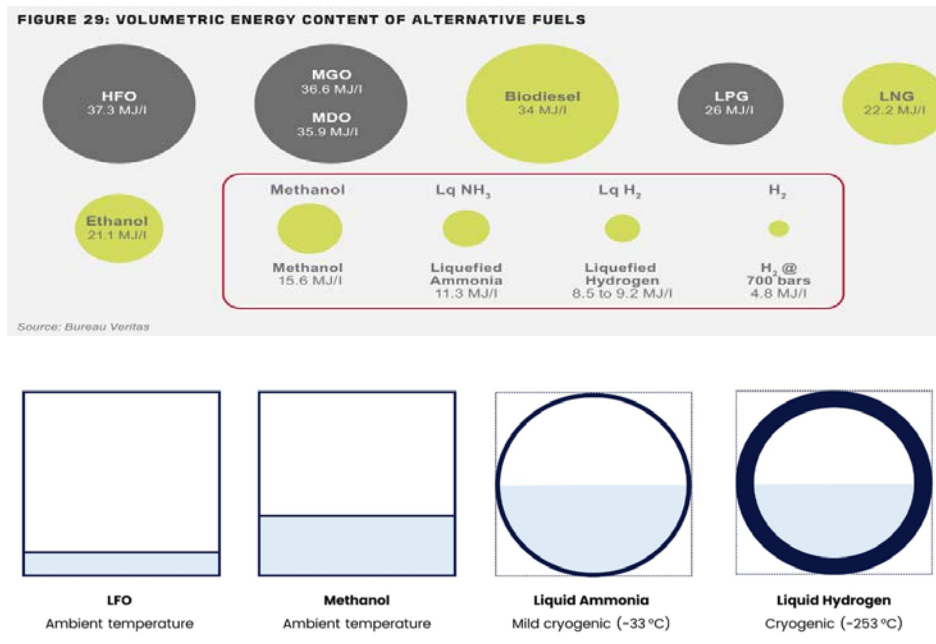


Expected Use of Renewable Hydrogen in Maritime Transport According to the Study's Baseline Scenario and Target Share

	2030	2040	2050
Share of renewable hydrogen in total maritime transport consumption	2.65%	5.00%	8.0%
Consumption of renewable hydrogen in maritime transport	432 t	784 t	1,200 t
Target according to RED III	>1.2%	-	-

Comparison of Alternative Marine Fuels

- Alternative fuels in general require more tank volume and/or complex storage systems
- Energy density of fuels varies significantly once translated into tank volume
- Conventional fuels (e.g. Heavy fuel oil) offer very high volumetric energy density - minimal tank space required
- Storage requirements vary widely - from simple ambient tanks (methanol) to complex pressurized and cryogenic systems (hydrogen)
- Taking into account both the fuel density and the storage system, the vessel endurance range indicates how often a vessel has to bunker energy



Izvor: Volumetric comparison marine fuels — Sustainable Ships

Table 6-1: Typical bunkering intervals for vessels using different alternative fuels

Fuel	HVO	LNG	LPG	Methanol	Liquid ammonia	Liquid hydrogen	Compressed hydrogen	Fully-electric
Vessel endurance range	Months	Weeks	Weeks	Weeks	Weeks	Days	Hours-days	Hours

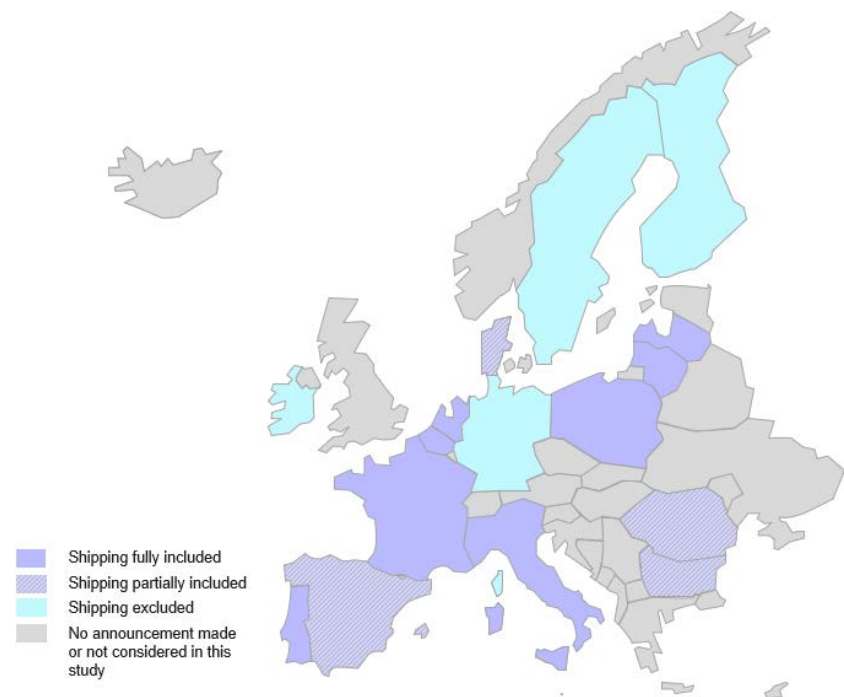
Izvor: *Alternative-Marine-Fuels-Study_final_report_25.09.19.pdf

Member states **are not required to set a mandate for all sectors**, as they need to achieve the **RED III objectives over the sum of all transport sectors**.

This has led some member states to exclude one or multiple sectors from the transposition.

- Aviation is excluded in most member states, since they generally consider ReFuelEU aviation sufficient to achieve their overall objectives.
- **The road and rail sectors are included in the transposition legislation for all member states**, with inland shipping included only in some.
- For maritime, many but not all of the concerned member states have at least partially included it in their transposition legislation.

Inclusion of shipping by member states in their RED III transposition



Source: Bureau Veritas

Specific Cases of some Member States



The Netherlands

Shipping inclusion:

Both national and international shipping are included, as well as inland shipping.

Flexibility is limited within the flexible credit allowance. The road sector's flexible allowance is 0%, which means that the maritime allowance will not be transferable to road transport, only to inland shipping.



Belgium

Shipping inclusion

National and international shipping included with different targets.

Compliance units can be transferred between obligated parties for a given sector (road, national shipping, international shipping) and between obligated parties in the maritime and road sectors.



Germany

Shipping inclusion

Shipping is fully excluded. Only the road sector is included.

Germany has removed maritime and aviation from the scope of its GHG intensity mandate, leaving only the road sector. In the current draft, it will not be possible to meet any GHG intensity targets from sustainable marine fuels.



France

Shipping inclusion

Both international and national shipping are included with the same progressive inclusion into the global GHG intensity target.

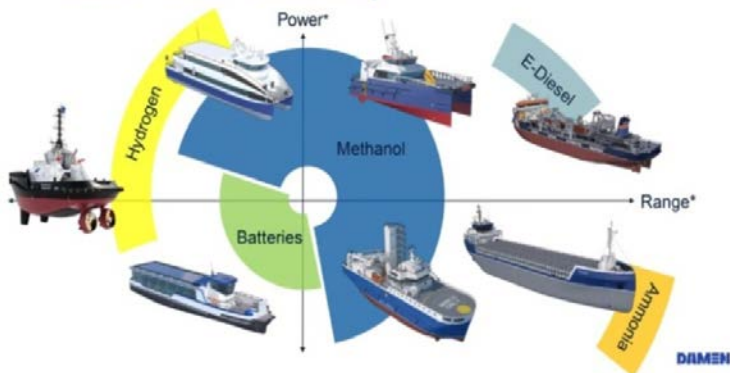
The GHG intensity target must be reached within the sector.

Certificates of renewable energy can be transferred to another obligated party in another sector using the same type of energy.

Due to different fuel characteristics, certain types and sizes of vessels will have different optimal solutions:

- **small- and medium-sized ships:**
 - batteries, hydrogen, bio-methanol, e-methanol
- **large ships in open seas:**
 - in the short term LNG
 - biofuels, ammonia, e-methanol, e-methane

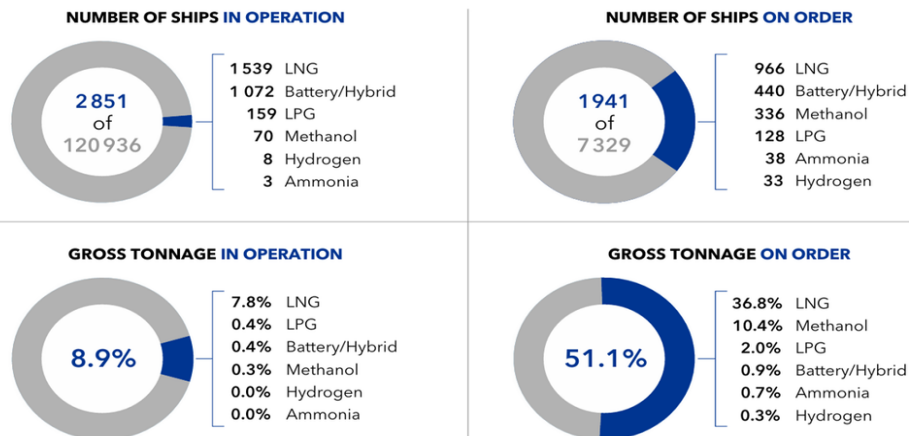
Future fuel roadmap



Alternative Fuel Ships

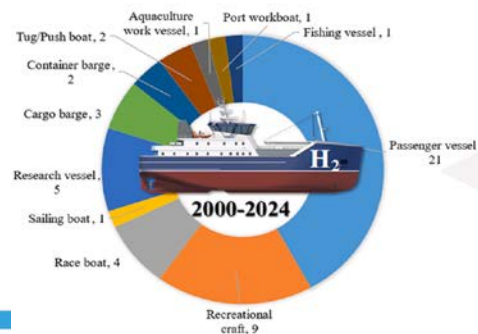
FIGURE 4-2

Alternative fuel technology uptake in the world fleet in the number of ships (upper) and gross tonnage (lower)



©DNV 2025

Sources: S&P Global, Alternative Fuels Insight (AFI) - afi.dnv.com, as of August 2025



Challenges:



Alternative Fuel Ships: Global Examples



MF Hydra (Norway)

- The first commercial hydrogen-powered ferry
- Projects: ferries, short-distance routes, pilot vessels
- Hydrogen is used in fuel cells → generates electrical energy
- The propulsion system is essentially electric (motor + batteries + fuel cell)



Sakigake (Japan)

- The first demonstration tugboat
- In development: bulk carriers and tankers
- Ammonia is combusted in the engine or used in fuel cells
- Often “dual-fuel” (ammonia + diesel)



Laura Maersk (Denmark)

- The first methanol-powered container ship
- Large-scale vessel orders (Maersk, CMA CGM)
- Methanol is combusted in engines (similar to diesel)
- Can operate as “dual-fuel”

Dual-fuel ships account for 75% of large containership orders, 20% of tankers, and 5% of bulkers.

Key Takeaways

Hydrogen has a key role



- Strong potential in transport, especially heavy-duty
- Important for sectors where electrification is limited

Regulation sets the direction



- EU framework defines targets, not technologies
- Flexibility allows different fuel pathways
- Member States adopt different approaches

But no single fuel is enough



- Maritime sector has diverse operational needs
- Technical and economic constraints vary by vessel type
- Multiple fuel solutions will coexist

What this means for maritime



- Portfolio of fuels: hydrogen, ammonia, methanol, biofuels
- Infrastructure and cost remain key challenges
- Gradual transition expected

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Assoc. Prof. Ankica Kovač, PhD
*University of Zagreb Faculty of
Mechanical Engineering and Naval
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PROJECT TransH2

TRANSITION TO HYDROGEN FUELLED CROSS-BORDER SEA-MOBILITY

Hydrogen in Maritime: State of the Art and Perspectives

TTE event | 22nd May 2026

About me..

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- In the top 2% of the world's most influential scientists.
- Head of Hydrogen Laboratory.
- Assistant Editor of International Journal of Hydrogen Energy.
- Evaluator within Horizon Europe, Clean Hydrogen Partnership, and Croatian Science Foundation.
- Founder and Chair of Renewable Hydrogen Energy Congress, RH2EC (<https://rh2ec.com>) and Training on Hydrogen and Fuel Cells (<https://h2res.com>).
- Designed first Croatian hydrogen-powered bicycle and installed first Croatian hydrogen refuelling station.
- Croatian representative in Hydrogen Europe Research.
- Member of Council of President of Republic of Croatia for Energy Transition.
- Vice President of Croatian Hydrogen Association.
- Vice President of Expert working group for development of Croatian Hydrogen Strategy.



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What Do We Know So Far?

- The sector's emissions are rising despite international and EU efforts, with maritime shipping responsible for around **3% of all global GHG emissions.**

If the sector were a country, it would be the world's sixth-largest GHG emitter.

- The IMO adopted a strategy to cut GHG emissions by 50% by 2050 and improve energy efficiency by 40% by 2030 compared to 2008.
- EU aims for a 55% reduction in emissions by 2030 and climate neutrality by 2050.
- The sector's emissions are projected to grow without swift mitigation measures, despite efficiency improvements.
- Ships are in service for over 30 years, requiring immediate action to replace fossil fuels with zero-carbon alternatives.



Transition from Fossil Fuels to Zero- Emission Ships

The industry faces challenges in replacing fossil fuels, with a small fleet (0.6%) using alternative fuels like LNG, methane, or biofuels as of 2020.

- Large ships require high energy density fuels, which current alternatives struggle to provide.
- Infrastructure development and supply chain security are critical for scaling up alternative fuels.
- Hydrogen and hydrogen-based fuels (ammonia, methanol) are promising, with the potential to meet technical and economic needs.
- Small vessels in ports and inland shipping are the initial focus for hydrogen adoption, aiming for zero-emission operations by 2030.

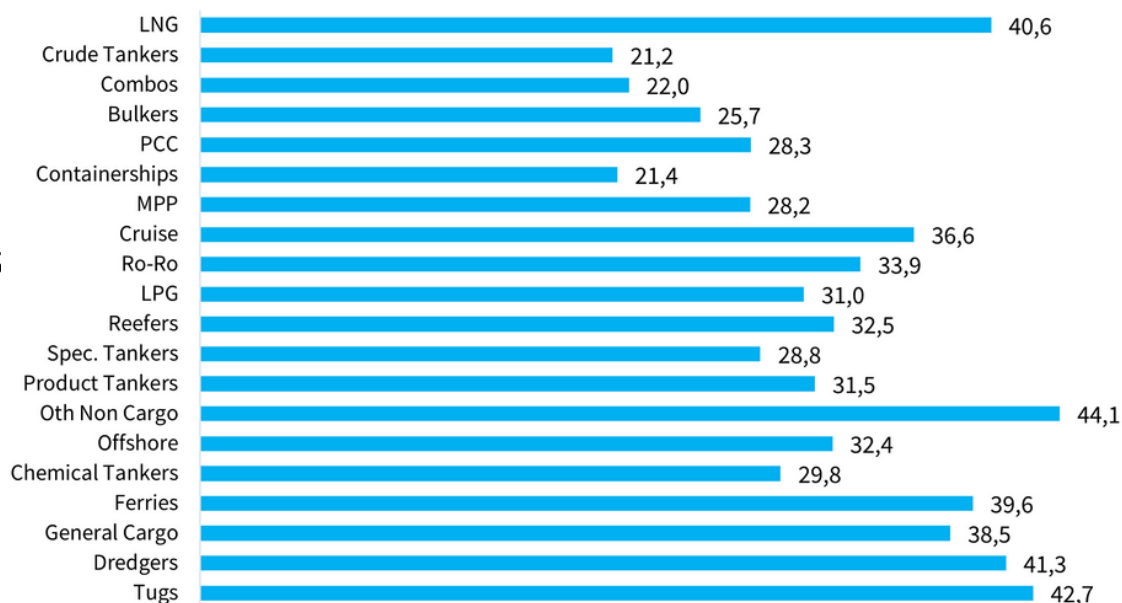


Urgency Due to Long Ship Lifetimes

Ships have an average lifetime of 30 years, necessitating immediate action to prevent continued reliance on fossil fuels.

- Over 50% of ships are over 15 years old with about 1/3 over 25 years old.
- Smaller ships, with an average age close to 40 years, offer high short-term hydrogen potential.
- Fleet renewal and new shipbuilding must incorporate zero-emission technologies to meet 2050 targets.
- The EU should legislate pathways for hydrogen-powered ships, with significant adoption expected by 2030.

source: Hydrogen Europe



Role and Potential of Hydrogen as Fuel

Hydrogen offers a zero-emission solution but faces challenges like high costs and storage.

- Hydrogen can be used in fuel cells or combustion engines, with efficiencies of 50-60% and 40-50%, respectively.
- Producing renewable hydrogen (green hydrogen) results in zero **Well-to-Wake GHG emissions.**
- Ammonia, derived from renewable hydrogen, is the most cost-effective synthetic fuel for large ships.
- Barriers include high hydrogen production costs, lack of bunkering infrastructure, and regulatory gaps.
- Hydrogen's role extends beyond shipping to sector coupling and broader decarbonization efforts, with a target of 10 million tonnes of EU hydrogen production by 2030.



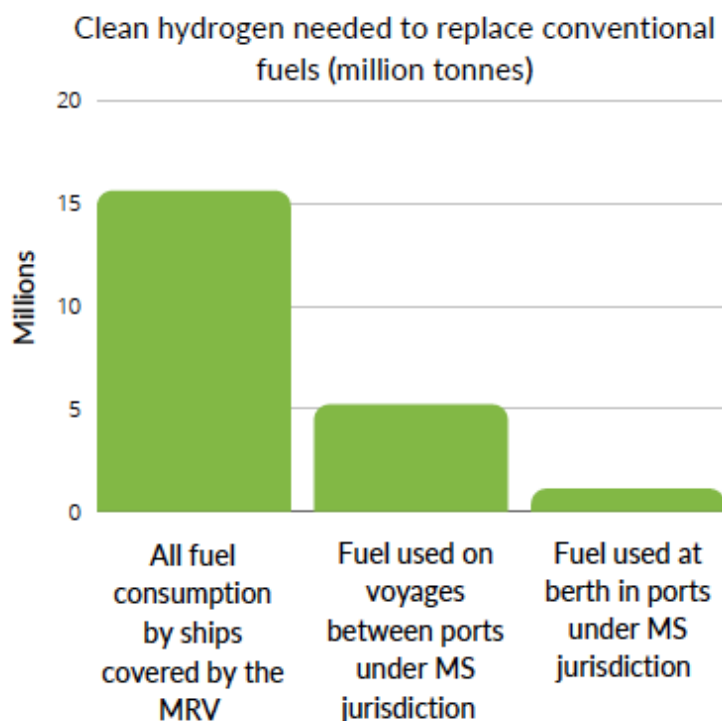
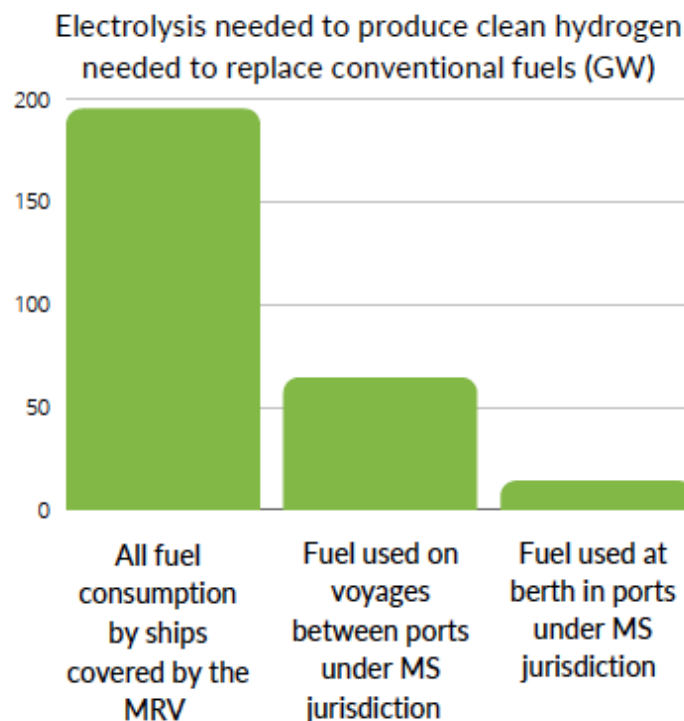
Hydrogen and Hydrogen-Based Fuels Technologies

Hydrogen can be stored as liquid, compressed gas, or chemically bound, and used in fuel cells or combustion engines.

- Fuel cells offer efficiencies of 50-60%, with potential for higher with heat recovery.
- Hydrogen-based fuels like ammonia and methanol are promising for large ships due to better volumetric energy density.
- Small vessels in ports and inland areas are ideal initial adopters, with infrastructure like HRS being developed.
- Hydrogen can provide auxiliary power for large ocean-going vessels (especially in ports) and main propulsion for smaller ships, such as ferries, tugboats, and inland vessels.



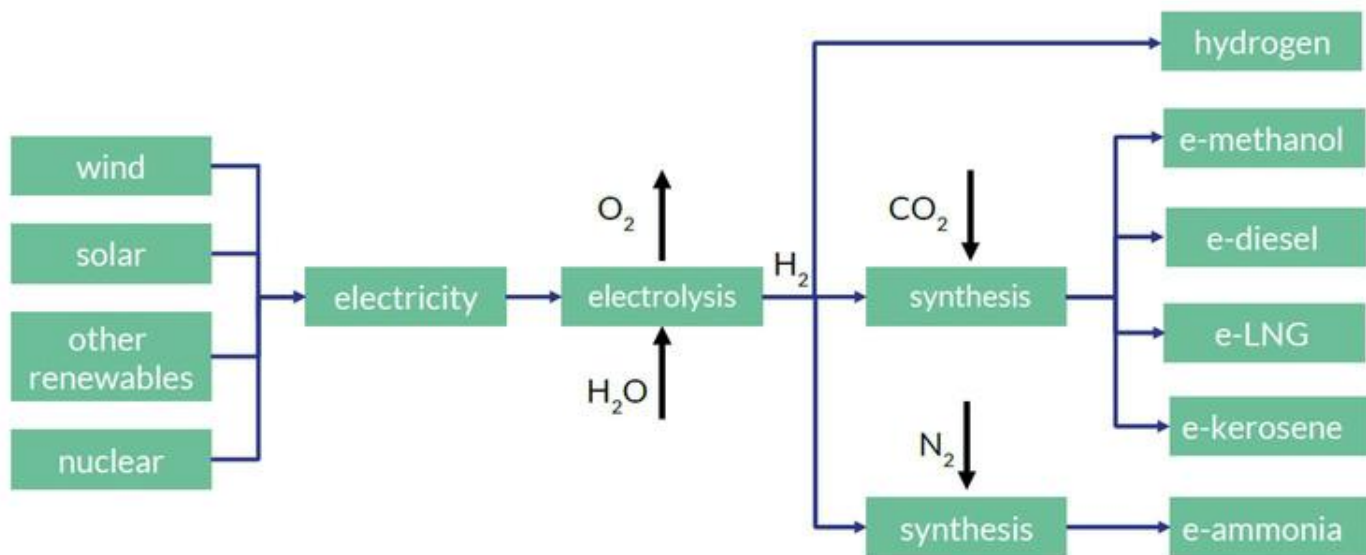
Clean hydrogen needed to replace conventional fuels and electrolysis needed to replace these fuels



* MRV - Monitoring Reporting and Verification Regulation

source: Hydrogen Europe

Alternative Hydrogen-Based Fuels and Production Routes



source: Hydrogen Europe

- Hydrogen-based synthetic fuels like ammonia, methanol, and LNG are promising for maritime decarbonization.
- E-ammonia, e-methanol, and e-LNG are the most promising today.

Infrastructure and Stakeholder Collaboration

Developing a dedicated hydrogen infrastructure and coordinating stakeholders are essential for sector-wide adoption.

- Ports are envisioned as hydrogen hubs, facilitating supply and bunkering.
- Stakeholders include shipowners, builders, fuel producers, ports, and regulators.
- EU-level cooperation is necessary to establish regulations, standards, and infrastructure obligations.
- Building a global infrastructure network is critical for supply security and market development.
- Collaboration aims to address technical constraints, regulation, and market demand for hydrogen and hydrogen-based fuels.



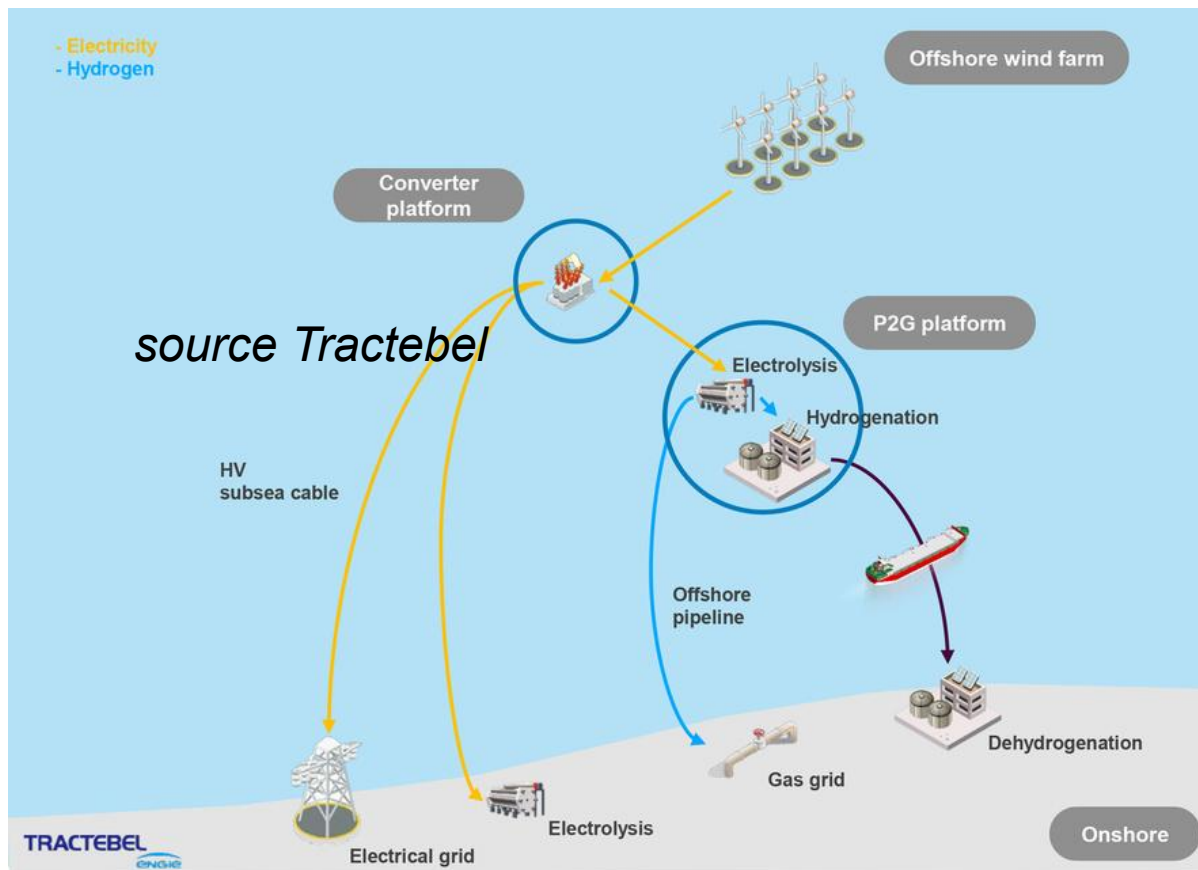
Ports as Hydrogen Hubs and Infrastructure Development

Ports are central to Hydrogen Economy, acting as production, import, storage, and distribution centers for maritime and industrial use.

- Major EU ports (Antwerp, Rotterdam, etc.) demand around 1.7 Mt of hydrogen annually, about 20% of EU consumption.
- Ports can develop hydrogen supply chains, including for ships, trucks, rail, inland waterways, and industrial sectors.
- Infrastructure development depends on sustainability, scalability, and storability criteria.
- Ports can also supply hydrogen to offshore platforms and wind turbines, creating sea-based hydrogen hubs.
- The EU aims to develop HRS and infrastructure aligned with TEN-T and TEN-E corridors.
- Offshore renewable energy can produce hydrogen at sea, with potential imports from regions like North Africa, Australia, and Chile.



Ports as Hydrogen Hubs



source: Tractebel

EU Policy Framework and Regulatory Initiatives

EU policies aim to accelerate maritime decarbonization through legislation, funding, and strategic planning.

- The European Green Deal emphasizes sustainable fuels, including hydrogen, for transport.
- Key initiatives include FuelEU Maritime, revision of AFIR, RED II, ETS, TEN-E, and Energy Taxation Directive.
- The EU plans to include shipping in the EU ETS, with revenues supporting maritime decarbonization.
- Targets include zero-emission ships by 2030 and significant hydrogen demand by 2030.
- Ports should develop roadmaps for hydrogen infrastructure, with a focus on rapid deployment.
- Harmonized standards and regulations for bunkering, safety, and ship design are essential.



Scalability and Sector Coupling

By 2030:

- Technologies will be ready for zero-emission new builds in short-sea and inland shipping.
- Hydrogen can provide auxiliary power to most new ocean-going vessels in ports.

By 2050:

- Majority of ships are expected to run on hydrogen or hydrogen-based fuels, supporting full sector decarbonization.

In nutshell:

- Hydrogen is the only sufficiently scalable technology for deep decarbonization across sectors, enabling energy system integration and supporting the transition in hard-to-abate segments like deep-sea shipping.
- Integration of hydrogen into maritime transport is critical for achieving climate neutrality, with coordinated policy, infrastructure development, and innovation needed to overcome current barriers and scale up adoption.

Challenges and Strategic Recommendations

- A comprehensive EU framework is necessary because no single regulation can fully decarbonize it.
- Revenues should fund innovation because market-based measures like ETS are helpful but insufficient alone.
- Ports must become hydrogen hubs because the scale of infrastructure investment is large.
- Standardization, safety, and international regulations need development for hydrogen ships.
- Lessons from LNG indicate the importance of harmonized bunkering and safety standards.

Immediate action is needed to start deploying zero-emission vessels and infrastructure to meet 2030 and 2050 climate targets.



Example of Good Practices

- The VIKING LIBRA, a new cruise ship under construction for Viking, was launched at the Ancona shipyard.
- It is scheduled for delivery at the end of 2026.
- With a length of 239 metres, and the capacity to accommodate up to 998 passengers in 499 staterooms, VIKING LIBRA will be the world's first cruise ship powered by hydrogen and will have a propulsion system based partially on liquefied hydrogen and fuel cells.



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You are welcome to visit:

<https://hydrogen.hr>

<https://h2res.com>

<https://rh2ec.com>

<https://smith2.hr>

Analysis of the Applicability, Relevance, and Challenges of Implementing Hydrogen as an Energy ~~Source~~ *carrier* in Croatian and Regional Mobility

Dražen Vrhovski, eering

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- FC has been invented back in 19th century
- Even the Green H2 concept dates back in late 19th/early 20th century as the Danish scientist, inventor and educationalist Poul la Cour used windmills to generate electricity needed to produce H2 to be used in lamps
- First fully functioning FC car was built in 1966 by General Motors
- The world's first commercial fuel cell buses debuted in the early 2000s through trials like the EU's CUTE project
- In 2000, the 22-person Hydra ship was demonstrated, and in 2003 the Duffy-Herreshoff water taxi went into service
- The MF Hydra, delivered in 2021 by Norwegian shipyard Norled, is the world's first ferry powered by liquid hydrogen fuel cells
- ...

...not many unknowns!





BEV

Compared to vehicles with ICE, BEVs are more powerful and easier to use and maintain. In layman's terms, BEV power units "produce" **movement**, without direct contact between the engine and the drive shaft, while ICE power units "produce" **heat** with large heat losses.

The simple operating principle of BEVs with low losses and advanced control methods means greater utilisation of available power and **greater energy efficiency**. The property of the electric motor to simultaneously serve as a generator converts each braking into recharging of the batteries. This in turn means lower operating costs, and due to the aforementioned simplicity of design, also **lower maintenance costs**. Finally, the electric vehicle is connectable and in the context of the generally accepted development paradigm of the "Internet of Things" (IoT), the BEV as such represents a far more favourable infrastructure element.

The **organisation of the transport system is significantly simpler** compared to H2 vehicles from the aspect of battery recharging, since it can be carried out wherever there is a power connection and with very low transmission losses. Finally, after-sales support for BEV vehicles is significantly **more developed** than of H2.



H2

BEV vs. H2

H2 vehicles are also electric. Instead of batteries, they get electricity from H2 FC. Compared to BEV batteries, hydrogen has got ca. **240x higher energy density** (40,000 Wh/kg vs. 167 Wh/kg) and allows for significantly **faster refuelling** of the vehicle's tank (10 min vs. 3 h). This allows H2-powered vehicles to transport larger loads or significantly longer range for the same vehicle weight.

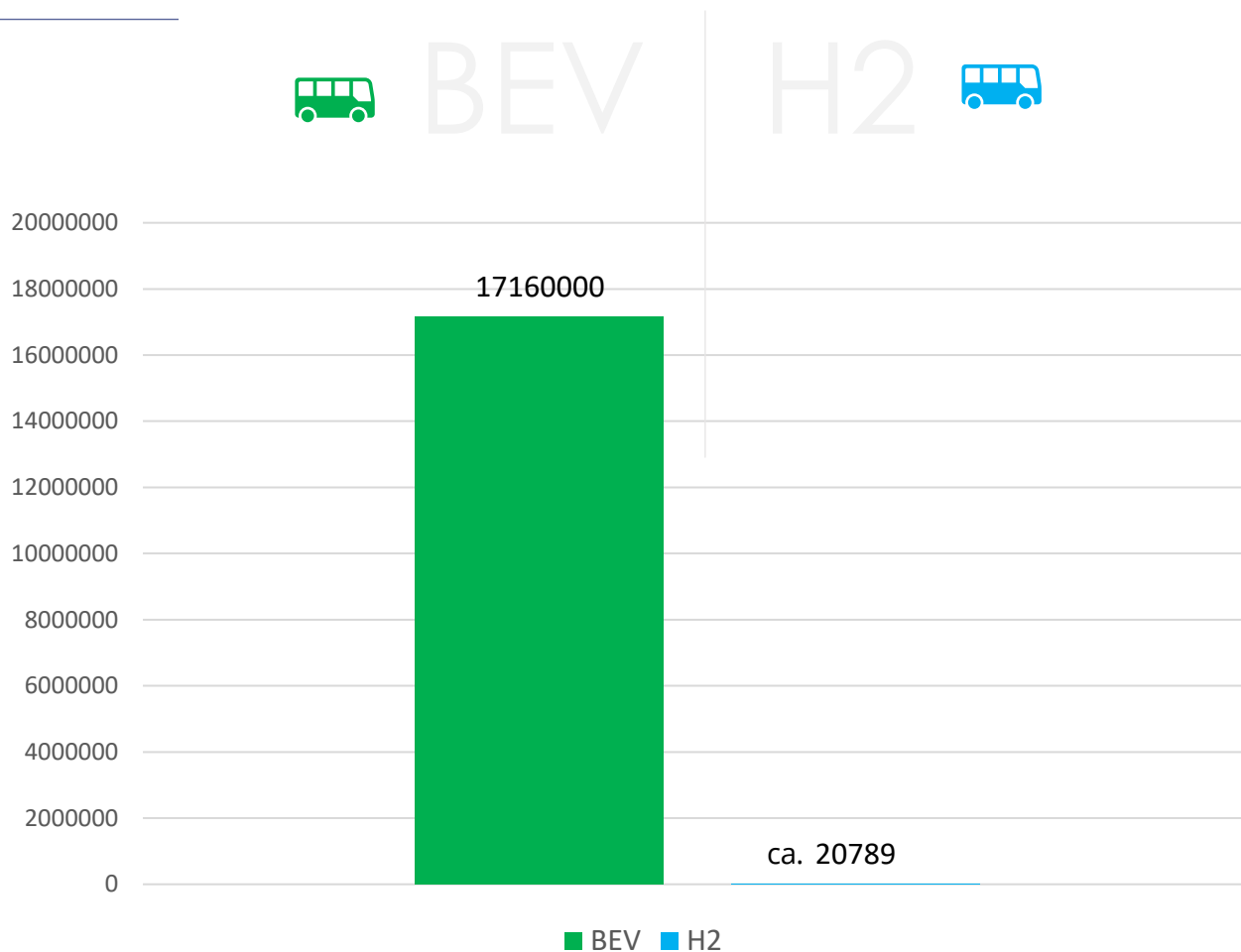
Despite the advantages, key disadvantages related to **the energy consumption** required for the **production and storage/distribution** of H2 limit its significant application. H2 is not available in free form in nature, and it must be produced (most often) by electrolysis and then stored at high pressures or liquefied. All of these processes require extremely large amounts of energy, which makes the overall energy balance less favourable compared to BEVs. In this context, it can be said that, just as BEV vehicles "produce" motion, and SUI vehicles heat, H2 vehicles need electricity to "produce" electricity from it again. Higher total energy consumption also means a higher cost of use, so the cost per km travelled for H2 vehicles is approx. **7x higher** than the cost of BEV vehicles.

Finally, the implementation of H2 vehicles is in the early stages of implementation and in this context there is currently no clearly defined **standardisation** of application elements or associated **legislation**.

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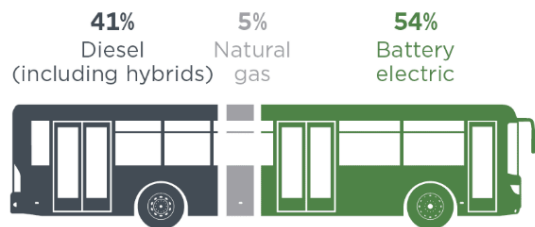
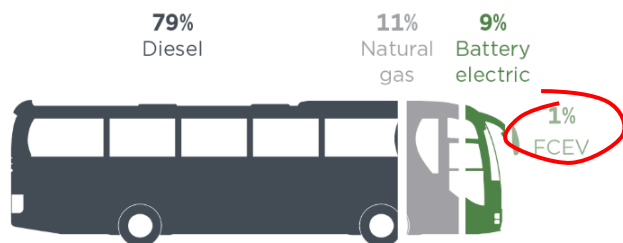
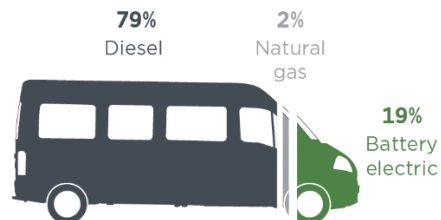
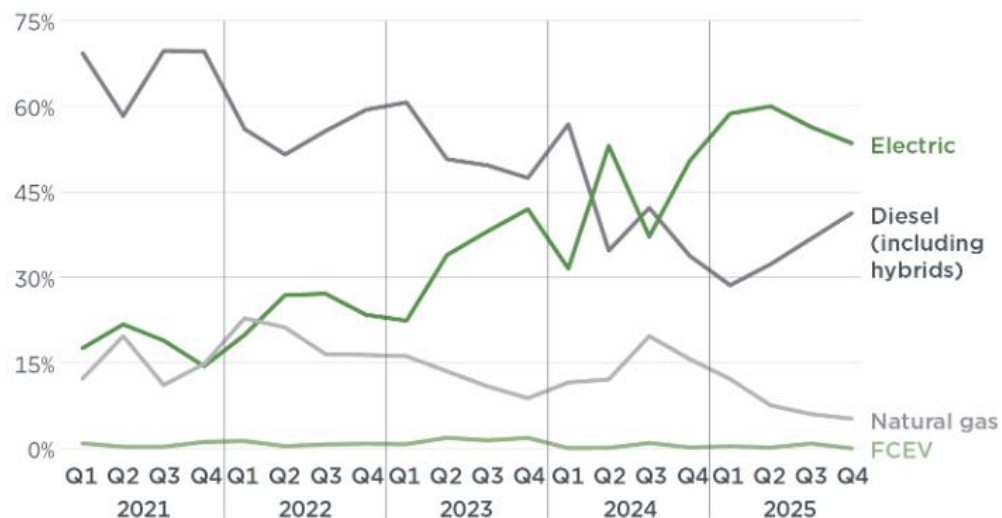


ZEMO vehicles sales in 2024 WW



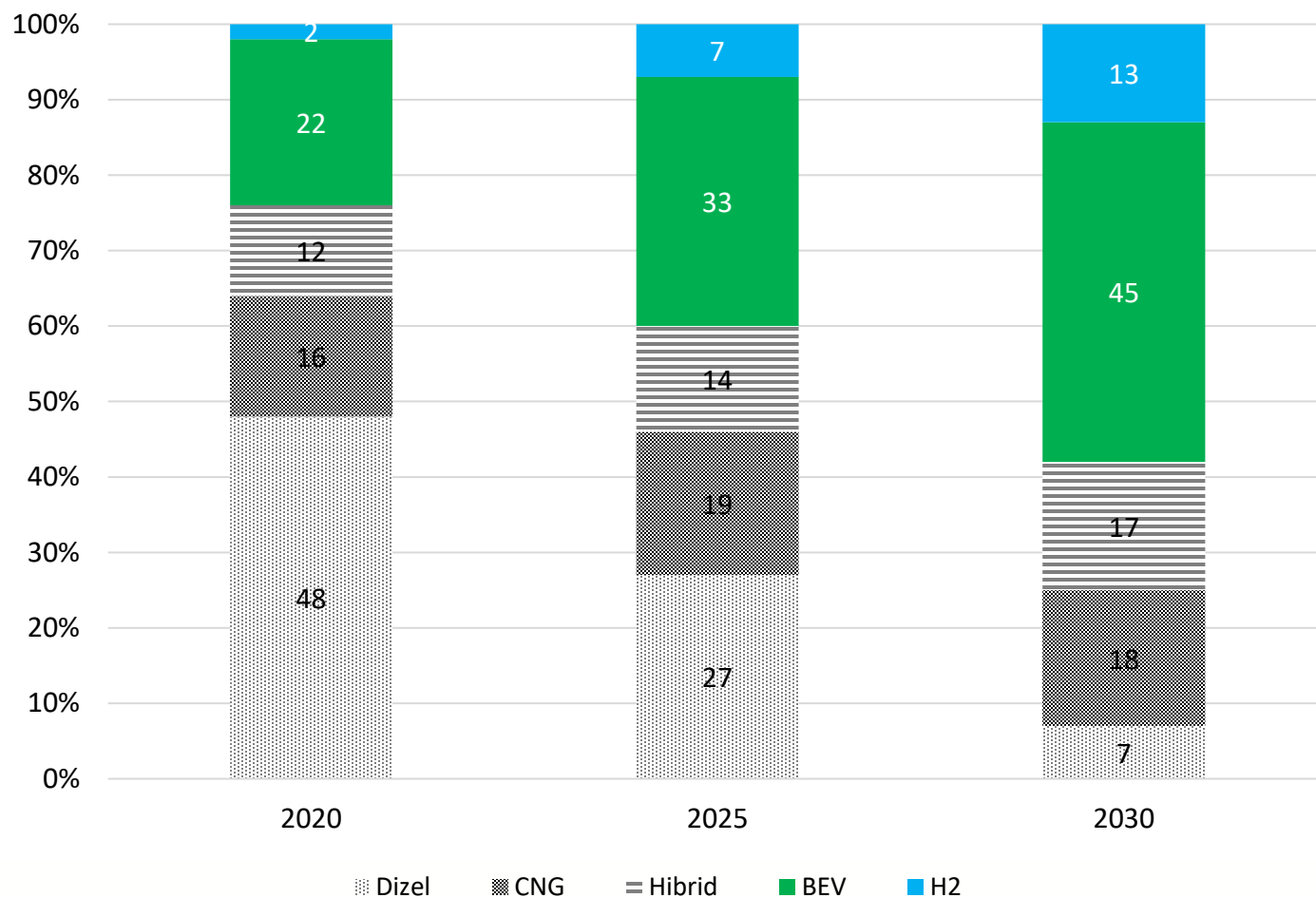
- In 2025, 39500 buses and coaches were sold in the EU-27, of which 9,800 were ZEMO vehicles → a 25% share, up from 17% the year before. The sales share of ZE buses and coaches in Q4 2025 was 29%

Sales in Q4/2025



Sales of city buses by powertrain

Expected market share by
powertrain categories



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- very limited hands-on experience
- reliance on practical nuances coming from abroad
- difficulties in addressing specifics of a given application

Sales of ZEMO buses & coaches

ZEMO Market Data - EU

Bus & Coach

Country	Q4 2024	Q4 2025	Q1-Q4 2024	Q1-Q4 2025
Austria	46 (24.9%)	136 (43.6%)	102 (10.1%)	248 (22.6%)
Belgium	81 (48.2%)	51 (27.9%)	194 (23.0%)	711 (48.9%)
Croatia	0 (0.0%)	0 (0.0%)	0 (0.0%)	9 (3.1%)
Cyprus	0 (0.0%)	0 (0.0%)	1 (1.6%)	0 (0.0%)
Czechia	25 (6.1%)	33 (15.2%)	59 (4.4%)	52 (6.4%)
Denmark	115 (85.8%)	110 (78.0%)	380 (67.9%)	410 (71.6%)
Estonia	0 (0.0%)	1 (4.5%)	17 (11.1%)	1 (0.9%)
Finland	0 (0.0%)	25 (56.8%)	135 (82.8%)	145 (63.0%)
France	148 (12.2%)	212 (14.7%)	661 (11.4%)	757 (12.5%)
Germany	207 (17.9%)	644 (30.5%)	732 (13.6%)	1,859 (27.2%)
Greece	3 (3.3%)	6 (4.8%)	272 (44.0%)	118 (17.4%)
Hungary	2 (3.8%)	31 (6.1%)	2 (0.6%)	65 (6.7%)
Ireland	6 (11.5%)	6 (8.2%)	238 (28.1%)	24 (2.7%)
Italy	565 (38.3%)	367 (29.0%)	1,047 (17.1%)	1,217 (24.5%)
Latvia	9 (14.1%)	18 (50.0%)	29 (8.2%)	54 (40.9%)
Lithuania	22 (37.3%)	97 (56.1%)	64 (26.7%)	235 (45.1%)
Luxembourg	78 (84.8%)	31 (39.2%)	238 (75.8%)	92 (35.8%)
Netherlands	217 (47.6%)	363 (91.4%)	409 (46.1%)	784 (71.9%)
Poland	19 (4.8%)	117 (18.2%)	131 (7.8%)	270 (12.6%)
Portugal	21 (25.3%)	58 (37.7%)	114 (15.6%)	113 (12.0%)
Romania	189 (48.0%)	318 (57.7%)	627 (34.6%)	1,288 (53.9%)
Slovakia	0 (0.0%)	8 (8.2%)	0 (0.0%)	8 (3.8%)
Slovenia	0 (0.0%)	7 (23.3%)	4 (2.5%)	14 (5.4%)
Spain	84 (10.1%)	147 (13.4%)	260 (6.0%)	419 (9.6%)
Sweden	164 (59.6%)	201 (47.9%)	251 (31.2%)	901 (45.7%)
EU-27	2,001 (25.8%)	2,987 (29.4%)	5,967 (17.0%)	9,794 (24.9%)

Italy – Croatia



- Croatian H2 Strategy does not strictly define the framework of hydrogen production but states the generic formulation that the goal is "*...to enable production of low-carbon hydrogen, which will primarily focus on renewable hydrogen with the aim of producing products with low or no CO2 emissions,*"
- The Strategy also claims that "*...Hydrogen production will, in the period up to 2026, initially be linked to the transport and industrial sectors. In transport, there are already projects in a high stage of readiness, while the industrial sector is the most ready to start using renewable hydrogen...*"
- Although the tech aspects of H2 use may be considered known, the Strategy advocates "*...encouraging the development of projects related to new renewable hydrogen production technologies...*" → PoC-ing
- Finally, the Strategy operates with the assumption that the cost of producing GH is 2,5÷5,5 €/kg



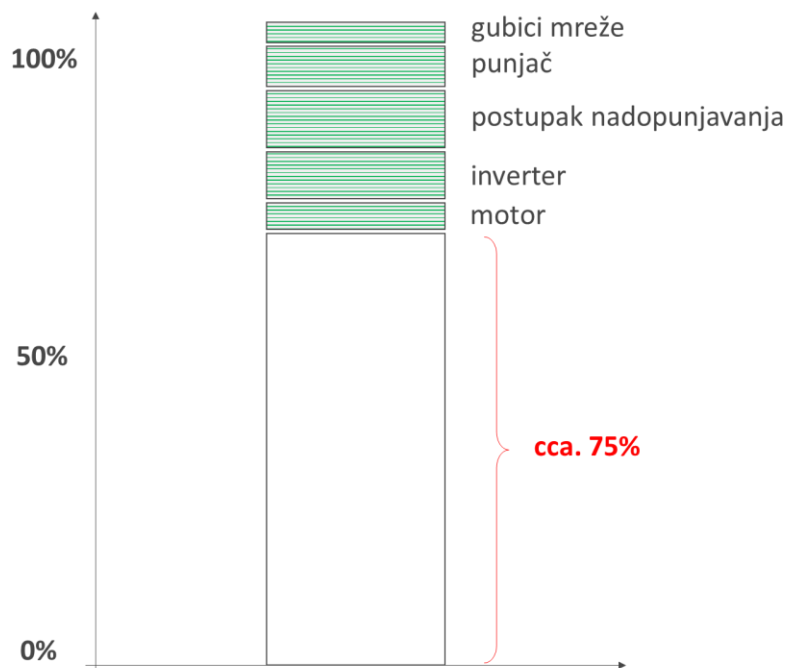
Italy – Croatia



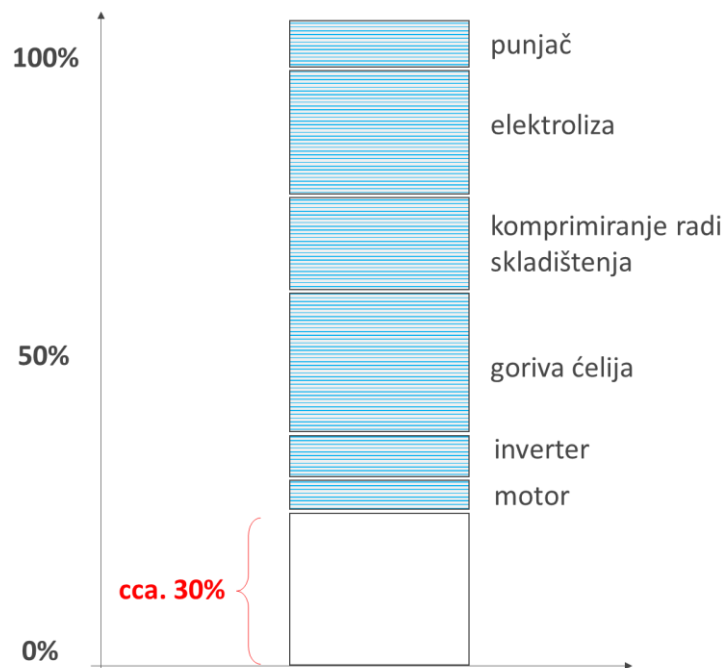
- Fuel cell long-haul trucks can reach TCO parity with their diesel counterparts by 2030 in Europe if the at-the-pump green hydrogen fuel price is around 4 €/kg
- The break-even hydrogen price varies among the countries considered in this study
- The highest break-even price is recorded in the United Kingdom at 5 €/kg, and the lowest is found in Poland at 3.5 €/kg
- Hydrogen fuel subsidies will be needed to justify the business case for FCETs in Europe during this decade
- Subsidies needed vary from 1.2 €/kg in the Netherlands to more than 4 €/kg in Italy and Germany (ca. 50% decrease in price)

If ZEMO efficiency aspects are added...

BEV



H2



...and tested in a case study

Technical solution 1 for city routes with SORT1 driving characteristics:

$B_{cap} = 55 \text{ kWh}$

$I_{OC} = 450 \text{ kW}$

Technical solution 2 for intercity routes with SORT3 driving characteristics:

$B_{cap} = 140 \text{ kWh}$

$I_{OC} = 450 \text{ kW}$

Average annual mileage per vehicle: **94.600 km**



BEV

H2



	Specifikacija	Qty	Unit price	Subtotal
Technical solution 1	Vehicle	4	430.000 €	1.720.000 €
	Battery set	4	20.000 €	80.000 €
	OP Charger (pantograph)	1	450.000 €	450.000 €
	ON Charger (depot)	4	30.000 €	120.000 €
	Operative cost per km		0,13 €	
	Cost of battery replacement	4	20.000 €	80.000 €
	Total op. cost (fleet, 7yr)	7	49.192 €	344.345 €
	Subtotal:			2.794.345 €
Technical solution 2	Vehicle	6	430.000 €	2.580.000 €
	Battery set	6	50.000 €	300.000 €
	OP Charger (pantograph)	2	450.000 €	900.000 €
	ON Charger (depot)	6	30.000 €	180.000 €
	Operative cost per km		0,13 €	
	Cost of battery replacement	6	50.000 €	300.000 €
	Total op. cost (fleet, 7yr)	7	73.788 €	516.518 €
	Subtotal:			4.776.518 €
Total cost of ownership for the entire fleet (10 veh):				7.570.863 €

	Specification	Qty	Unit price	Subtotal
Technical Solution 1 & 2	Vehicle	10	640.000 €	6.400.000 €
	Battery set	0	n/a	0 €
	OP Charger (pantograph)	0	n/a	0 €
	ON Charger (depot)	0	n/a	120.000 €
	Operative cost per kg H2		7,5 €	
	Cost of battery replacement	0	n/a	0 €
	H2 consumption per km		0,11	
	Total op. cost (fleet, 7yr)	7	760.181 €	5.321.267 €
Total cost of ownership for the entire fleet (10 veh):				11.721.267 €



Break even H2 price: €2/kg

Italy – Croatia



- Refuelling stations that couldn't maintain reliability → eg. Aberdeen's entire fleet sat idle for 18 months because one refuelling station failed
- Operating costs that exceeded projections by 200-300%
- BEV alternatives simply worked
- ...a number of H2 mobility implementations got to be discontinued
 - **France:** Paris shuttered the world's largest hydrogen taxi operation
 - **Poland:** Poland's hydrogen program is collapsing across 26 cities simultaneously
 - **UK:** Aberdeen scrapped the world's first hydrogen double-decker bus fleet after those buses sat idle for 18 months
 - **Austria:** Wiener Linien cancelled its contracts for new hydrogen fuel cell buses, and major operators like OMV have closed publicly available hydrogen stations across Vienna, Graz, and Innsbruck
 - **Germany:** Wiesbaden, local transit operator ESWE Verkehr halted its fuel cell bus trials, retired its fleet, and dismantled its H_2 filling station in favour of a simpler, battery-electric transition



Investment Requirement

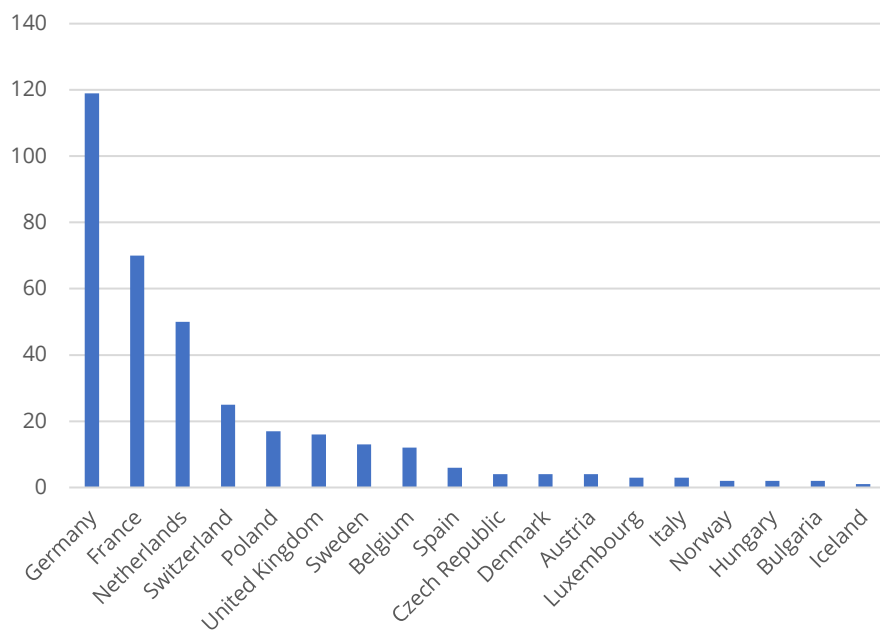
Italy – Croatia



Typical price of building a H2 refuelling station: €3 mio

Typical price of building a fast charging station (per charging point): €0,1 mio

Number of installed H2 pumps



Too few to support wider H2 use

# registered cars*	49.33 mio	1,99 mio
# of reg trucks*	226,1k	17,3k
# of reg buses & coaches*	85,6k	5,9k
# of BEV chargers (2023)**	120.625	1.074
# of H2 stations (2025)*	119	0

Penetration



0,0024

0,0005



0,00000238

0

CRO to reach similar H2 infrastructure proliferation:

0,00000238 x 2 mio x €3 mio

€14 mio investment

- ZEMO as a game changer in the mobility sector
- Benefits of electrification are established in terms of pollution and noise reduction, however ZEMO fleets bring new challenges for transport operators
- Main challenges and choices in the transition to ZEMO operations include:
 - Finding the most appropriate technology according to operational needs
 - Getting involved new stakeholders such as utility providers and civil work contractors
 - Developing new skills internally, particularly in the areas of planning, driving and maintenance
 - Implementing capacitated monitoring systems for buses/vessels and chargers → critical to successful and reliable operation of the PT system
 - Defining a robust and data-substantiated roadmap customised to specifics of the PTO → phased wise ZEMO implementation as opposed to a BigBang approach
- Golden rule(s): BEV over H2 + realisation of the grid connection in time is crucial!

how likely is this to happen seamlessly in CRO/region?

- Rolling out H2 mobility is primarily a matter of economics not technology
- A lot of momentum has been built around H2 → it is time to demonstrate real H2-related assets and real capacities to produce green H2
- Implementation will make sense and be economically justifiable only if seen as integrated with other elements of the supply chain at a given territory
- Although valuable piloting has been made, Croatia does not have its own infrastructure and know-how required for large scale H2 implementations → reliance on experiences from abroad
- High investment cost required wise planning and highly capacitated teams as failures may be catastrophic



Croatian Chamber of Economy

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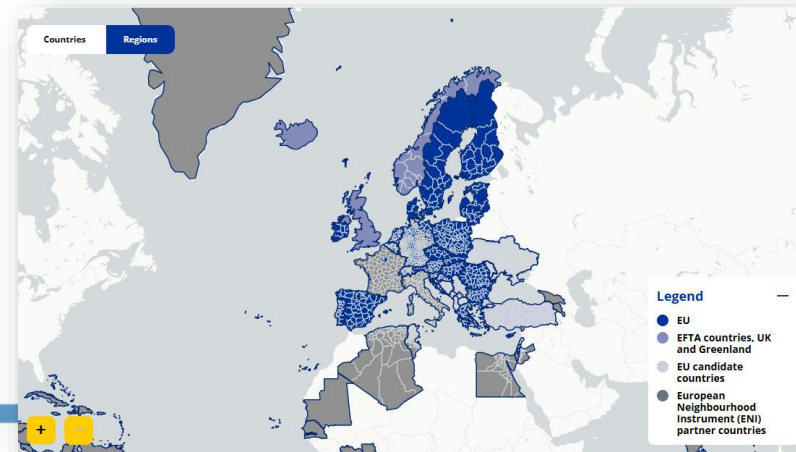
Contribution of the Interreg Framework and the TRANS-H2 Project to the Operational Use of Hydrogen in the Adriatic Maritime Transport Sector

Dražen Vrhovski, eering

Italy – Croatia



- EU framework aimed at advocating, stimulating and funding **larger cooperations** in a variety of sectors
- Cooperation between regions and countries to help their economic and social development by **tackling the obstacle of borders**
- Series of cross-border, transnational and interregional funding programmes (86) covering geographically wide territories including EU candidate countries, EFTA countries, UK, Greenland and others
- 64 cross-border programmes Italy-Croatia being one of them
 - CRO: 8 regions
 - ITA: 25 regions



Interreg in Numbers

Interreg figures (2021-2027) - Data from State of Interreg 2025

5 979

Projects selected

7.5 B

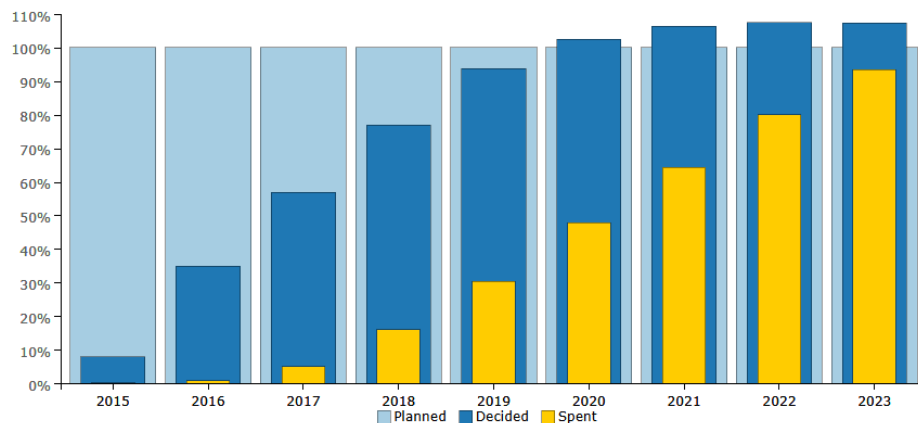
EUR Funding committed

70%

Funding allocated to projects

...currently

2014-2020

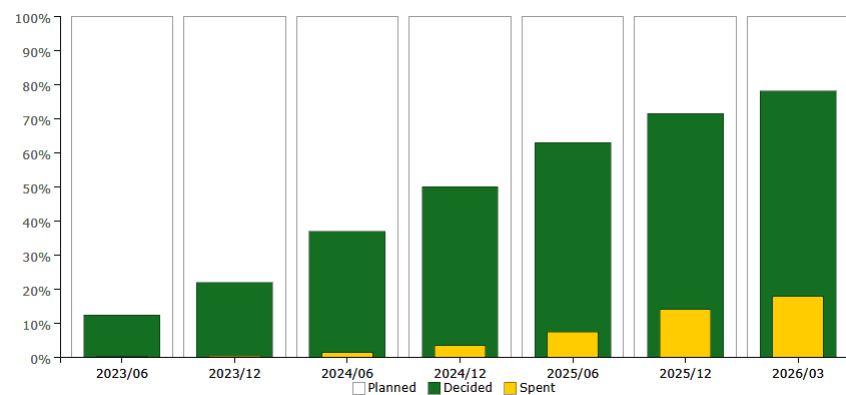


Total EU budget (ex National): 9,4 B



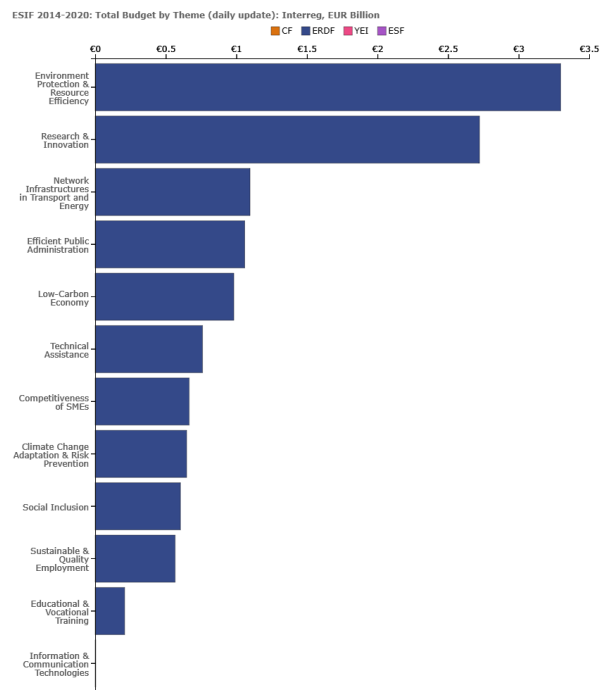
13,4% increase

2021-2027



Total EU budget (ex National): 10,6 B

2014-2020



Refresh Date: 08/05/2026

Interreg in Numbers

Interreg figures (2021-2027) - Data from State of Interreg 2025

5 979

Projects selected

7.5 B

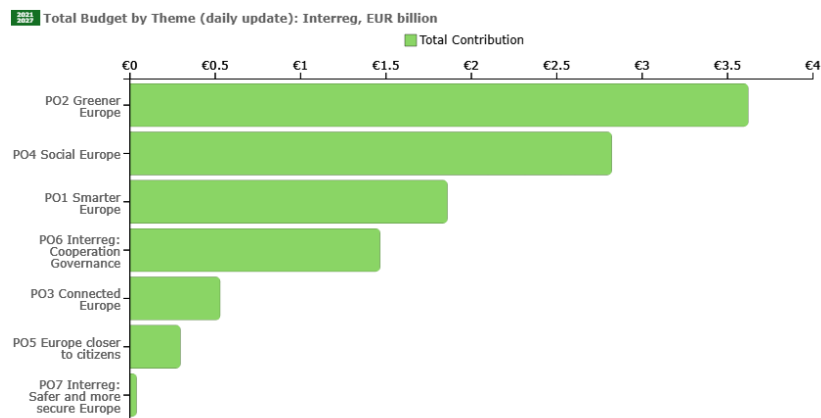
EUR Funding committed

70%

Funding allocated to projects

...currently

2021-2027



Refresh Date: 20/05/2026

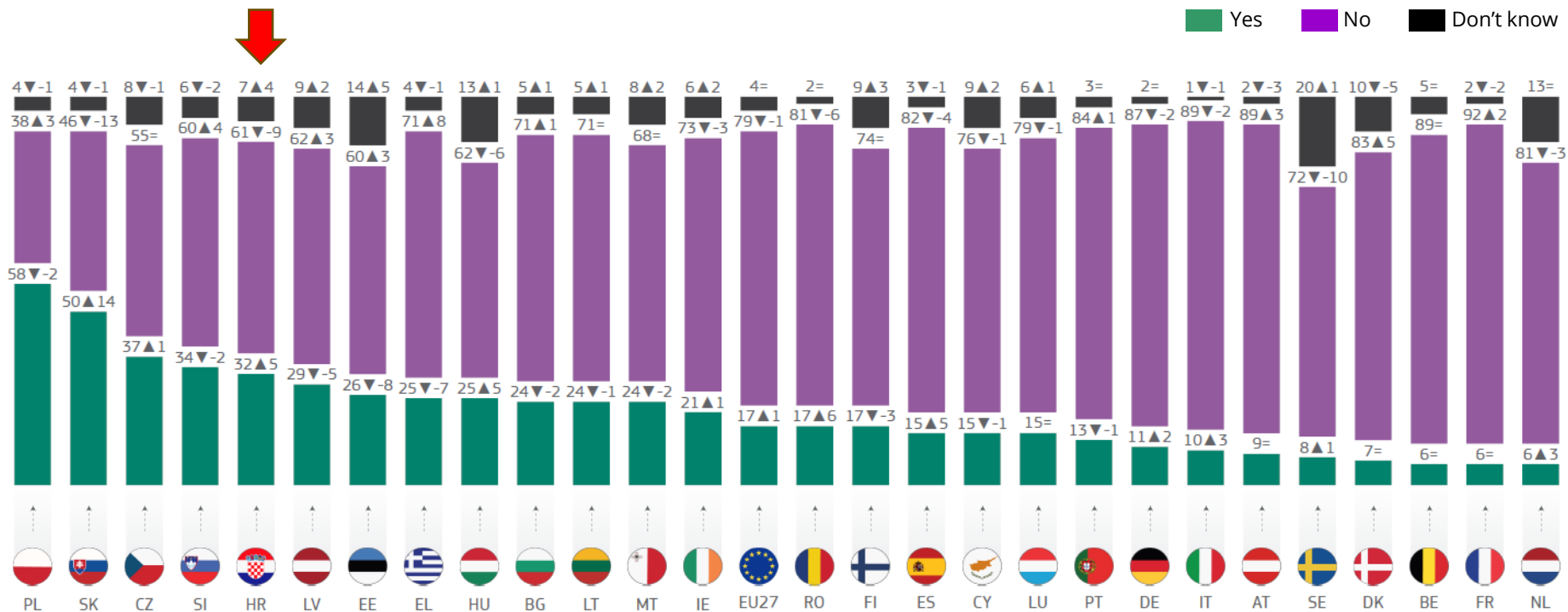
Italy – Croatia



...according to [Eurobarometer](#)...

- 79% of EU citizens who are aware of EU-funded projects think that these projects have a **positive impact** in their region or city
- 57% said that EU-funded projects in their area contributed “somewhat or to a large extent” to their feeling of **being EU citizens**

Q1: Have you benefitted in your daily life from a project funded by the European Regional Development Fund (ERDF) or the Cohesion Fund?



Italy – Croatia

...according to [Eurobarometer](#)...



Q2: Which regions would you target for investments under EU regional policy?

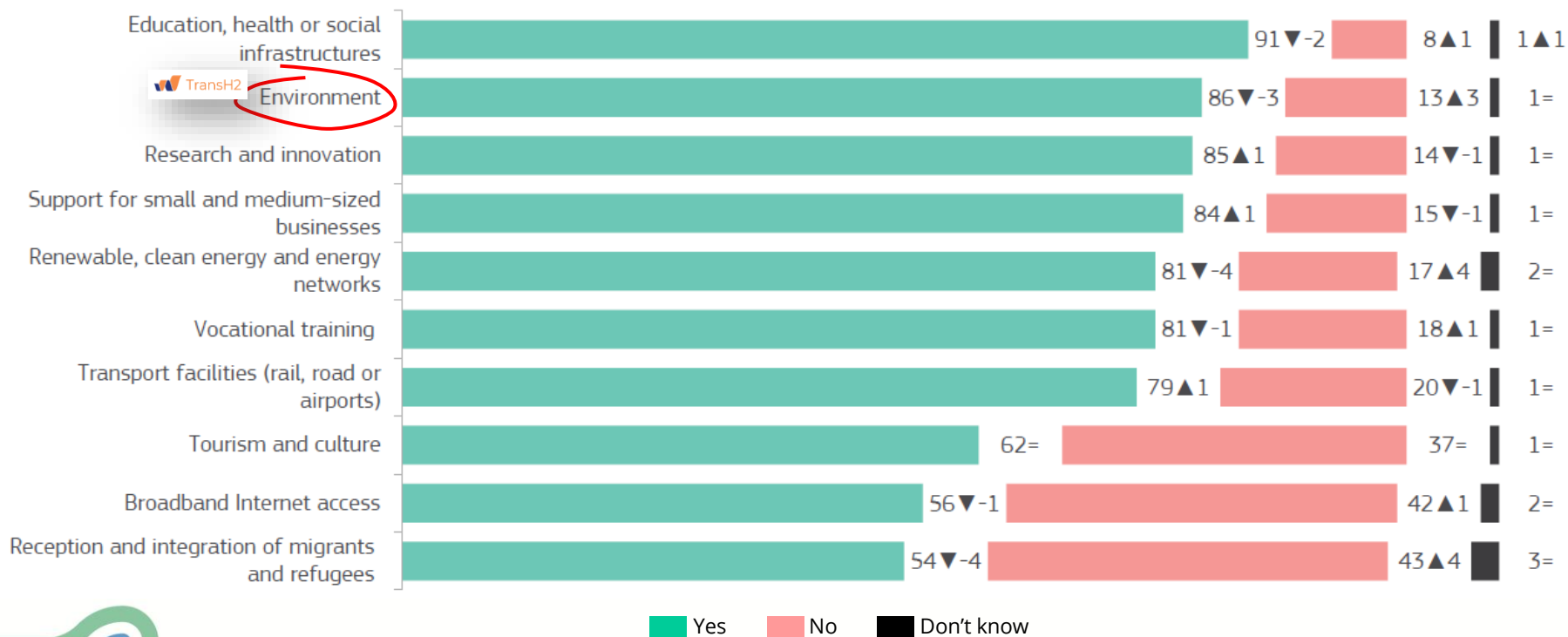


	EU27	BE	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	
																													
Regions with high unemployment	63	71	68	69	60	60	61	60	60	66	46	56	73	66	59	70	58	75	60	59	59	70	62	68	59	82	57	66	
Deprived urban areas	51	69	36	56	47	33	43	50	48	63	50	34	 TransH2	46	54	54	69	39	54	34	52	54	79	32	64	46	36		
Remote rural or mountain areas	50	42	52	53	35	40	55	49	62	65	61	61	59	77	47	46	38	37	34	43	57	52	49	65	70	61	42	44	
Border regions	27	30	22	41	21	41	49	26	52	29	16	20	12	23	41	41	26	27	26	30	33	34	15	23	26	30	37	20	
Developed regions, in order to maintain or improve their competitiveness	23	37	15	17	24	35	18	19	12	21	18	11	23	22	25	24	24	21	23	15	19	24	13	25	17	28	21	23	
Islands and outermost regions*	22	20	5	9	28	25	23	26	27	33	32	49	 TransH2	17	20	7	8	23	5	40	12	25	12	29	10	19	7	16	13
Other (SPONTANEOUS)	2	0	2	1	3	3	2	1	0	1	2	1	2	0	2	0	1	1	2	2	2	1	0	0	2	1	0	1	
Don't know	4	3	2	3	7	5	2	2	1	3	4	3	4	2	4	1	4	2	5	6	4	2	4	1	2	1	3	8	

* (which are territories that are part of the EU, but that are located far from the European continent, such as the Canary Islands, the Azores or Guadeloupe)

X Most frequently mentioned response

Q3: Which domains and sectors of your city or region you consider important to be invested in?

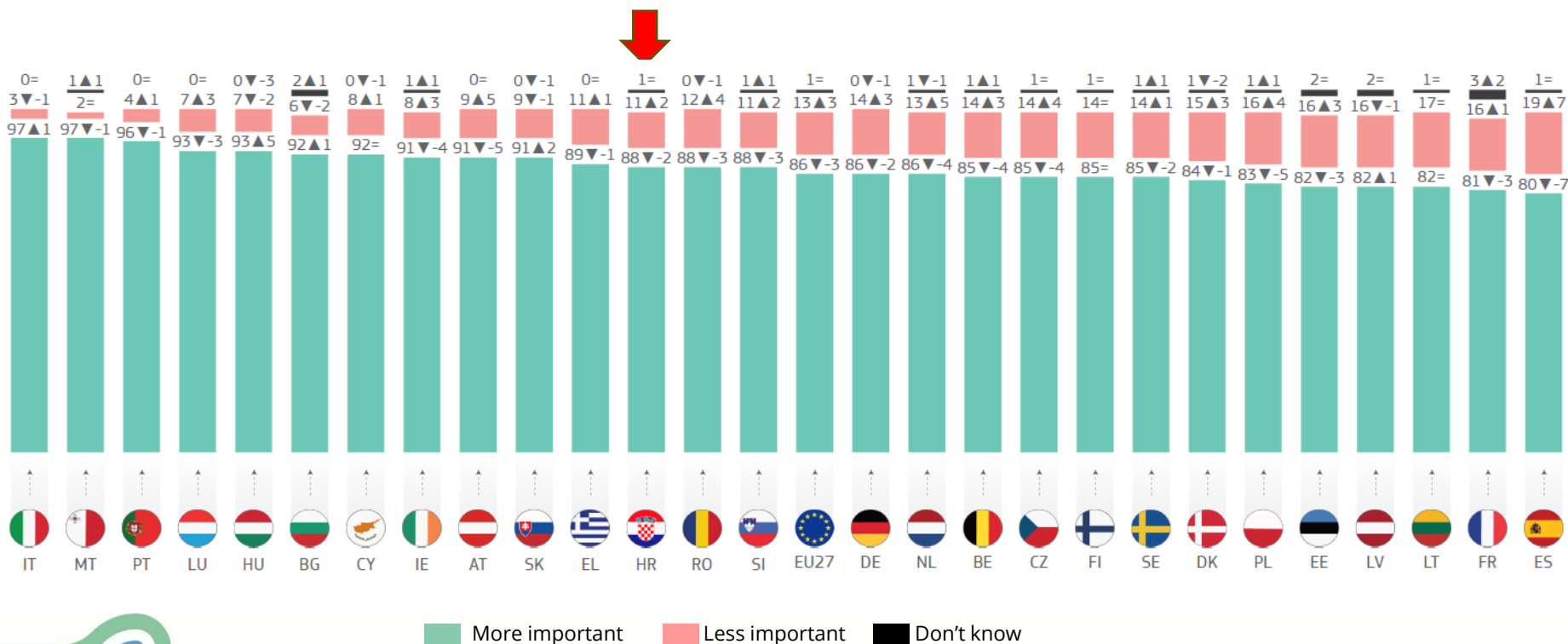


Italy – Croatia

...according to [Eurobarometer](#)...



Q4: How important do you consider **ENVIRONMENTAL** issues to be with respect to the EU regional policy?

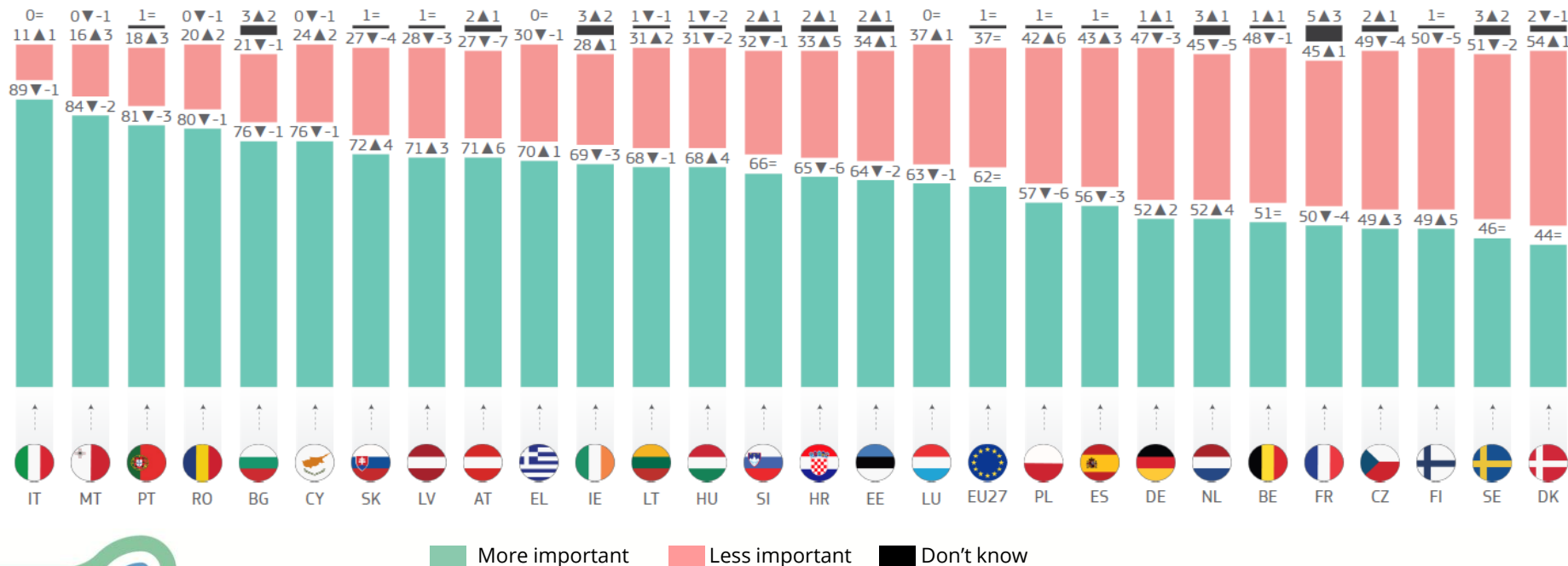


Italy – Croatia

...according to [Eurobarometer](#)...



Q5: How important do you consider **TOURISM AND CULTURE** to be with respect to the EU regional policy?



Italy – Croatia

...according to [Eurobarometer](#)...



Q6: Which, if any, of the following forms of EU support you've heard about before?



	EU27	BE	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE
The European Regional Development Fund (ERDF) and/or the Cohesion Fund	49	32	62	64	20	28	63	66	70	57	34	74	59	43	56	51	54	65	67	28	41	81	61	68	71	84	46	29
The European Social Fund	44	40	33	39	17	30	47	50	54	68	32	40	64	36	33	40	51	40	54	25	51	55	57	46	38	66	31	13
Interreg	11	8	7	7	6	11	12	11	14	13	5	14	11	14	7	9	21	14	8	3	17	17	15	23	18	19	11	9
The Just Transition Fund	13	11	10	13	8	7	39	12	19	11	12	13	13	7	4	6	12	12	18	8	10	39	9	16	28	14	9	11
Next Generation EU/Recovery Plan	31	22	47	21	20	15	12	37	63	43	17	38	54	42	16	40	39	21	33	17	34	41	29	42	33	80	16	15
Erasmus+	60	61	49	63	41	51	68	54	74	58	66	57	69	79	63	61	56	69	67	27	58	70	69	55	75	78	61	43
The European Solidarity Fund	42	43	24	40	22	31	38	42	68	41	40	52	61	52	23	31	56	44	49	32	49	53	39	46	45	48	25	17
Horizon Europe	12	16	10	9	11	8	13	18	13	12	10	9	16	17	6	8	22	15	20	8	14	13	16	11	10	12	9	10
Connecting Europe Facility	11	7	11	12	7	7	25	8	11	10	7	11	15	9	17	45	12	22	25	4	13	10	11	25	10	20	7	8
None of these (SPONTANEOUS)	15	17	15	14	35	28	11	9	4	11	14	7	4	10	16	12	10	10	10	31	10	4	4	13	7	3	18	33
Don't know	1	1	1	1	0	1	1	1	0	0	1	1	0	0	1	1	1	1	1	4	1	1	2	0	0	0	0	1

Italy – Croatia

...according to [Eurobarometer](#)...



Q7: European regional policy also invests in the cooperation between regions from different countries. Are you aware of any of the following cooperation initiatives?



	EU27	BE	BG	CZ	DK	DE	EE	IE	EL	ES	FR	HR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE
Legal EU cooperation agreements between regions (so-called European Groupings of Territorial Cooperation)	25	20	22	29	15	23	22	18	18	33	21	23	25	14	14	23	29	27	44	19	33	25	26	41	20	34	18	15
Interreg	17	11	9	10	8	16	15	18	18	24	9	17	19	15	9	12	27	18	18	4	31	24	23	29	21	23	14	12
European Urban Initiative and URBACT	16	11	14	15	9	17	10	21	12	16	13	11	18	13	15	16	18	18	32	11	14	19	13	42	18	12	11	4
Macro-regional strategies	16	7	16	20	4	15	7	14	9	9	10	17	18	7	9	14	14	10	21	12	15	45	12	29	14	16	5	3
None of these (SPONTANEOUS)	52	63	59	51	72	56	61	54	59	44	62	51	52	51	65	54	38	50	35	73	34	31	44	30	51	45	64	73
Don't know	2	1	5	2	1	2	2	2	2	3	5	3	0	15	3	3	3	3	2	2	3	0	6	0	2	2	2	1

X Most frequently mentioned response

Italy – Croatia

Priorities



Sustainable growth
in the **blue economy**

Current Projects: 13



Green and resilient
shared **environment**

Current Projects: 31



Sustainable maritime
and multimodal
transport

Current Projects: 10



Culture and **tourism**
for sustainable
development

Current Projects: 23



**Integrated
governance** for
stronger cooperation

Current Projects: 22

- Total 2021-2027 budget: €222,7 mio
- 99 projects in total
- CRO: 8 regions → IŽ, PGŽ, KŽ, LSŽ, ZŽ, ŠKŽ, SDŽ, DNŽ



CRO Lead Partners



CRO All Partners



Italy – Croatia



- Interreg VI-A Italy–Croatia 2021-2027 → 1st Call for Standard and Small-Scale project proposals
- Priorities and Specific Objectives
 - Sustainable growth in the blue economy
 - Developing and enhancing research and innovation capacities and the uptake of advanced technologies
 - Developing skills for smart specialisation, industrial transition...
 - Sustainable maritime and multimodal transport
 - Developing and enhancing sustainable, climate resilient, intelligent and intermodal national, regional and local mobility, including improved access to TEN-T and cross-border mobility
 - Culture and tourism for sustainable development
 - Enhancing the role of culture and sustainable tourism in economic development, social inclusion and social innovation
 - Integrated governance for stronger cooperation
 - Other actions to support better cooperation governance



Italy – Croatia



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Italy – Croatia



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Enhancing the sustainability of sea-mobility in the Adriatic Sea region by...

Developing low-carbon
solutions for representative
maritime routes

Analysing zero-emission
fuels such as hydrogen

Demonstrating the
feasibility and benefits of
these solutions



• **Sustainable maritime and multimodal transport**

- Developing and enhancing sustainable, climate resilient, intelligent and intermodal national, regional and local mobility, including improved access to TEN-T and cross-border mobility

Promoting their adoption among port authorities, transport
operators, and other key stakeholders

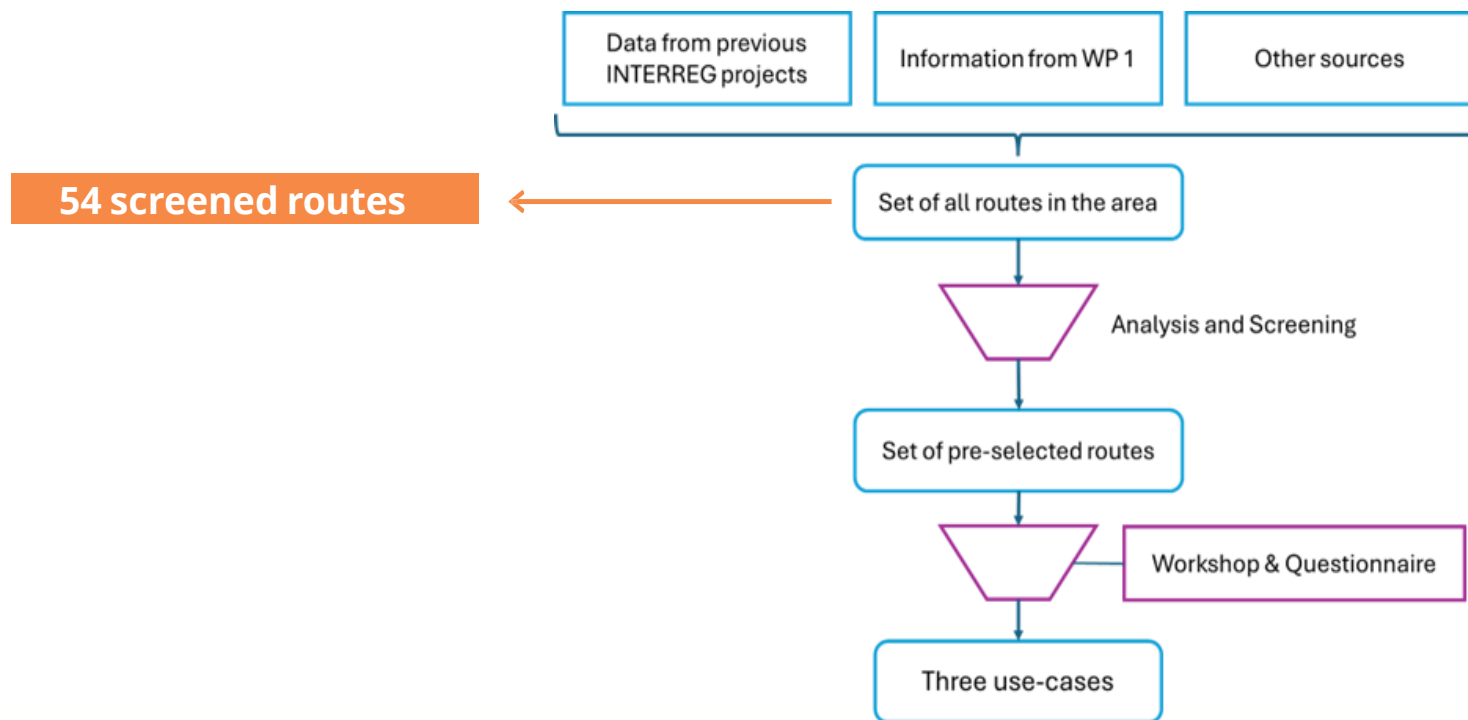
...and establishing a complete hydrogen supply chain, including

Vessel development

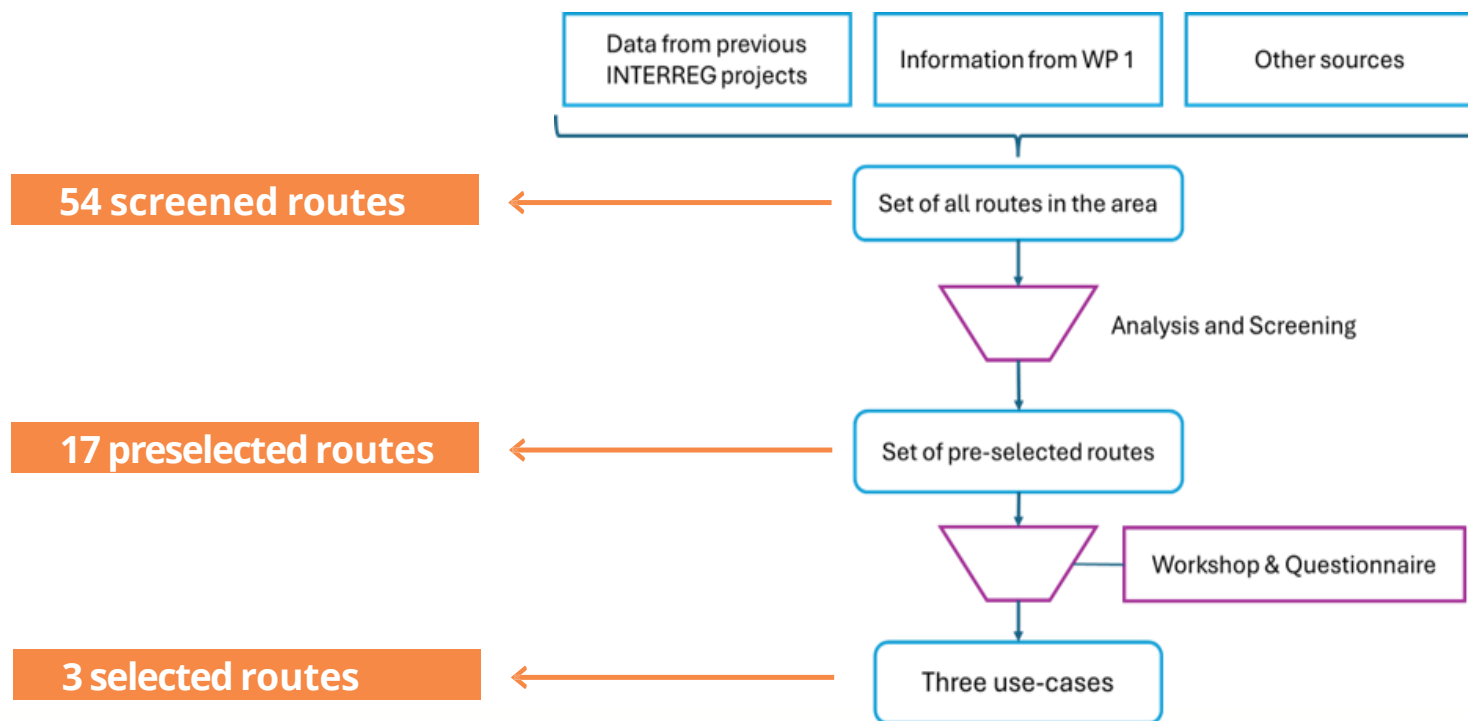
Port refuelling infrastructure

...to support EU Sustainable and Smart Mobility Strategy for market ready ZeMo vessels by 2030.

Selecting representative maritime routes in the Adriatic Sea



Selecting representative maritime routes in the Adriatic Sea



Route	Route type	Vessel type	Frequency	Passenger flow	Distance (NM)	Travel time (h)	Ship's name on passenger line
Tronchetto – Lido	ITA-ITA	RO-RO	161/w	-	3.5	0.67	Metamauco/Lido di Venezia
Punta sabbioni – Lido	ITA-ITA	RO-RO	252/w	-	1	0.16	
Pellestrina – Lido	ITA-ITA	RO-RO	252/w	-	1.5	0.41	Ammiana
Valbiska – Merag	CRO-CRO	RO-RO	83-91/w	1142556	6	0.41	Illovik
Misnjak - Stinica	CRO-CRO	RO-RO	91-161/w	954711	2	0.33	Rapska Plovidba
Prizna - Zigljen	CRO-CRO	RO-RO	84-147/w	943260	4	0.25	
Korcula - Orebic	CRO-CRO	RO-RO	98-154/w	735503	2	0.25	Sveti Krsevan
Porozina - Brestova	CRO -CRO	RO-RO	84-91/w	553627	3	0.33	
Tkon - Biograd	CRO-CRO	RO-RO	68-133/w	455791	2	0.25	Kijevo
Split – Supetar	CRO-CRO	RO-RO	61-98/w	367709	10	0.83	Hrvat
Sucuraj - Drevenik	CRO-CRO	RO-RO	42-77/w	366714	4	0.58	Laslovo
Ploce - Trpanj	CRO-CRO	RO-RO	21-28/w	238768	9	1	Pelješčanka
Zadar – Ošljak – Preko	CRO-CRO	RO-RO	157-196/w	230799	3	0.33	Cres, Sveti Juraj
Sobra - Praprtano	CRO-CRO	RO-RO	42/28 w	146126	6	0.75	Valun
Ancona - Split	ITA-CRO	RO-RO	2-3/w	184184	129	8 to 11.5	Marko Polo/Aurelia
Bari - Dubrovnik	ITA-CRO	RO-RO	2-4/w	69049	107	6.3 to 8	Dalmacija
Ancona – Zadar	ITA-CRO	RO-RO	1-2/w	35941	80	7 to 9	Zadar

Technical vs. Environmental assessment low-high season

Technical assessment

Analysis of

- Route distance
- Service frequency
- Vessel speed
- Installed capacity
- Fuel consumption

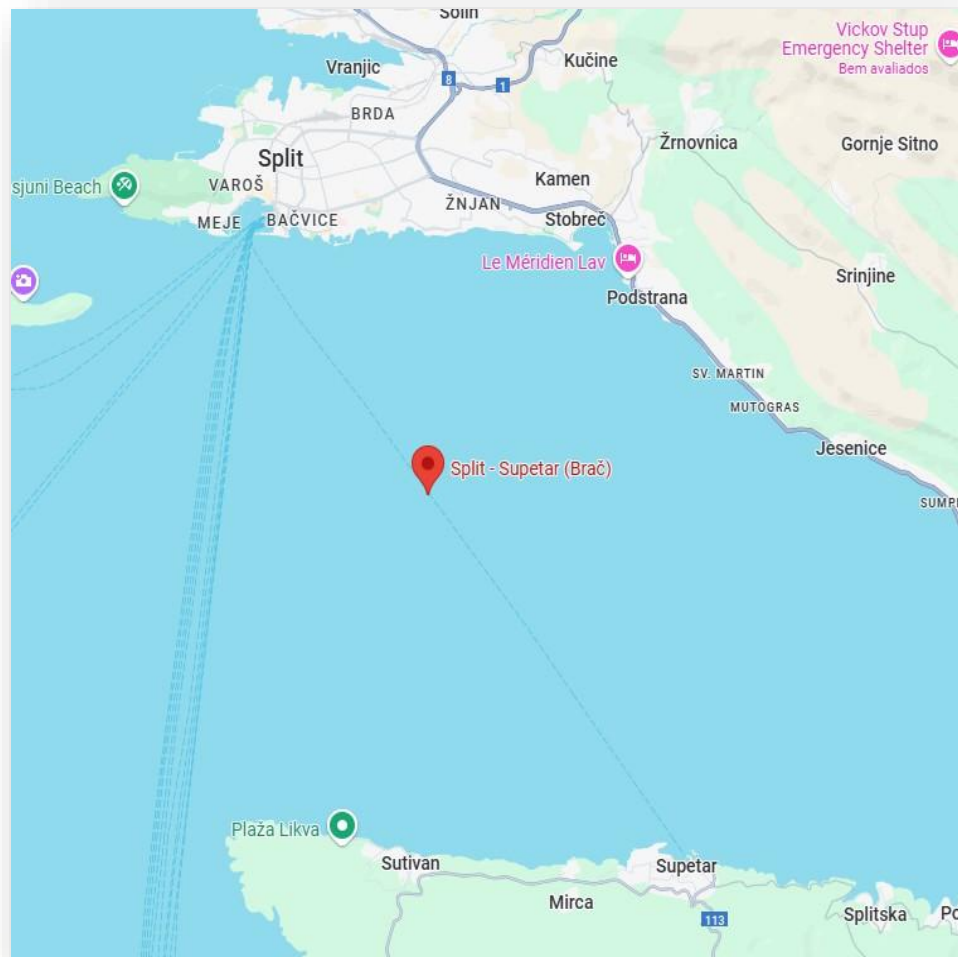
Environmental assessment

Analysis of

- Air quality conditions
- Natura 2000 protected areas
- Potential CO₂-eq emission avoidance

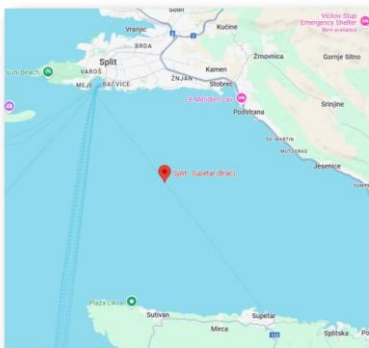
Split-Supetar

Use-case for regional
maritime routes in Croatia.
(10 NM)





Split-Supetar



Hrvat

Route data:

- Frequency: 61-98 trips/week*
- Distance: 10 NM
- Service speed: 11.5 knots
- Trip duration: 0.83 h (~50 min)

Engine and Energy data:

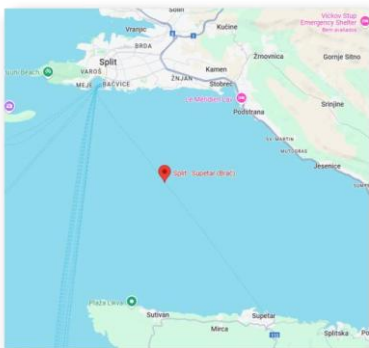
- Engine installed power: 2.14 MW
- Req power @ 11,5 knots: 1.487 MW
- Engine efficiency: 38%
- Energy demand per trip: 1239.16 kWh

Diesel fuel consumption:

- SFC (CAT 3508B DG): 222 g/kwh
- Fuel per trip: **275 kg**



Split-Supetar



Hrvat

Hydrogen fuel cell assumptions:

- Fuel Cell Efficiency: 50%
- H2 LHV: 33.3 kWh/kg

Quantity of H2 required:

- Required energy input:

$$\frac{1239.16 \text{ kWh}}{0.5} = 2478,32 \text{ kWh}$$

- H2 per trip:

$$\frac{2478,32 \text{ kWh}}{33.3 \text{ kWh/kg}} \approx \mathbf{75 \text{ kg}}$$

Italy – Croatia



- The activities realised so far demonstrated active participation of project partners and stakeholders
- Activities realised have advanced previous knowledge base with important know-how and experiences resulting from TransH2 project undertakings made
- The work presented has addressed relevant maritime routes and implementation aspects not only with regards to the criteria defined by the project partners and the project application, but also against criteria benefiting all the key stakeholders
- The technical assessment made provided key information for the techno-economic analysis used in the follow-up phases of the project



Italy – Croatia



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sHYpS

sHYps – Viking Hydrogen



Sustainable HYdrogen
powered Shipping

sHYpS is an EU co-funded project aiming to develop a novel LH₂ swappable storage solution, suitable to multiple types of vessels. It speeds up achieving IMO's target for 2030 and 2050.

sHYpS consortium has designed, built and is now testing a prototype of an intermodal ISO 45 LH₂ container and the evaporator unit with tank connection space.

Integrate and test the LH₂ storage system, the fuel handling system and the electric connection to the ship backbone, onboard one Viking's newbuild cruise ship.



Italy – Croatia



Participant organisation name
NAVALPROGETTI SRL
VIKING HYDROGEN AS
VRV SRL (CHART INDUSTRIES)
CENERGY SRL
UNIVERSITY OF TRIESTE
LLOYD'S REGISTER
HYPULSION SAS - PLUG POWER EUROPE
RICARDO CONSULTING ENGINEERS LIMITED
RICARDO PRAGUE S.R.O.
JEUMONT ELECTRIC SAS
PORT OF BERGEN (Bergen Havn As)
KONTOR 17 MPM
CIAOTECH SRL (PNO GROUP)



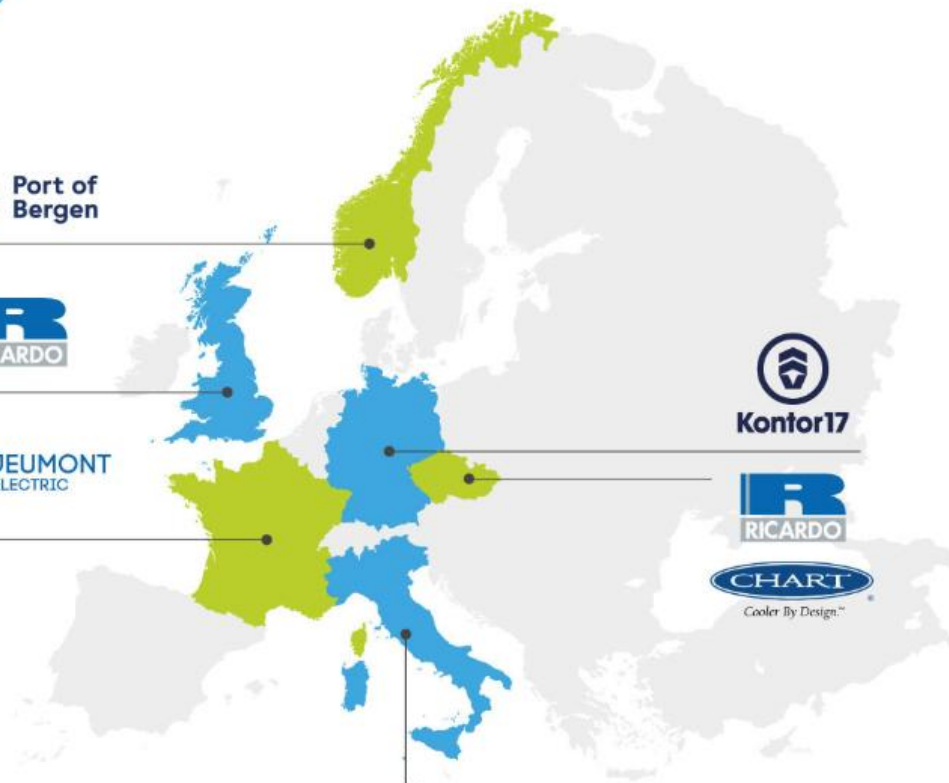
Kontor17



Cooler By Design™



UNIVERSITÀ
DEGLI STUDI
DI TRIESTE



VIKING OCEAN

In 2015, Viking introduced its first ocean ship with the naming of the 930-guest all-veranda Viking Star.

- Viking's ocean ships have been designed with energy-efficient hull, propeller arrangements and engines with heat recovery systems.
- Viking is the first ocean cruise line equipped with an efficient hull design, LED lighting throughout the ship, and advanced water treatment systems, featuring [40%] lower green-house gas emissions than similar ships in 2008.
- Additionally, Viking ships are the first newbuilds in the world with a closed-loop exhaust cleaning system designed so that pollutants can be removed and disposed of safely.



VIKING OCEAN ROADMAP TO HYDROGEN ON BOARD

Since 2019 it was planned to elongate the hull of Odin class ship by 11 mt, beginning with Viking Vela (delivered in 2024).

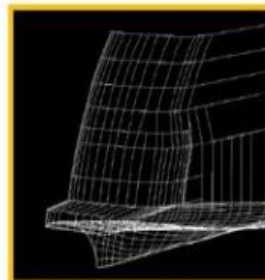
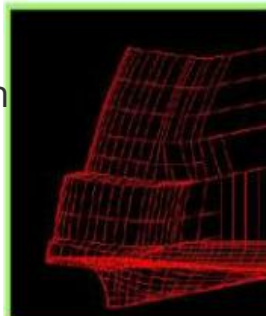
That choice has allowed more cabins and reserved space underneath planned for installation of systems to cross fjords in zero emission.

In 2021 Viking made a feasibility study for the hydrogen system on board to cross the World Heritage Fjords.

In the same year Viking participated to a European Horizon Tender for decarbonization with adoption of liquid hydrogen.

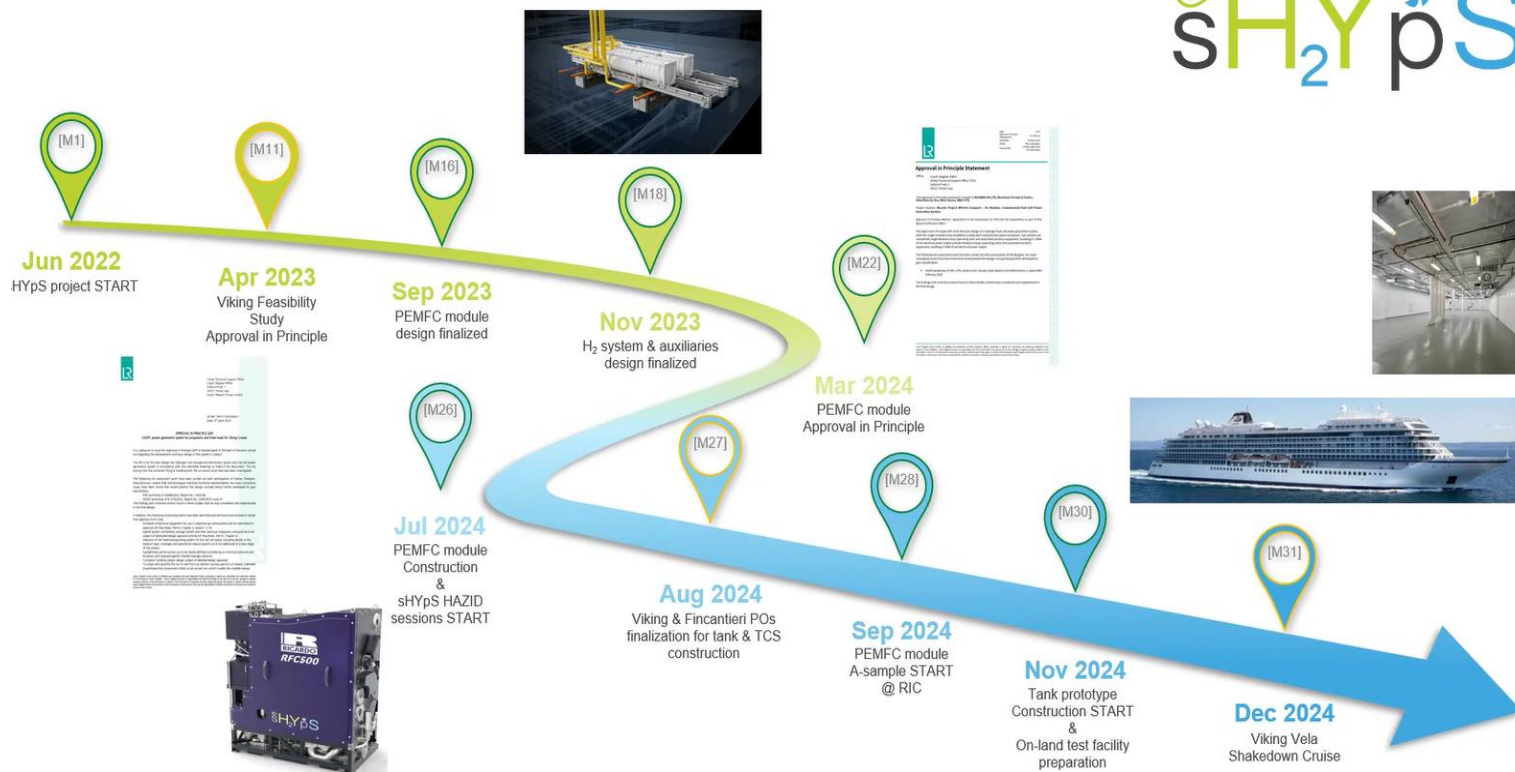
Viking and the consortium of 13 partners was awarded with 8 million euros for financing of the **project sHYpS**.

Viking I-X series

Additional premium
passenger outdoor
area at deck 2Photorealistic
render image

Italy – Croatia

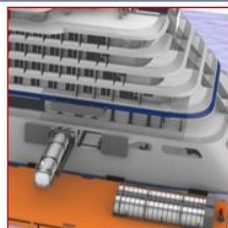
sH₂YpS



Italy – Croatia



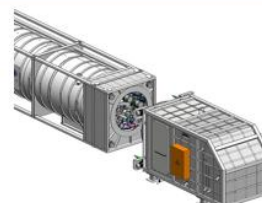
1 HANDLING SYSTEM



2 HYDROGEN STORAGE



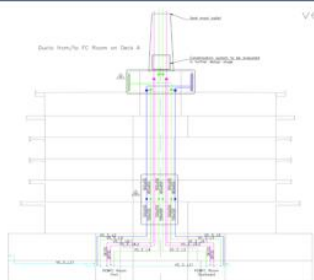
3 TANK-TCS
COUPLING SYSTEM



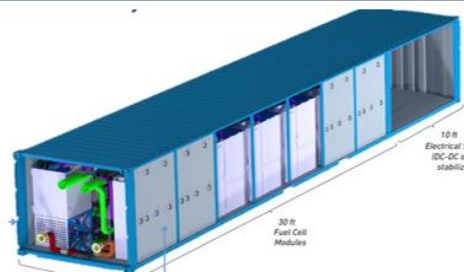
4 HYDROGEN FROM LIQUID to GAS



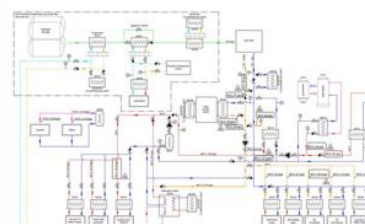
5 VENTILATION, PROCESS AIR,
VENTING AND INERTIZATION



7 POWER GENERATION AND MANAGEMENT



8 HEAT RECOVERY SYSTEM



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Area for Economic Policies, Human Capital
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By Stefano Quattrini

<https://www.linkedin.com/in/stefano-quattrini-8262b16/>

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Unlocking hydrogen in the maritime industry

Marco Molica Colella
Lead Funding & Finance
Hydrogen Europe

**76% of EU
external trade**

**≈ 65% electrolyser
capacity in China**

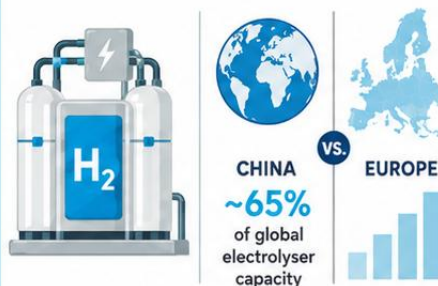
**High-cost fuels +
weak demand
signals**

1 SECURITY OF SUPPLY



Shipping carries **76%** of EU external trade, including essential energy, food and goods. But future clean fuel demand will increasingly rely on imports. Without diversified supply chains, Europe risks repeating fossil fuel dependencies and exposure to geopolitical shocks and price volatility.

2 GLOBAL COMPETITIVENESS



Europe is strong in innovation, but it lags in deployment. China holds around **65%** of global electrolyser capacity. Without scaling domestic production and infrastructure, Europe could lose industrial leadership and deepen external dependencies.

3 HIGH COSTS & INVESTMENT RISK



Clean shipping fuels remain significantly more expensive than conventional options. Investment is constrained by uncertain demand and misaligned market incentives, slowing large-scale adoption.



WHAT IS NEEDED?

Targeted policy support is needed to de-risk early markets, support domestic scale-up, and build diversified clean fuel supply



**Hydrogen
Europe**



EU Framework for Maritime Transport: State of Play

Drivers

- FuelEU Maritime long term investment technology choices (penalties of 2,400 €/t for conventional fuel consumed above the GHG limit)
- IMO Net zero framework, post-postponement

Constraints

FEUM

- No binding RFNBO targets under FEUM.

ETS

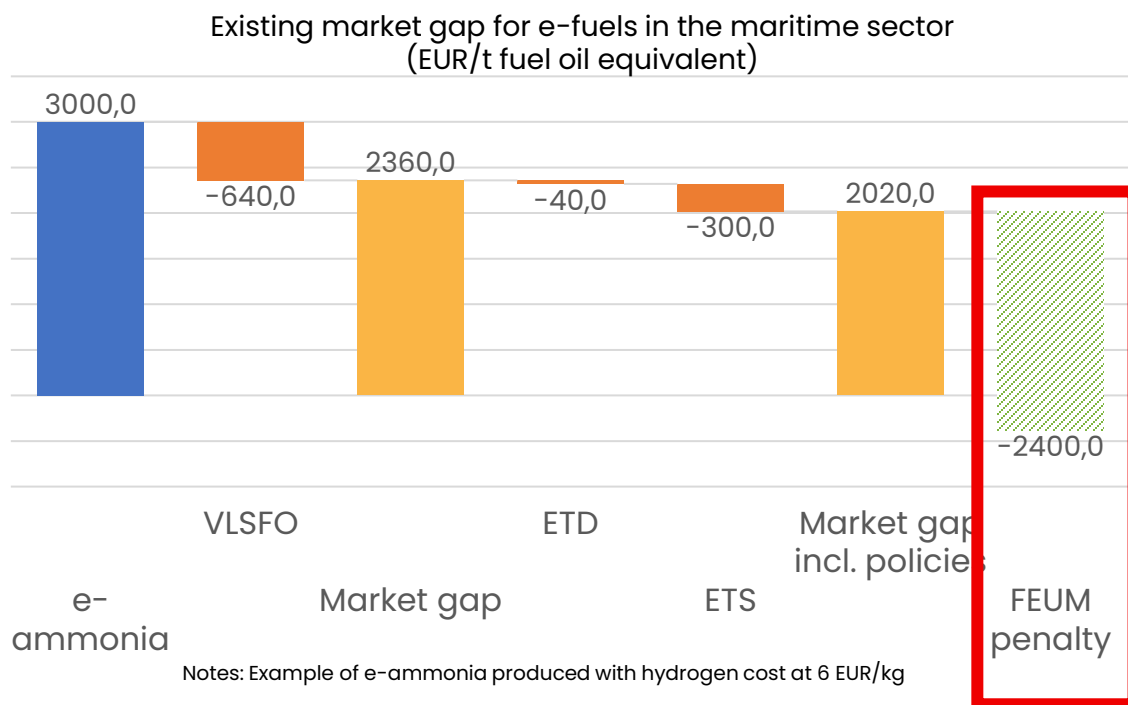
- ETS Maritime covers 70% of verified emissions for 5000+ GT vessels. Non-CO2 emissions to be included as from next year.

The IMO MEPC.2 vote postponement should be seen as such – a postponement. The EU legislative Framework can act as a guide for the NZF.



Legislatively, the EU has the right approach with the combination of a fuel standard and a carbon pricing mechanism. But the funding gap remains.

Impact of the FuelEU Maritime



The non-compliance penalty introduced in the FuelEU Maritime regulation (2,400 EUR/t) would provide the needed incentive – **but there are no RFNBO specific targets in FuelEU Maritime.**

This combined with relatively small objectives until 2030 means that the penalty will not make much difference for e-fuels (afterall – if the target can be met using LNG no one will be facing the penalty)

Non-compliance penalty in the FEUM can really make things move

The problem is not only funding, but market design

Why fuels are not scaling up

- Producers need long-term revenue certainty for FID
- Buyers ask for short term contracts for immature markets with green-premia
- Governments need catalytic tools to bridge the price gap under tight public budget

The ETS Opportunity

- In 2026, shipping ETS is expected to raise approx. €8 billion, with projected revenues by 2030 going up to €11 billion (source T&E).
- A share of these revenues should be used to scale e-fuel production sector...

STIP: will it cover the funding gap?

What's included?

- Possible upcoming measures for Maritime Fuels analogous to SAF support.
- Member State 'encouragement' to propose earmarking of maritime revenues.
- Possible upcoming MRV framework for ETS Maritime and FuelEU Maritime.
- The Commission will 'examine' how PPAs could be extended to RLCF.

What is missing?

- **Binding RFNBO FuelEU Maritime targets.**
- **Earmarking of ETS Revenues back to the maritime sector.**
- **Demand-side policies: maritime transport as a 'lead market'**

Total mobilisation of **€2.9 billion until end-2027** through different funding mechanisms.

→ However, total investment needs are around **€34.7–46.7 billion**

Sustainable Transport investment Plan (STIP) is a step in the right direction, but the funding gap remains. A combination of binding FEUM targets, and the use of ETS revenues can ensure that this gap could be covered without endless reliance on additional funding.



Sustainable Transport Investment Plan

Strategic roadmap to boost renewable and low-carbon fuels for aviation and waterborne transport

Market Design: an opportunity from Double Sided Auction

In December 2025, the **Sustainable Transport Investment Plan (STIP)** announced the launch of preparations for an **EU-wide market intermediary** for production of sustainable aviation and marine fuels via **double-sided auctions**.

How do DSA Work?

1. Buy long-term

A market intermediary purchases clean fuels via long-term contracts.

This gives producers revenue certainty and supports projects reaching FID.

2. Resell shorter-term

The intermediary resells volumes to offtakers such as bunker suppliers, ship owners and operators.

Shorter-term resale contracts help buyers manage price risk as markets mature.

3. Pay only the gap

Public support covers the difference between production costs and market price.

Support is paid only upon verified delivery of volumes.



Sustainable Transport Investment Plan

Strategic roadmap to boost renewable and low-carbon fuels for aviation and waterborne transport

Market Design: an opportunity from Double Sided Auction

At the end of 2025, the **e-SAF Early Mover Coalition** was **joined by 8 member states and the European Commission** to pool funds for a European e-SAF tender. To date, more than EUR 2 billion has been allocated to the tender.

The European Commission and national governments can replicate the best practice to scale-up of clean shipping fuels and infrastructure.

How to implement

1. Pilot Tender – Short Term

European national governments commit funding to a double-sided auction tender for the early production and offtake of clean shipping fuels within an e-SMF Early Movers Coalition.

2. ETS reusage – mid term

The European Commission sets up an EU-wide intermediary to conduct further tenders to ensure the scale-up of clean shipping fuels and infrastructure, funded through recycled EU ETS revenues from the maritime sector.

3. Next

The European Commission and national governments can replicate the best practice of pooled funding to accelerate the market scale-up of clean shipping fuels and infrastructure.



Sustainable Transport Investment Plan

Strategic roadmap to boost renewable and low-carbon fuels for aviation and waterborne transport

E-SMF Early Movers' Initiative

A coalition of industry associations — T&E, H2Global, ECSA, Ammonia Europe, etc. — developing a pilot double-sided auction for e-SMF, modelled on the eSAF Early Movers' Coalition.

Timeline:

- **04 June 2026 → Launch event**
- **2026–2028 → Pilot auction setup (2–3 years)**
- **2034 → FuelEU Maritime RFNBO sub-target kicks in**
- **To join initiative, please reach out to s.demeestere@hydrogeneurope.eu and o.staudenmayer@hydrogeneurope.eu**

E-SMF Early Movers Initiative:

Enabling Europe to scale clean shipping fuels now through double-sided auctions



SIGNATORIES



Download the
position paper →



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Expo+Conference

26 - 30 October 2026

Brussels Expo, Belgium

euhydrogenweek.eu

2026 NOVELTY: FLOORPLAN ZONES

Dedicated zones of the Expo, focusing on thematic areas and priorities of the hydrogen sector:

1. Resilience
2. SMEs
3. Mobility
4. Electrolysis
5. Research

6. National associations
7. EU regions
8. Infrastructure/ports
9. Energy
10. Country partner/
international pavilions



Early bird rates apply until 1st August.

Hydrogen Europe members benefit from an additional discount.



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Onboard utilization of liquid hydrogen: an overview

Storing fuel at 20 K and turning it into propulsion — physics, system architecture, and where the technology stands

Rodolfo Taccani
University of Trieste

16 June 2026

WHY THIS MATTERS

Hydrogen decarbonizes the hard-to-electrify modes — but only if you can carry it

Batteries are too heavy for long-range aviation, deep-sea shipping and heavy haulage. Hydrogen offers $\sim 3\times$ the energy per kilogram of kerosene with zero carbon at the point of use. The catch is volume: even as a cryogenic liquid it is bulky, so how you store it on board dominates the vehicle design.

$\sim 3\times$

energy per kg vs. jet fuel

0

CO₂ at point of use

20 K

storage temperature

AGENDA



Fundamentals

Properties & the cryogenic challenge



Storage

On-board tank architecture & boil-off



Conversion

Fuel cells vs. combustion



Applications

Space, air, sea, road — and outlook

Liquid hydrogen in numbers

20.3 K



Boiling point (-253 °C)

Colder than any fuel; only liquid helium is colder. LNG is -162°C.

71 kg/m³



Liquid density

≈ 1/12 the mass-density of water; very light, very bulky.

120 MJ/kg



Lower heating value

≈ 2.8× kerosene per unit mass.

× 845



Gas→liquid volume gain

1 m³ of LH₂ = 845 m³ of gas at ambient.

**~0.45
MJ/kg**



Latent heat of boil-off

Tiny — small heat leaks vaporize the fuel.

≈ 30 %

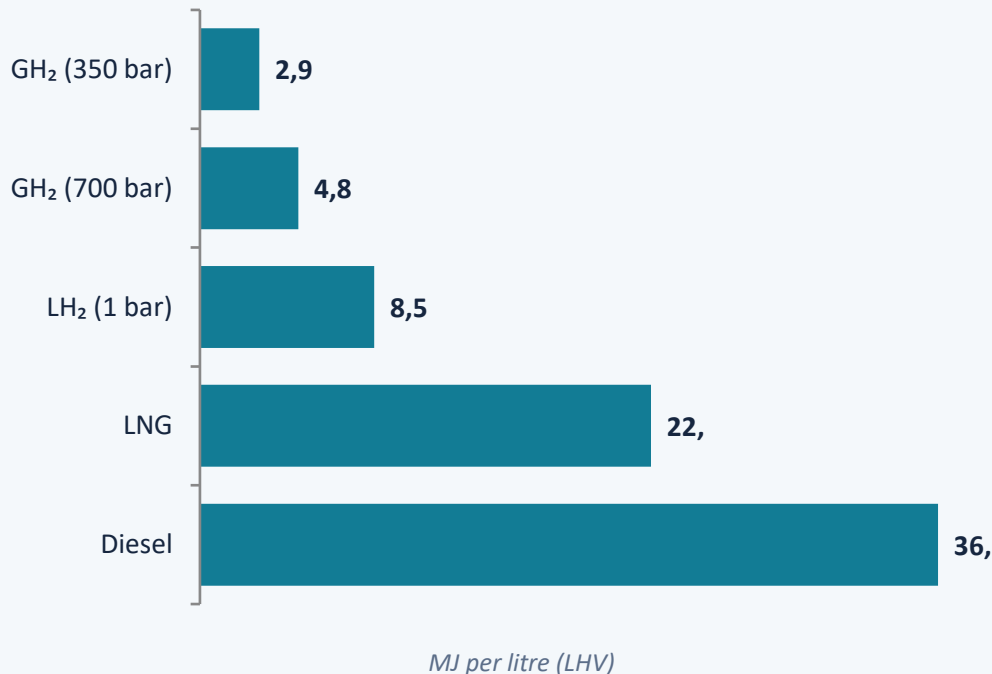


Energy spent liquefying

Share of H₂'s energy needed to cool & liquefy it.

STORAGE TRADE-OFF

Why liquid? It is the densest practical way to pack hydrogen



On-board utilization of liquid hydrogen — an overview

Among on-board options, LH₂ stores the most energy per litre of hydrogen — but it still trails fossil fuels several-fold. That volumetric gap, not weight, is the central design driver.



LH₂ ≈ 1.8× the energy density of 700-bar gas

...yet still ~4× less than diesel. Tanks get big — the reason airframes and ships have to be re-designed around the fuel.

Two physics problems unique to liquid hydrogen



Ortho → para conversion

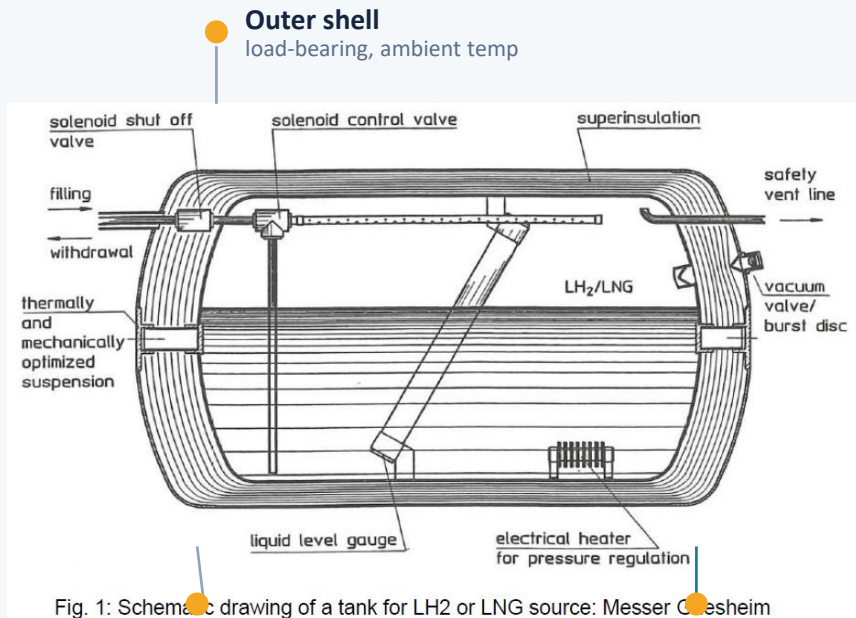
- At room temperature H_2 is ~75% ortho; at 20 K it equilibrates to ~99.8% para.
- That spin conversion is exothermic — it releases more heat than the latent heat of vaporization.
- Without catalytic conversion during liquefaction, a tank can self-boil-off most of its contents in days.



Boil-off & dormancy

- Heat always leaks in; the liquid boils, pressure rises, and gas must eventually be vented or used.
- Typical losses: ~0.3–1 % per day for large, well-insulated tanks — far more for small ones.
- "Dormancy" — how long a parked vehicle can sit before it must vent — becomes an operational metric.

The tank is a vacuum-insulated thermos



Vacuum + MLI
multi-layer insulation

Inner vessel
holds the LH₂



Near-spherical / cylindrical

Minimizes surface-to-volume → less heat leak. Drives aircraft to rear-fuselage tanks.



Low pressure, ~1–6 bar

Unlike 700-bar gas tanks; walls can be thinner but must stay leak-tight.



Material care

Austenitic steels / Al alloys / composites resist embrittlement & cold-shrink.

Four ways to deal with boil-off gas

Heat leak can't be eliminated, only managed. Real systems combine these — the right mix depends on mission length, dormancy needs and available power.



Vent / vaporize

Release boil-off through a vent mast (safely upward). Simple, but loses fuel.



Burn / use it

Feed boil-off gas straight to the fuel cell or engine — turn loss into useful power.



Re-liquefy

On-board cryocooler condenses the gas back to liquid. Zero loss, but power-hungry & heavy.



Pressure ride

Let pressure rise in a stronger tank to delay venting — extends dormancy on the ground.

Two conversion routes: fuel cell vs. combustion



Fuel cell (PEM)

H₂ → electricity electrochemically

- Efficiency ~50–60 %, only water exhaust
- Quiet; ideal partial-load performance
- Needs clean, conditioned, gaseous H₂
- Adds an electric powertrain + cooling



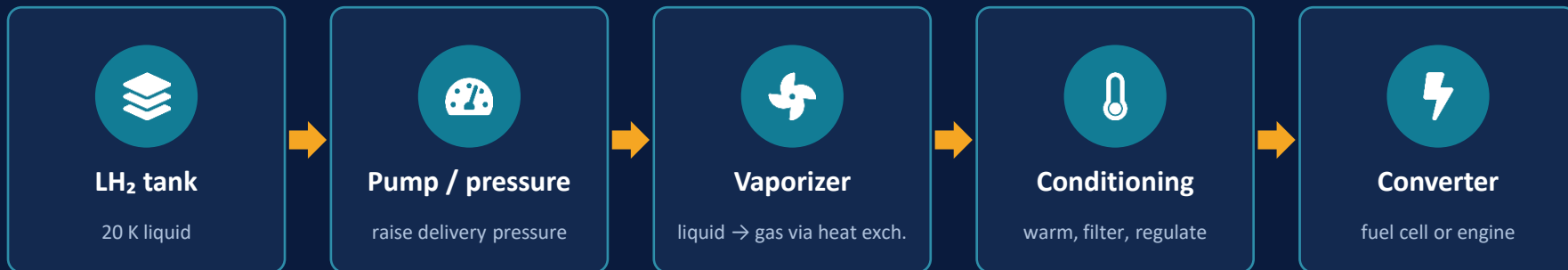
Combustion (turbine / ICE)

Burn H₂ as a drop-in-ish fuel

- Reuses turbine/engine know-how & power density
- Tolerates lower-purity hydrogen
- No CO₂ — but hot flame makes NO_x to control
- Lower efficiency than fuel cells

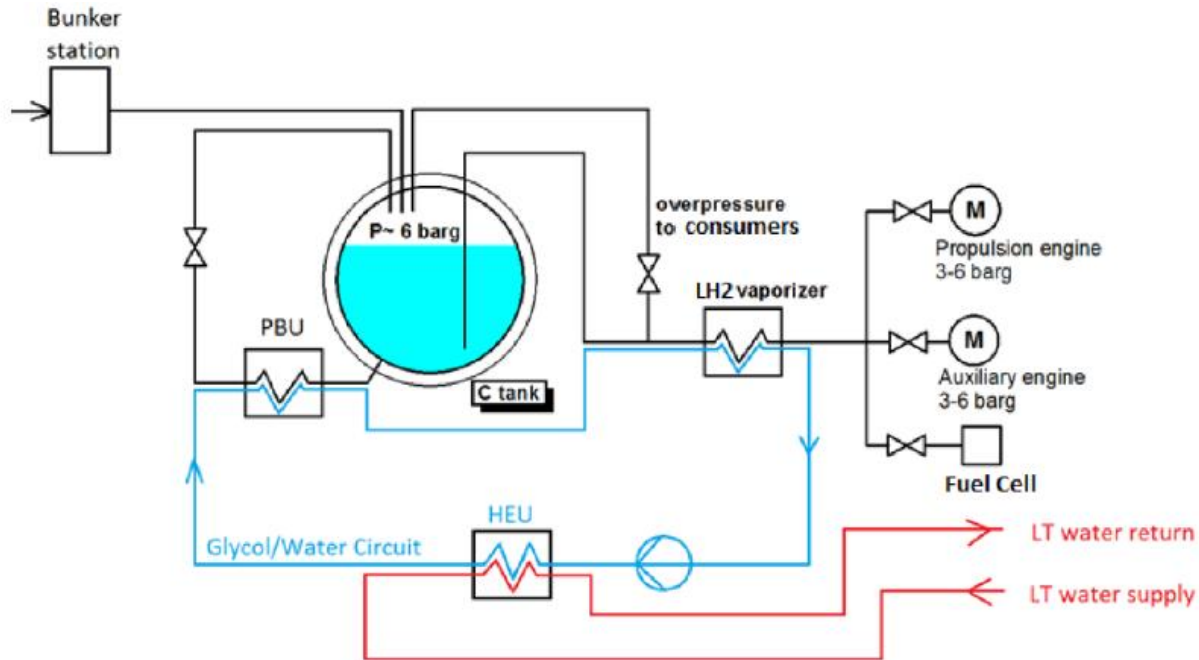
From cryogenic tank to useful power

The fuel must be drawn, pressurized, vaporized and warmed before any converter can use it — the "balance of plant."



Cold is an asset, not just a cost. The vaporizer's heat demand can be met by waste heat from the fuel cell or engine, and the cryogenic "cold exergy" can pre-cool electronics or intake air — recovering some of the liquefaction penalty.

Not just a tank



MAN Energy Solutions/MAN Cryo, "LH₂ Marine Power Pack – Hydrogen Power Pack for Passenger Vessels", 2021

On-board LH₂ across the transport modes



Space

Mature

Decades of heritage: LH₂/LOX upper stages (Ariane, SLS, Centaur). The benchmark for handling cryogenic H₂.



Maritime

First vessels sailing

MF Hydra (Norway) & MV Sea Change run on LH₂ fuel cells; Viking's hydrogen cruise ship and larger cargo concepts are following.



Aviation

R&D, slowed timeline

Airbus ZEROe confirmed a fuel-cell concept (TRL 3, early 2026) and is flying an A380 LH₂ testbed — but entry-into-service pushed beyond 2035.



Road / rail

Niche, emerging

Trucks mostly use compressed gas; sub-cooled LH₂ refuelling (sLH₂) is being demonstrated for long-haul heavy duty.

Different from hydrocarbons — not simply more dangerous

Hydrogen's hazards are real but distinct; designing for them is well understood from decades of industrial and aerospace practice.



Wide flammability

4–75 % in air, very low ignition energy → strict leak control & ventilation.



Buoyant & fast

Lighter than air; leaks disperse upward quickly rather than pooling — an outdoor advantage.



Invisible flame

H₂ flames emit little visible light & low radiant heat — needs UV/IR flame detection.



Cryogenic hazards

Cold burns, asphyxiation in confined spaces, embrittlement — material & venting design.

What still has to improve



Energy & cost

Liquefaction's ~30 % penalty and green-H₂ price must fall to compete with fuels and batteries.



Boil-off & dormancy

Better insulation and on-board re-liquefaction to make long parking and storage practical.



Lightweight tanks

Composite cryo-tanks to lift the system-level gravimetric advantage, especially for flight.



Infrastructure & rules

Bunkering, airport hubs and harmonized codes — the non-technical gating items.



The bottom line

LH₂ is the energy-densest practical hydrogen store for vehicles.

The hard problems — boil-off, weight, cost — are engineering, not physics barriers.

First ships sail today

Passenger ferry Hydra (2023)

Two fuel cell engines for 400kW
4 tons of LH2
Bunkering with truck



Source: <https://www.norled.no/en/nyhet/the-worlds-first-ship-powered-by-liquid-hydrogen-impresses/>

Luxury Yacht Breakthrough (2025)

Liquid hydrogen for propulsion
About 4 tons of LH2
Bunkering in Amsterdam with truck



The Shyps EU Project (2026)



A novel LH2 swappable storage solution, has been developed which can be adapted to multiple types of vessels and speed up achieving IMO's target for 2030 and 2050.

LH2 content: 2000 kg



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www.shyps.eu

Onboard utilization of liquid hydrogen: an overview

Thank you!
Questions welcome

Rodolfo Taccani
University of Trieste

16 June 2026

Designing Digital Twins for Energy Transitions: The H₂ Smart Lab Approach

16 June 2026

Introduction

- ✓ Digital transformation is reshaping industrial systems through advanced information, communication, and connectivity technologies.
- ✓ The European Green Deal promotes the concept of a 'Twin Transition', where digital innovation and sustainability evolve together.
- ✓ The energy sector is becoming increasingly decentralized, requiring intelligent monitoring, coordination, and predictive capabilities
- ✓ New concept as prosumers, democratization of energy production, energy curtailment are becoming familiar
- ✓ Digital technologies are now, more than before, considered strategic enablers for accelerating decarbonization and improving energy resilience.



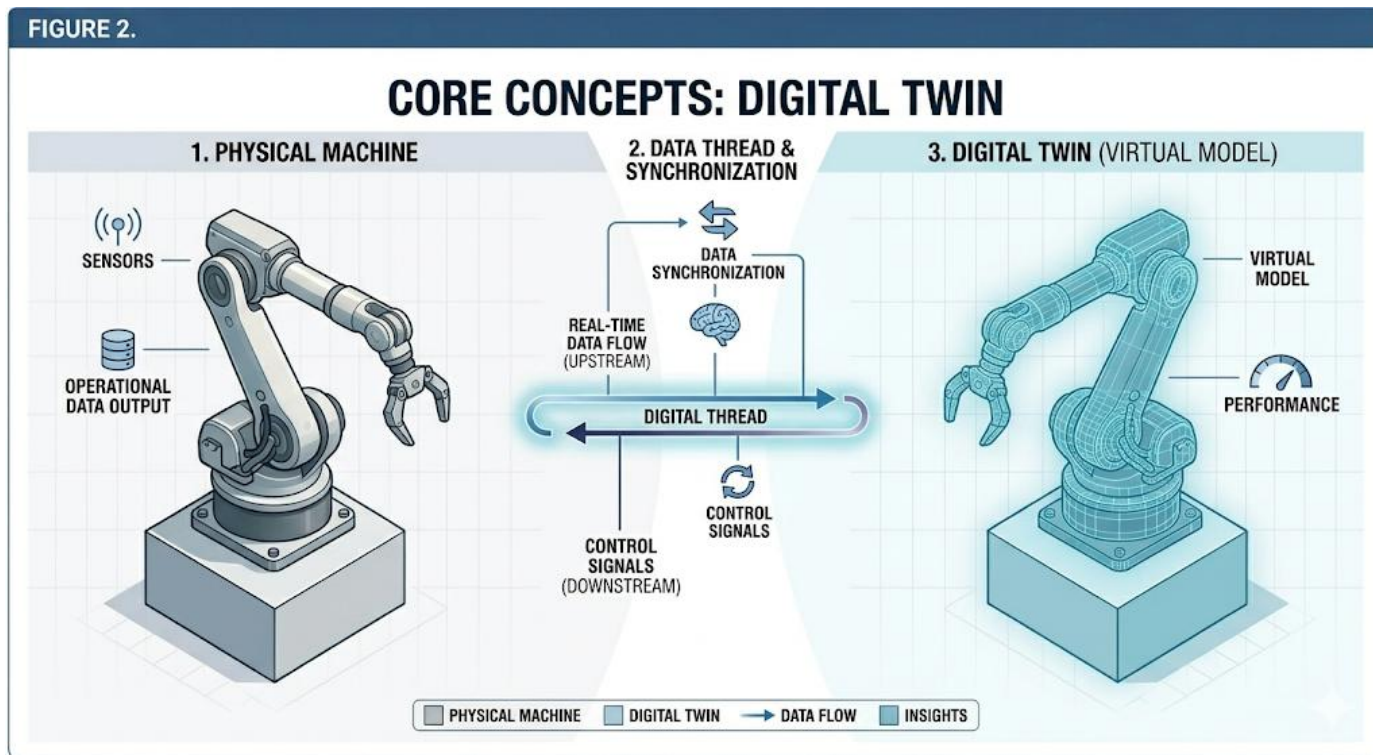
Why Digital Twins Matter

- ✓ A Digital Twin is a dynamic virtual representation of a physical system continuously updated through real-time data.
- ✓ Unlike static simulation models, Digital Twins evolve during the lifecycle of the infrastructure and support adaptive decision-making.
- ✓ The integration of sensors, IoT platforms, and analytics enables predictive maintenance and operational optimization.
- ✓ Digital Twins create a bridge between physical and digital environments, improving system visibility and responsiveness.



Digital Twins

Bi-directional relation between a physical artifact and its set of virtual models (Schleich et al., 2017)

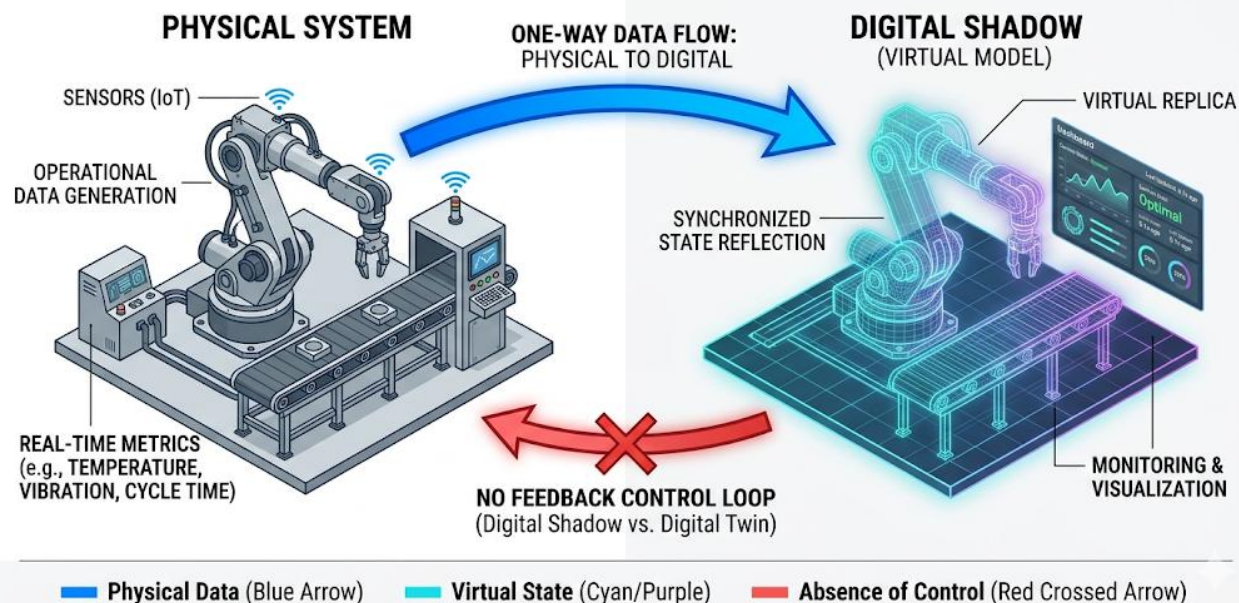


Source: AI-generated, Gemini AI

Digital twin as a digital mirror or shadow, facilitating seamless transmission of data between physical and virtual worlds (Caramia et al, 2026)

FIGURE 1

A Digital Shadow



Source: AI-generated, Gemini AI

Digital Twin as an Enabler of Energy Transition

- ✓ Renewable energy systems require flexible and intelligent infrastructures capable of handling variability and uncertainty.
- ✓ Digital Twins support forecasting, real-time monitoring, and optimization of renewable energy production and consumption.
- ✓ In a hydrogen production plant, the technology enhances coordination between distributed assets such as electrolyzers, renewable plants, and storage systems.
- ✓ By improving efficiency and reducing “waste”, Digital Twins contribute directly to sustainability and carbon reduction goals.



Hydrogen in the Future Energy Landscape

- ✓ Green hydrogen is emerging as a key energy vector for achieving climate neutrality and industrial decarbonization.
- ✓ Hydrogen can support hard-to-abate sectors including heavy industry, mobility, and long-term energy storage.
- ✓ The integration of renewable electricity and electrolysis technologies creates new opportunities for flexible energy systems.
- ✓ However, hydrogen systems require advanced monitoring, safety, interoperability, and optimization capabilities.



North Adriatic Hydrogen Valley (NAHV) initiative



Friuli-Venezia Giulia ERDF
2021-2027

Allocation of flexibility
quota for green hydrogen

NEW Calls to support the
regional hydrogen
ecosystem helping
investments in innovation
and industrial development

Regional Law 13/2023,
Art.7

Call for proposal to support
the creation or
modernization of Research
Infrastructure in the
renewable hydrogen sector



ESF Development and
Cohesion Plan

NEW Call for funding of
researchers, technologists
and research activities to
support infrastructure

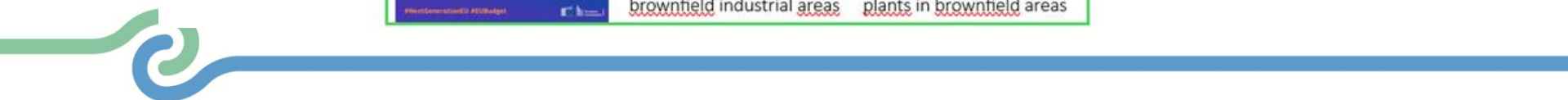


Call for proposal to support
to renewable hydrogen
production plants in
brownfield industrial areas

NEW Call for proposal
to support renewable
hydrogen production
plants in brownfield areas



AMETHYST



A DT case study: H2 Smart Lab

LR 13/2023, articolo 7, commi 14 e
15 bis:

- ✓ The H2 Smart Lab is a real-scale experimental platform developed to test hydrogen technologies in operational conditions.
- ✓ Public–Public research infrastructure on hydrogen systems, coordinated by Area Science Park with UniTS and SISSA.

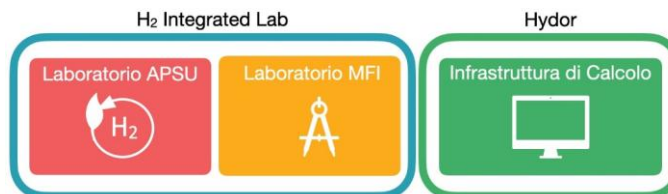
Two nodes, three components:

Node 1 — H2 Integrated Lab:

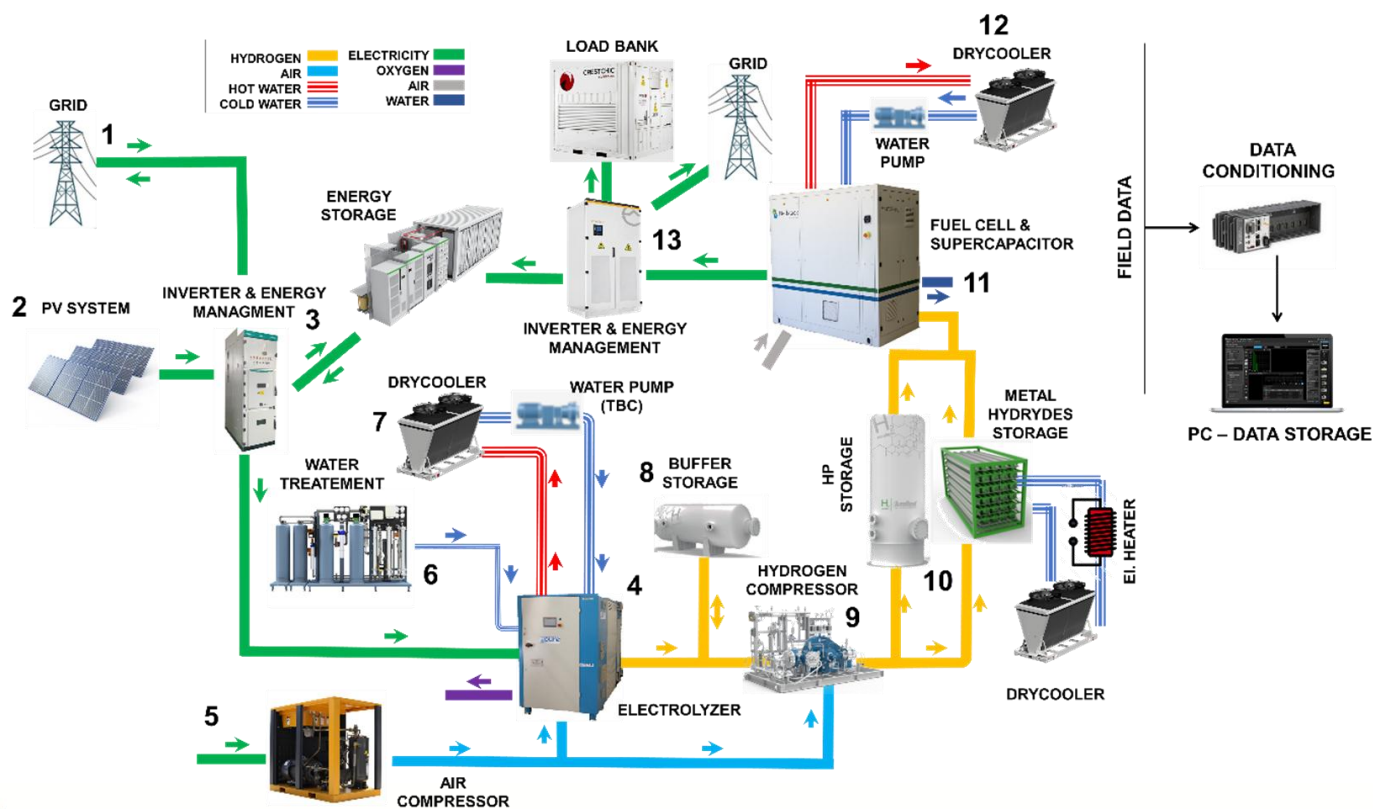
- APSU — Analysis of hydrogen Production, Storage and Utilization - AREA
- MFI — Measurements on hydrogen-supply chain (sensor network) - UNITS

Node 2 — Hydor:

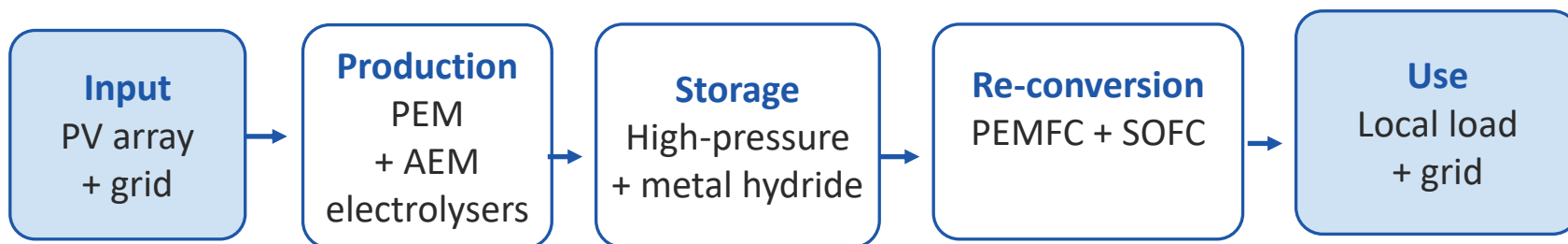
- Computing & data infrastructure for the digital twin - SISSA



The H2 Smart Lab - APSU



The H2 Smart Lab - APSU



≈ 110 sensors throughout the loop · temperature, pressure, flow, H₂ purity, electrical

Power input — PV plant + grid connection

Electrolysers — PEM + AEM (two technologies on the same plant for comparison)

Storage — high-pressure tank + metal-hydride storage (different time-scales)

Fuel cells — PEM + SOFC, plus supercapacitor buffer

Throughput — ≈ 0.93 kg H₂ / h ; instrumented along the entire chain

The Concept of 'Digital Twin by Design'

- ✓ Traditional Digital Twins are often implemented after physical infrastructures have already been developed.
- ✓ In APSU a different approach called 'Digital Twin by Design', is followed. Here digital integration is embedded from the beginning.
- ✓ Sensors, communication protocols, and data models are intentionally designed to support future analytics and interoperability.
- ✓ This approach increases flexibility, reduces integration costs, and improves long-term scalability:
 - Sensor placement and sampling rates are chosen with downstream analytics in mind.
 - Each measurement is tied to a typed entity in our domain ontology from the moment it is acquired.
 - Data schemas, governance, and access control are defined before the plant is operational, not after.



The Concept of 'Digital Twin by Design'

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In APSU a different approach called 'Digital Twin by Design', is followed. Here digital integration is embedded from the beginning.

Sensors, communication protocols, and data models are intentionally designed to support future analytics and interoperability.

This approach increases flexibility, reduces integration costs, and improves long-term scalability:

- Sensor placement and sampling rates are chosen with downstream analytics in mind.
- Each measurement is tied to a typed entity in our domain ontology from the moment it is acquired.
- Data schemas, governance, and access control are defined before the plant is operational, not after.



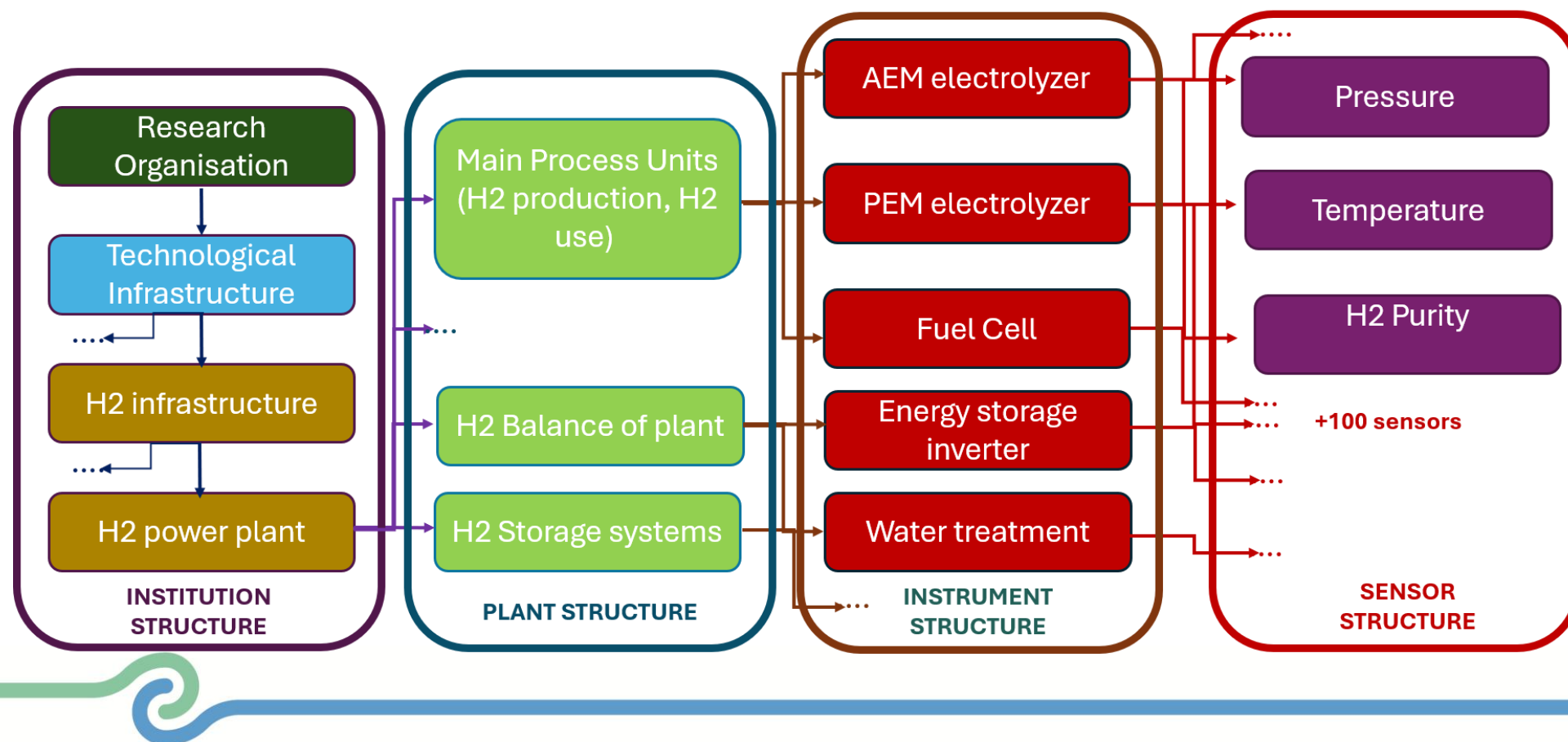
Multi-Layer Digital Twin Architecture

The H2 Smart Lab architecture integrates multiple dimensions of the hydrogen infrastructure into a unified framework.

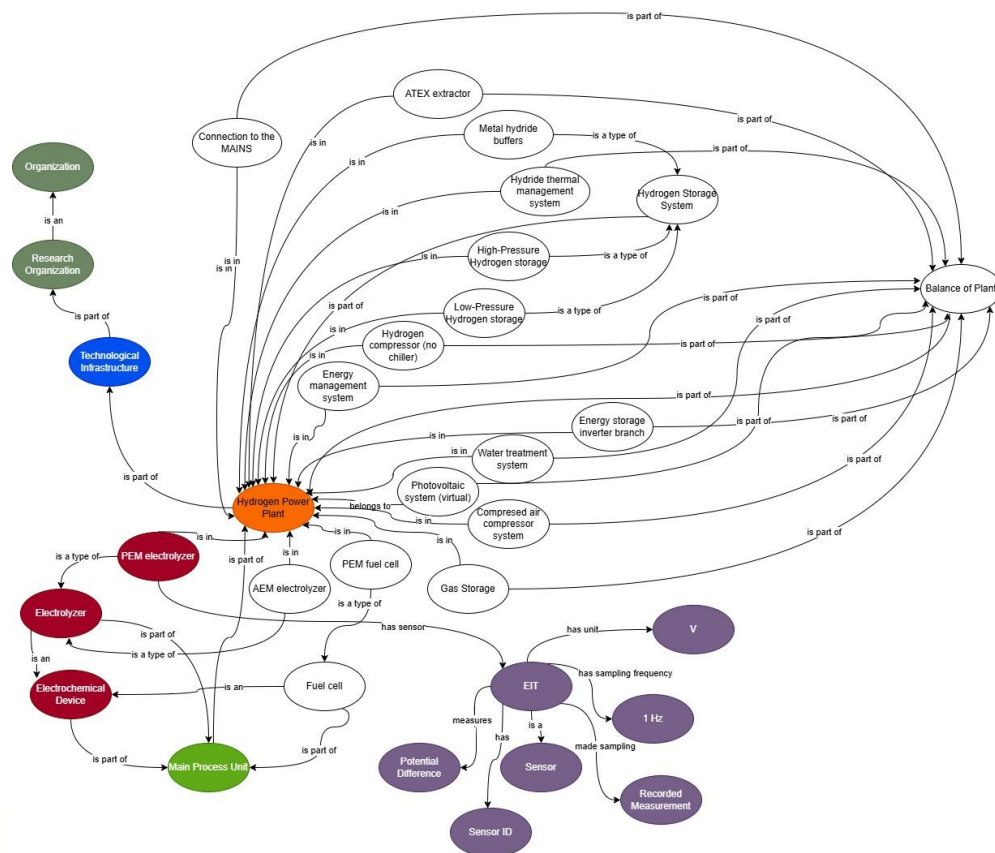
- The technical layer includes physical assets, sensors, energy systems, and operational parameters.
- The operational layer supports monitoring, control, simulation, and predictive maintenance functions.
- The economic and environmental layers evaluate efficiency, resilience, resource optimization, and decarbonization impacts.



Multi-Layer: technical fisical asset



The ontologies



Operational Benefits of the Digital Twin

- ✓ Real-time monitoring enables early detection of anomalies and operational inefficiencies.
- ✓ Predictive analytics improve maintenance planning and reduce downtime of critical components.
- ✓ Scenario simulation supports optimization of renewable energy coupling and hydrogen production strategies.
- ✓ Stress testing and durability analysis enhance reliability and technological readiness without risking the infrastructure
- ✓ Artificial Intelligence enhances Digital Twin capabilities through machine learning and advanced predictive models this pave the way for new applications: i.e remote maintenance, and operator training.



To conclude

- *Digital twin by design* can support the development of technological infrastructures intrinsically prepared for advanced monitoring, semantic interoperability, and hybrid simulation.
- Aligning sensing strategies, metadata architectures, and modeling requirements from the early design phase, support scalable digital twins and data-driven operational optimization.
- The complexity and safety-critical nature of hydrogen systems limit the short-term realization of fully bidirectional digital twins. Robust validation procedures, reliable semantic integration, and long-term operational datasets remain necessary to ensure trustworthy interaction between physical infrastructures and their digital counterparts.
- Future work will therefore focus on validating the proposed framework through the progressive commissioning of H2SmartLab and the integration of operational data into hybrid/shadow digital twin models.



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Thanks for your attention

Zero emissions maritime propulsion: alt-fuels & digitalization

A view from class

Lloyd's Register EMEA | Fabrizio Cadenaro

Transnational Training and Education event

Trieste | 16 June 2026

▶ **Alt-Fuels Regulatory Framework update**
Alternative approaches
How does digitalization help?
A few cases

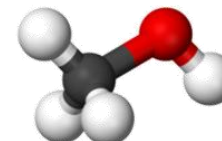
Alt-fuels highlights

LNG (&NG) – Benchmark for alternative fuels, modest reduction in CO₂

Methanol – Some applications, toxic, pairs with reformers & FC

Hydrogen – Zero local emissions potential, works with FC, strongly cryogenic, complex storage technology needed

	LNG	MeOH	NH ₃	LH ₂	Diesel
Liquid storage temperature [°C]	-163	Atm	-33	-253	Atm
Storage pressure [bar]	0 – 10+	Atm	0 – 10+	0 – 10+	Atm
Density [kg/m ³]	430+	790	682 with 121 of H	70	840
Flash point [°C]	-188	12	n/a	<-253	>60
Explosive vapours risk	High	High	Low	High	Low
Toxicity	No	Yes	Yes	No	Low
Local (TTW) zero CO ₂ ?	No	No	Yes	Yes	No



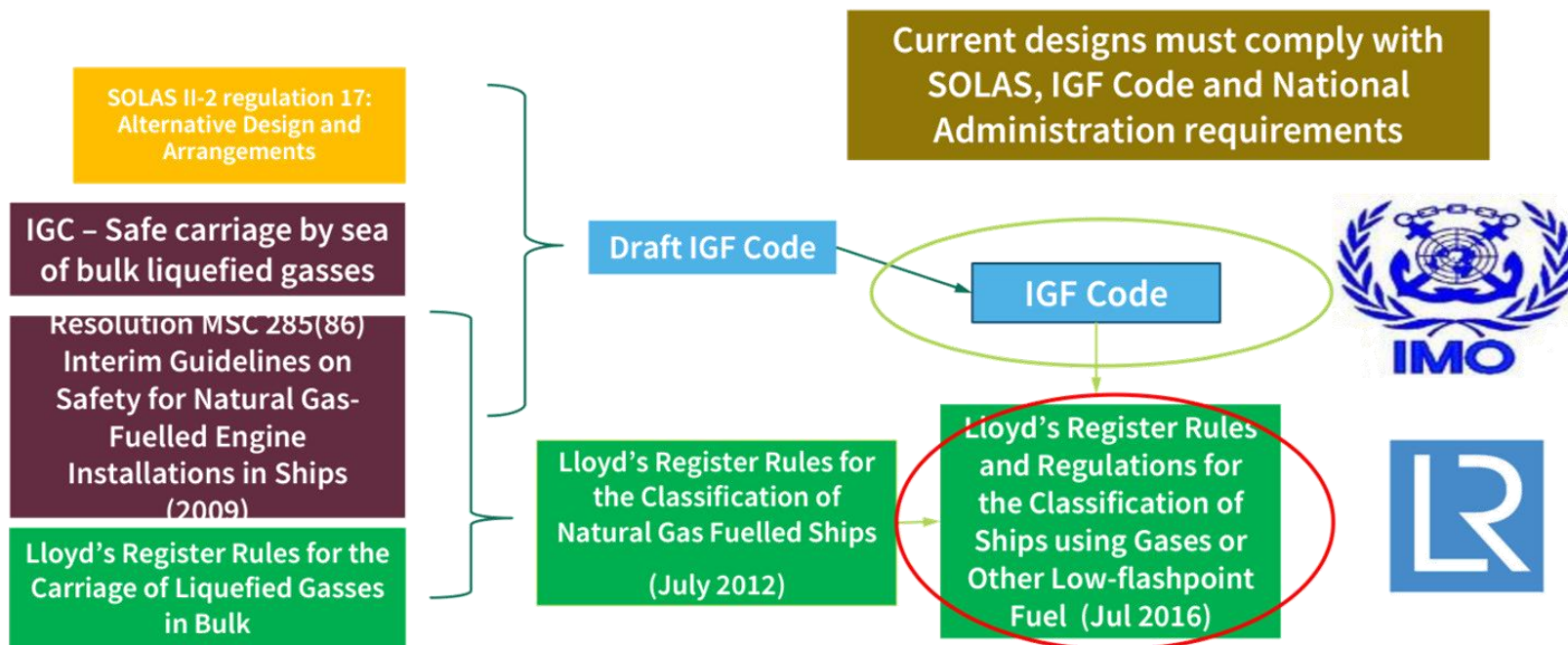
A glance to the developing regulatory framework

	MeOH	LH2/H2	Fuel cells	NH3
IMO	<ul style="list-style-type: none"> MSC.1/Circ.1621 - Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel 	<ul style="list-style-type: none"> MSC.420(97) Interim recommendations for carriage of liquefied hydrogen in bulk Interim guidelines for the use of hydrogen as fuel & interim recommendations for the carriage of liquefied hydrogen in bulk finalized @ IMO CCC11 	<ul style="list-style-type: none"> MSC.1/Circ.1647 Interim Guidelines for the Safety of Ships Using Fuel Cell Power Installations 	<ul style="list-style-type: none"> MSC.1/Circ.1687 Interim Guidelines for the Safety of Ships Using Ammonia as Fuel Interim guidelines for the use of ammonia cargo as fuel finalized @ IMO CCC11
LR	<ul style="list-style-type: none"> LR Rules for Ships using Gases or other Low-Flashpoint fuels - Appendix LR1 	<ul style="list-style-type: none"> LR Rules for Ships using Gases or other Low-Flashpoint fuels - Appendix LR3 Guidance Notes for Liquid Hydrogen Systems 	<ul style="list-style-type: none"> LR Rules for Ships, Pt 5 Ch 26 LR Type Approval Test Spec 7 (fuel cells) Guidance Notes on the Installation of Fuel Cells on Ships 	<ul style="list-style-type: none"> LR Rules for Ships using Gases or other Low-Flashpoint fuels - Appendix LR2 Guidance Notes for Fuel System RA, Hazard Identification – Hydrogen and Ammonia

Rule and regulation development for LNG

LR

SOLAS II-2 regulation 4.2.1 limits the flashpoint of oil fuels to 60°C or higher



What about other alt-fuels?

- Although several interim guidelines are being developed and/or published by IMO, formally IGF Part A-1, the most detailed, is applicable to natural gas fuel only.
- Other installation should be formally guided by IMO Alternative Design and Arrangements process in accordance with MSC.1/Circ.1455.
- LR has developed the RBC – “Risk Based Certification” framework to support development and approval of alternative designs with the aim to feed into MSC.1/Circ.1455 and satisfy relevant Flag requirements
- It is expected that the IGF code will be developed to cover fuels like H2/LH2, MeOH, LPG, NH3, however this is a long process with intermediate steps.

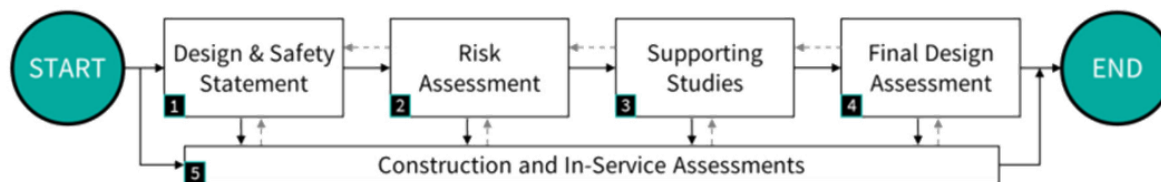


Figure 1.2.1 Risk Based Certification (RBC) process

IMO FLL & SFCS

- Methanol still contains carbon, therefore combustion products contain CO₂. However bio-methanol or methanol otherwise produced with carbon capture technologies may be net-zero.
- Similarly, brown hydrogen produced from fossil fuel wouldn't be a local zero emission fuel but not a lifecycle zero emission fuel.
- IMO has been developing a dedicated certification framework in this respect which includes:
 - FLL – Fuel Lifecycle Label which will document the fuel GHG intensity and may accompany the bunker delivery note.
 - SFCS – Sustainable Fuel Certification Scheme, which will certify the GHG emission factors and sustainability themes or aspects as documented on the FLL

This will allow, starting with 2027, an annual certification GHG footprint of marine fuels with a well-to-wake approach. See MEPC.403(83) Reg. 34.

MEPC.403(83) actually recalls previous MEPC.391(81) (2024 LCA Guidelines).

Alt-Fuels Regulatory Framework update

- ▶ Alternative approaches
- How does digitalization help?
- A few cases

An alternative: Chemical storage - Liquid Organic Hydrogen Carriers

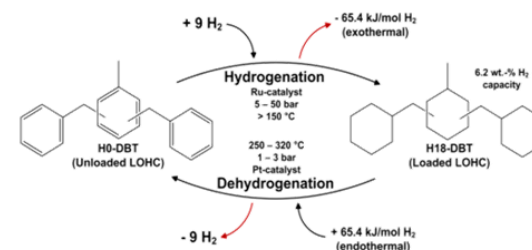
Certain hydrocarbon (oils) molecules exhibit the ability to **bond** with and release a number of hydrogen atoms with a certain amount of energy involved. They can be seen as “**energy carrying compounds**”.

Hydrogen atoms can be bonded and release through relatively simple **catalytic process**, the liquid is then **cycled** between the energy-rich and energy-lean states.

They are in general expected to be little or non toxic and almost or non-flammable, can be stored and handled just like “traditional” oils.

Hydrogen weight percentage can be in the **4% - 6%** range, oil density is similar to water => H₂ storage density competitive with LH₂

Many **risks** associated with hydrogen are **reduced** at the cost of carrying the **liquid oil ballast**



Introduction to Nuclear

What is Nuclear?

- Nuclear reactors generate heat through controlled nuclear fission
- Heat is converted to electrical, mechanical, or thermal power
- Used for propulsion, industrial mission, and other shipboard needs
- No direct GHG or other emissions
- Refuelling periods measured in years or decades
- High reliability and limited maintenance

Nuclear Energy Sources

- Radioactive heavy materials with high energy density
- Strictly regulated across production, distribution, handling, and use
- Expensive fuel, can cost more than the ship and reactor combined



Potential to disrupt the shipping industry

Nuclear potential

New relationships between ship operators and reactor owners

Ship owners may buy power generated by reactor rather than owning it

No need for regular bunkering

Reactor can run for multiple years without refuelling

Refuelling schedules range from 5-8 years to 30 years

High energy density compared to diesel

Properties of nuclear reactors	Value
GHG emissions	None
Sulphur (SOx)	None
Nitrogen (NOx)	None
Energy density comparison	Uranium 235 - 3 900 000 MJ/kg, Diesel - 45 MJ/kg

Alt-Fuels Regulatory Framework update Alternative approaches

- ▶ How does digitalization help?
A few cases

How can digitalization help?

Advanced and digital technologies may provide several advantages or alternative, for instance in areas like safety/risk reduction or optimization of human involvement:

- Highly automated, fail-safe and remotely controlled alt-fuels system requires less local human intervention, thus reducing risk.
- Remote surveys
 - may help to speed up processes in niche applications, where highly skilled people may not be readily available
 - May greatly reduce risk for the people in highly dangerous situations, e.g. using cameras, remotely controlled vehicles, etc.
- Remote monitoring of assets such as portable energy storage units helps to track and ensure asset conditions, safety and reliability.

How can digitalization help?

And provide advanced system management features which help to improve system performance, dependability and longevity:

- Advanced power management systems capable of dealing with engines, batteries, fuel cells
- LR class notation “Hybrid Power (+)” aims to provide enhance performance & dependability of electrical power system through considerations, among others, of system simulation, which can be considered as a digital twin. Functions can cover:
 - Automatic configuration of the power system based on predicted energy flow;
 - Automatic system isolation and reconfiguration in the event of a single failure
 - System performance optimisation covering emissions, efficiency, availability, reliability or operating cost;

Alt-Fuels Regulatory Framework update

Alternative approaches

How does digitalization help?

▷ A few cases

Fincantieri 6332 – Viking Libra – LH2/FC Powered Cruise Ship

Fincantieri Hull 6332 – Viking Libra - LR 9852468 – 14th ship of this series recently built
The “Target” ship for the Shyps project



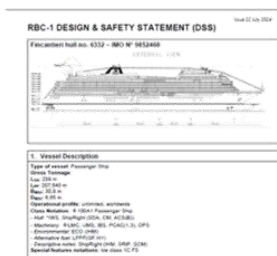
Length between perpendiculars	195.5 m
Length overall	228.50 m
Breadth at water line	30 m
Design draught (Scantling)	6.65 m (6.65 m)
Gross Tonnage	Approx 53739 GT
Net Tonnage	Approx 21501 NT
Service speed	19 Knot
Total number of people on board (LSA)	1539

- 2 x 45' ISO LH2 container tank, swappable, with abt. 2.5 tons of LH2 each
- 2 x containerized PEM fuel cell generators, 3MW each



LR RISK BASED CERTIFICATION (RBC)

Phase	Details
RBC-1	PAR (Preliminary Appraisal of Rules) - Fuel cells PAR (Preliminary Appraisal of Rules) - LH2 DSS (Design Safety Statement)
RBC-2	HAZID workshop
RBC-3	FMECA Workshops GAS DISPERSION & EXPLOSION ANALYSIS QRA (Quantitative Risk Assessment)
RBC-4	HAZOP
RBC-5	Commissioning & maintenance manuals, procedures, documents, etc.



Niche Application – Luna Rossa Chase Boat

- High speed chase boat designed and built for Luna Rossa participation to the the America's Cup
- Carbon fiber catamaran with hydrofoils
- Compressed H2 storage
- 2 x 80kw PEM fuel cells
- 2 x 40kwh batteries
- 50+ kts, up to 75nm range
- LR worked as advisor on risk assessment and safety matters, relatively challenging in a such compact design.



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 **TransH2**

Questions?



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 **TransH2**

Fabrizio Cadenaro, MRINA, Ceng
Lead Specialist Alternative Fuels
Global Technical Support Office
Lloyd's Register EMEA

Thank you



fabrizio.cadenaro@lr.org

DIGITal Twin applications for the PORT of Trieste

Giacomo Morassutti

Port Network Authority of the Eastern Adriatic Sea

Next Innovation Road, Trieste – 16.06.2026

Partnership: 7 port authorities

- Port of VENICE
- Port of TRIESTE
- Port of RAVENNA
- Port of RIJEKA
- Port of PLOČE
- Port of ZADAR
- Port of SPLIT



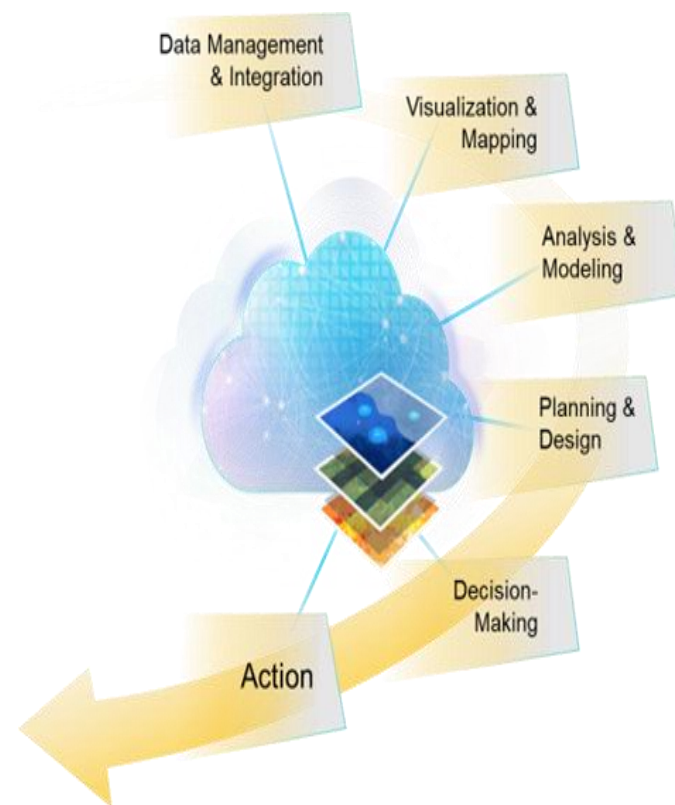
Project duration: 30
months
April 2024 - September
2026

Total Project budget €
2.384.226,00

GOAL: providing a suitable array of digitalization tools (Digital Twins - DT), to boost ports' data-led planning capacities, operational sustainability predictive maintenance, and improved territorial management

Port Authorities are public bodies with key impact on local economy that must ensure efficient port operations. This includes strategic planning;

Adriatic Ports are significantly increasing digitalization and automation in a scalable and sustainable way, capable of producing a cultural change toward a “data-driven” port management.





INFORMATIVE

Real Time- connected to
sensors from multiple
sources

DESCRIPTIVE

Virtual Representation of the
Physical Asset or Network

PREDICTIVE

Capable of Predicting
outcomes.

COMPREHENSIVE

Simulations of outcomes
and make
recommendations

AUTONOMOUS

Self Learning and
Decision making with.
No Human Interaction

Reality Capture

IoT Sensors

Machine
Learning

Virtual Model
(Static)

Analytics

Scenario based
Modeling

Forecasting &
Simulations

Autonomous
Operations

Adaptive

Remote Controlled
Inspections

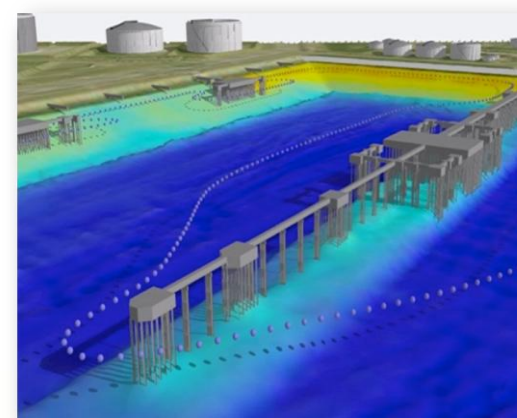
Virtual Model
(Dynamic)

Advanced
Analytics

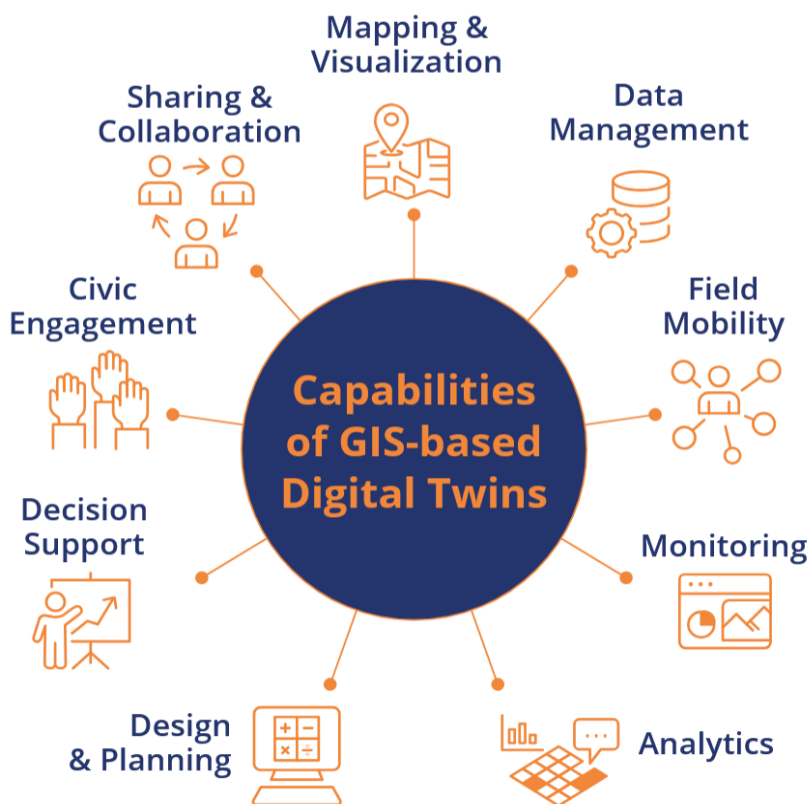
AI Assist
with Decision

HOW TO ENABLE DT APPLICATIONS:

1. “Strategic Co-Design of DT applications in Adriatic Ports”
2. “Common solutions for digitalization in Adriatic ports : uptake of lessons learned”
3. “Testing innovative solutions for DT applications in Adriatic Ports ”



PORTS OF TRIESTE AND MONFALCONE



- Increase data accessibility and reliability through single-truth data platform
- Situational awareness
- Integrated Facility Management
- Port Safety and Operations
- Spatial and marine planning support

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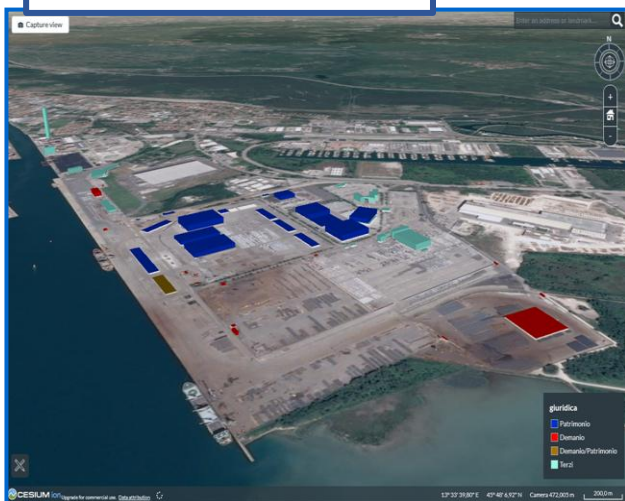


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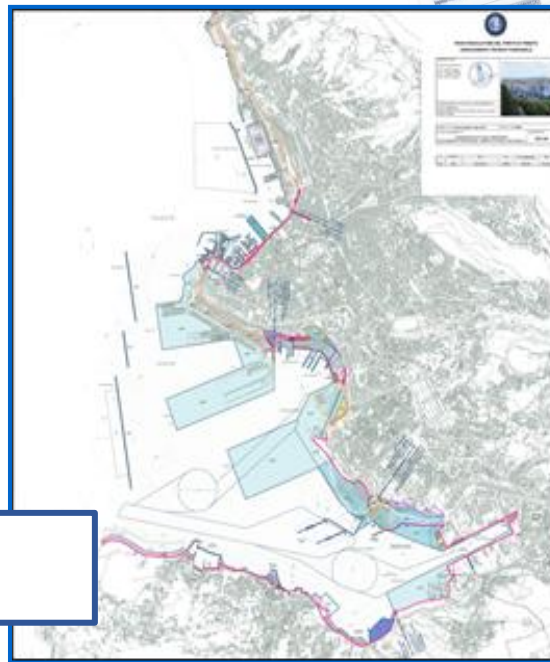


Tridimensional
models



Administrative
data

Real-time
data



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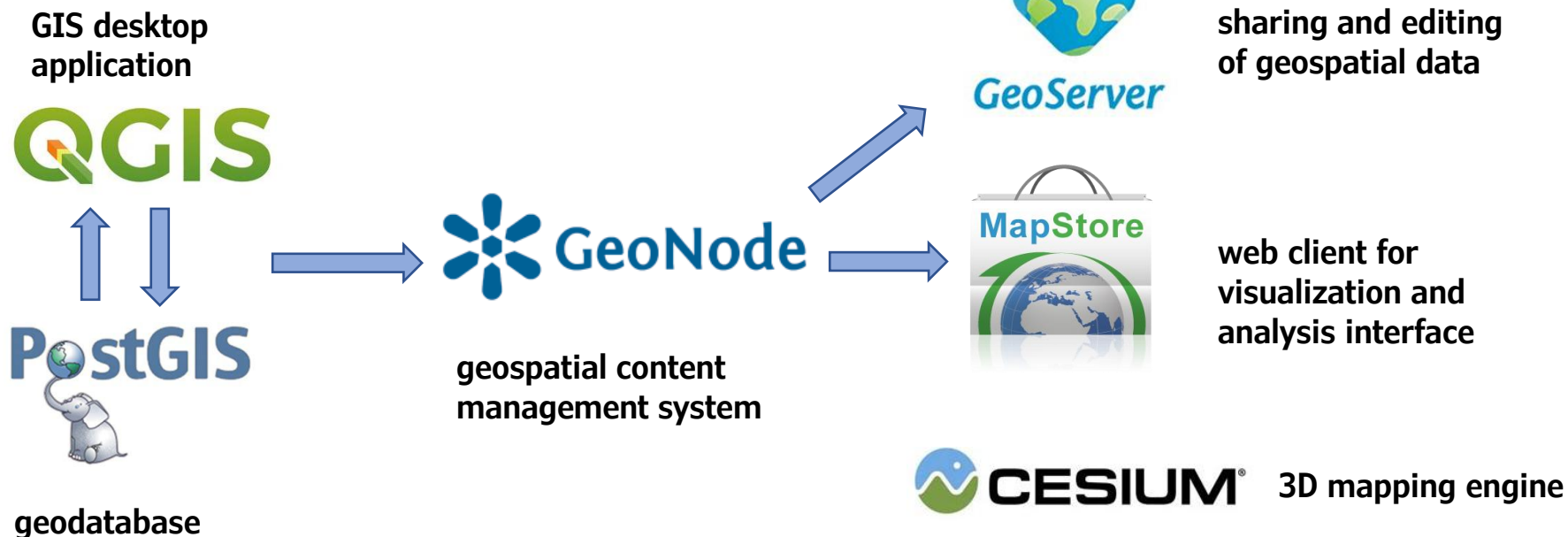
Technical
data



TARGET USERS

- PNA employees
- Port Community
- Other Public bodies
- Service and Maintenance companies
- Civic community

SYSTEM ARCHITECTURE



IN CONCLUSION

100%
CLOUD BASED

100%
OPEN SOURCE

100%
SCALABLE

- **DATA PLATFORM**
 - Single-truth geodatabase
 - webGIS for trusted data accessibility
- **3D MODEL**
- **BIM – GIS interoperability**
 - Common nomenclature and metadocumentation
- **REAL-TIME DATA REPOSITORY**
 - Facility Management
 - Integrated environmental monitoring



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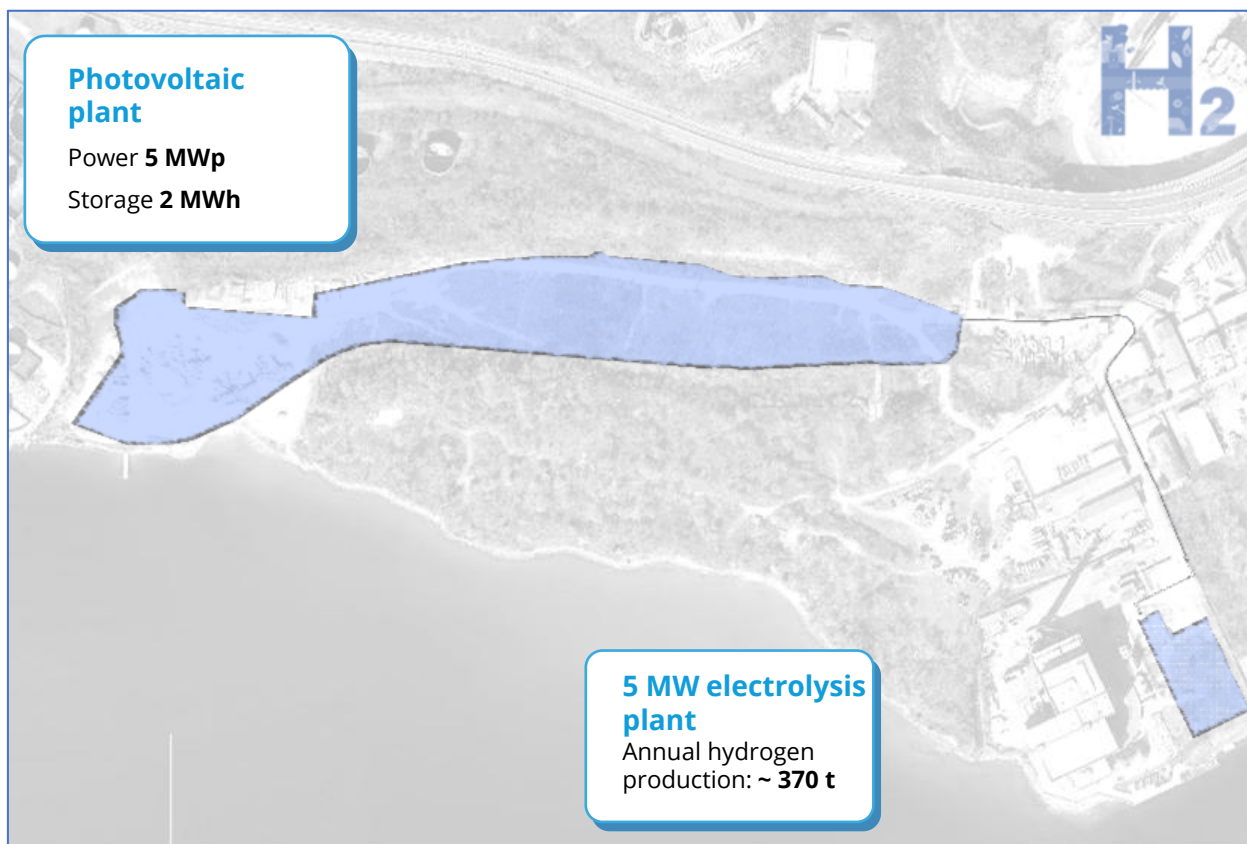
 +39 333 3737159

 <https://www.italy-croatia.eu/web/digitports>

Hydrogen Hub Trieste

AcegasApsAmga | Sviluppo impianti Nuovi Vettori | Massimo
Giacomini

Hydrogen Hub Trieste – Highlights



Hydrogen Hub **H₂**
Trieste

AcegasApsAmga

Investment: 22+ mln €
Funded by PNRR & Horizon EU

Completion of construction works



Hydrogen Hub Trieste – Highlights



AcegasApsAmga is building a plant for the **hydrogen production** from **renewable sources** in industrial symbiosis with the Trieste Waste-To-Energy plant.

The main objective is to contribute to the achievement of the objectives set by the European Green Deal by **reducing CO2 emissions in the transport and industrial sectors**.



Electrolyser: 5 MW



H2 production: 370 ton/year

H2 production from FV and BESS: ≥ 116 ton/year



FV plant: 5 MWp (6,6 GWh/year)

BESS: 2MWh



Total renewable energy: 23 GWh/year

Process water: 5.600 mc/year



Hydrogen Hub Trieste – Highlights

The hydrogen production plant will use **purge water from the evaporative towers** and **renewable electricity**, partly produced by a **new photovoltaic plant** with a subservient storage system (BESS) and partly electricity drawn from the electricity grid with Guarantees of Origin (GO).

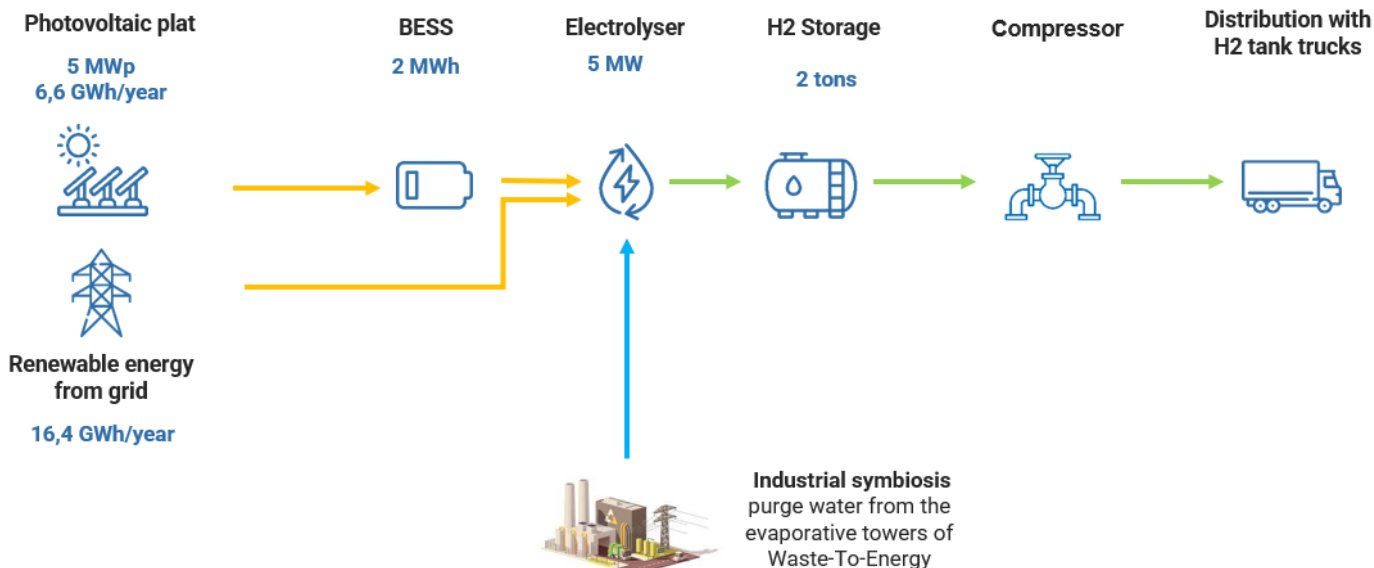
All self-produced energy from the photovoltaic plant plus BESS **will have to be self-consumed in the hydrogen production plant** (PNRR constraint).



The FV plant will be built in a degraded and unused area

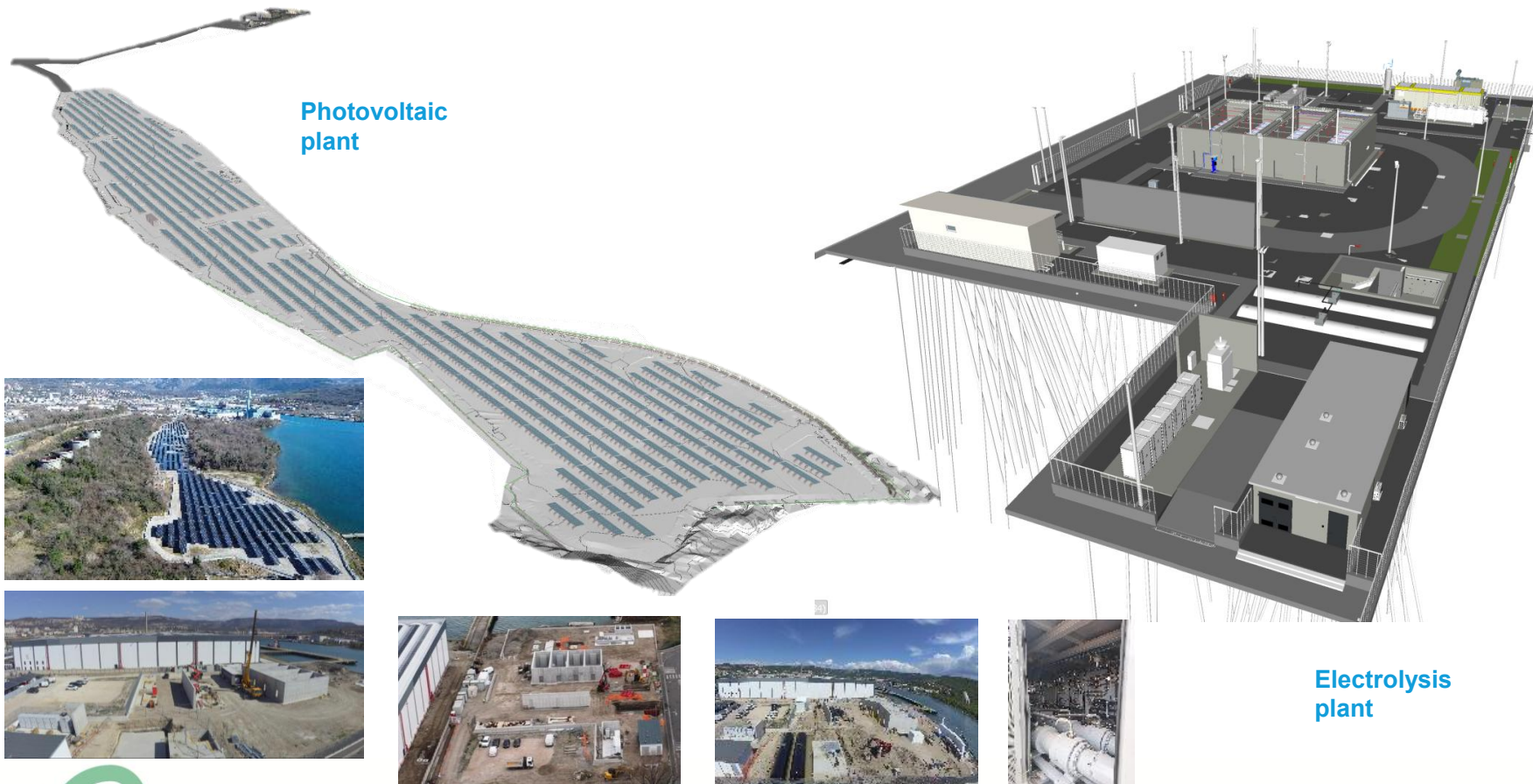


The H2 production plant will be built in a disused industrial area

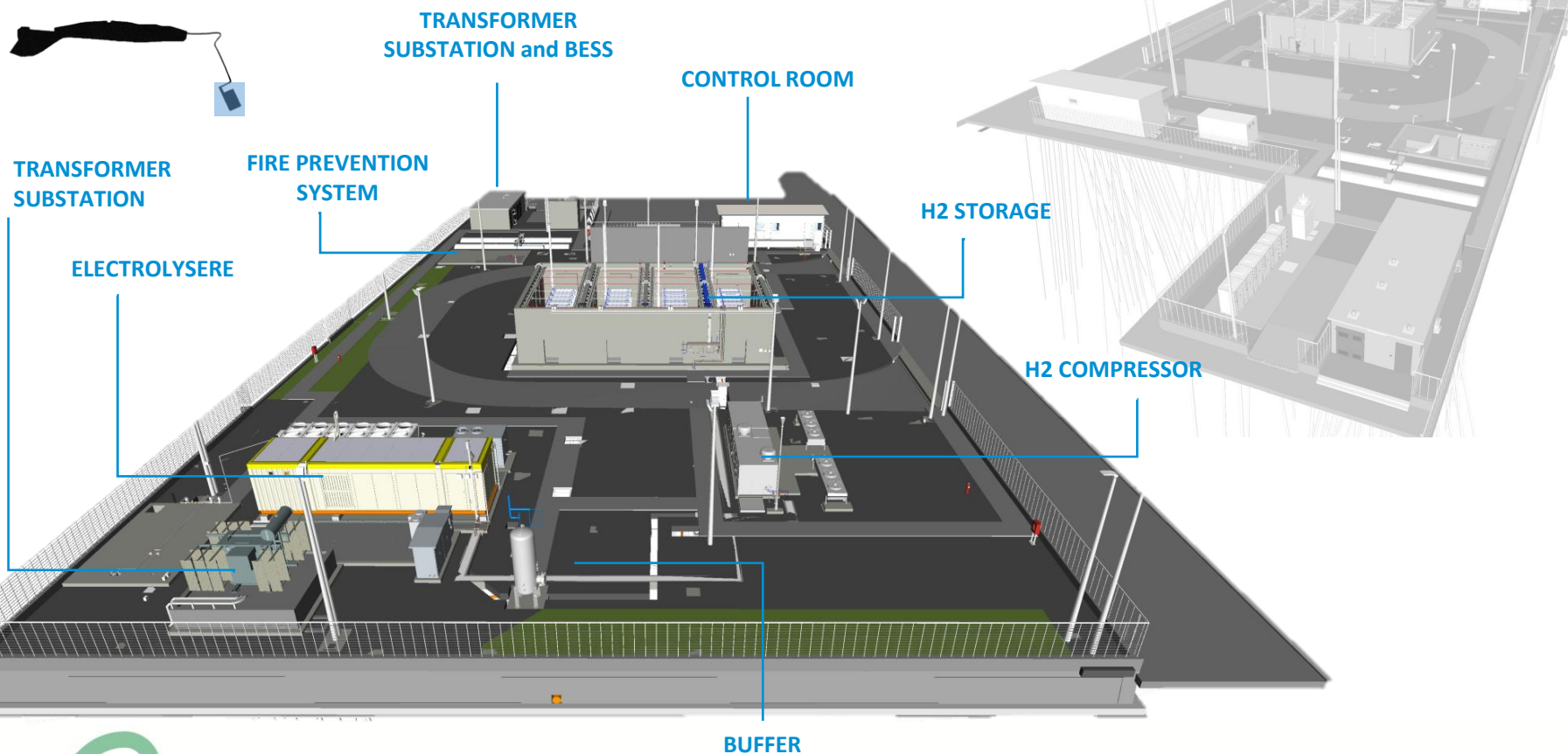




Hydrogen Hub Trieste – layout



Hydrogen Hub Trieste – layout



Hydrogen Hub Trieste – layout



FIRE PREVENTION PIPING

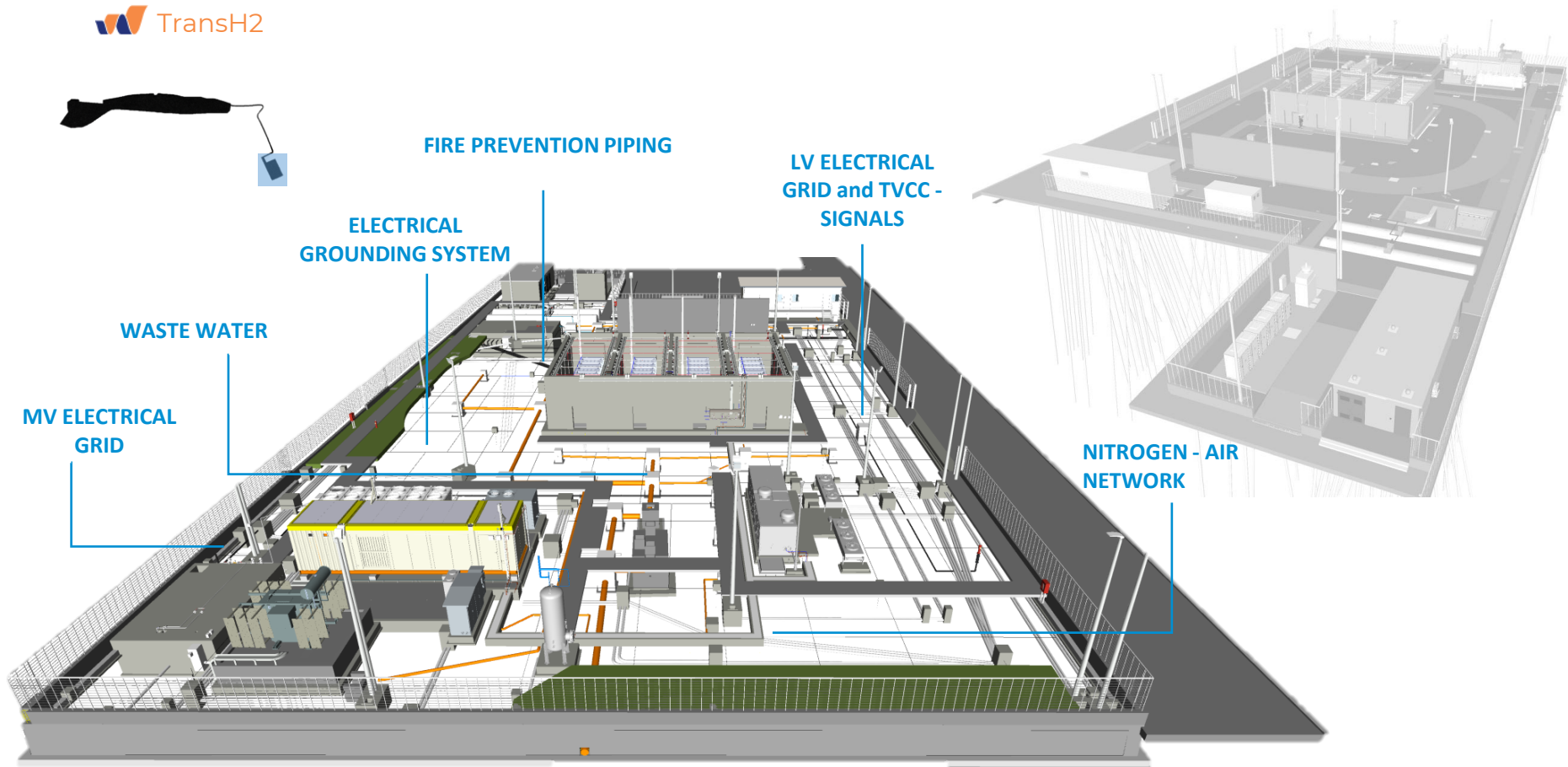
LV ELECTRICAL
GRID and TVCC -
SIGNALS

ELECTRICAL
GROUNDING SYSTEM

WASTE WATER

NITROGEN - AIR
NETWORK

MV ELECTRICAL
GRID



Hydrogen Hub Trieste - PV



Hydrogen Hub Trieste - PV



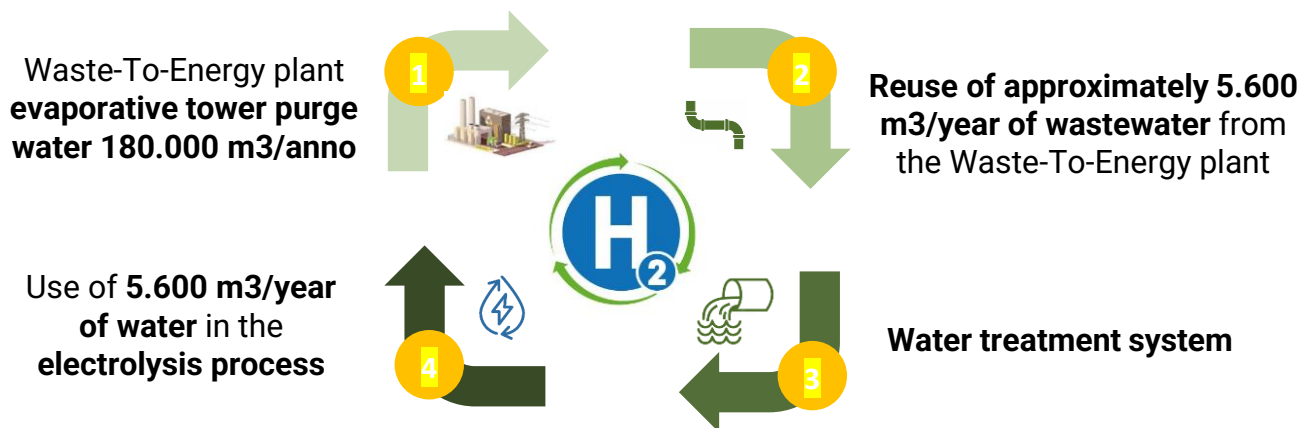
Hydrogen Hub Trieste – Circular economy

Valorization of abandoned areas

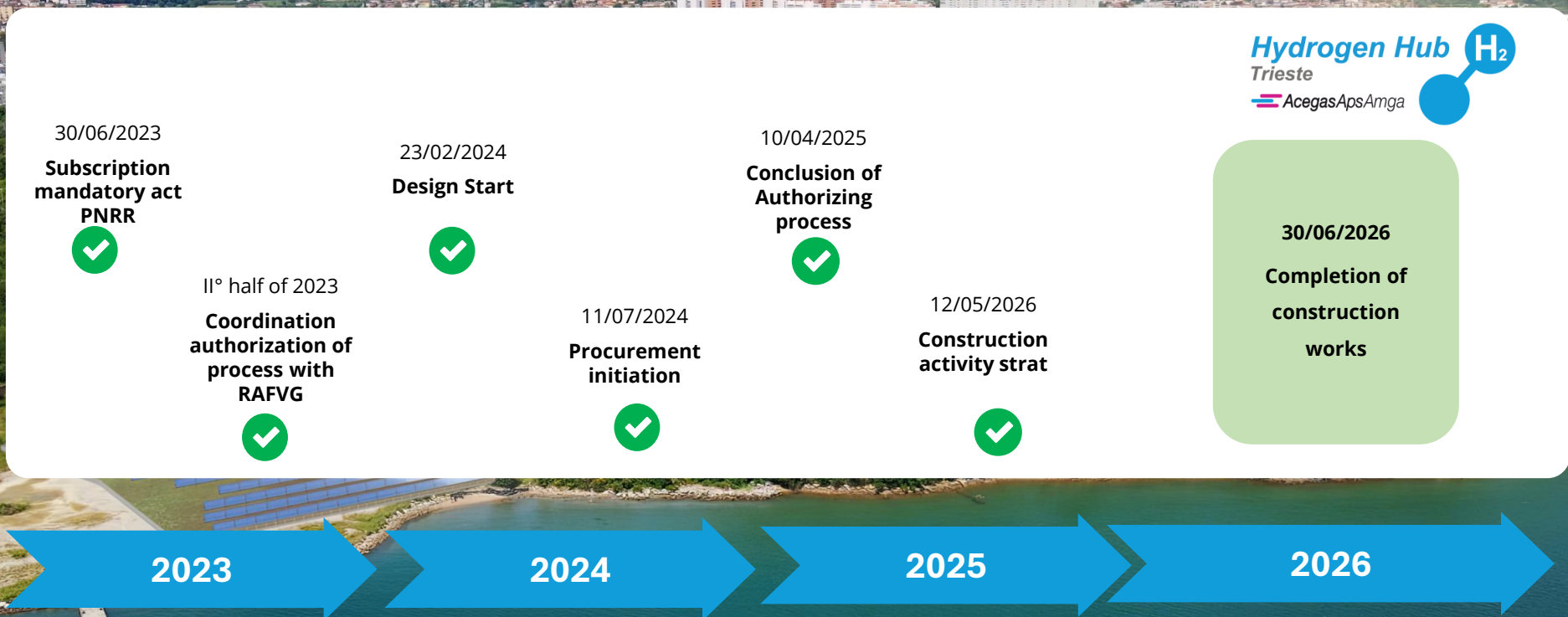
The construction of the **photovoltaic plant** on a **Site of National Interest (SIN)** allows for the **restoration of otherwise unused areas with production potential to value.**



Industrial symbiosis: Waste To Energy – Hydrogen production plant



Timeline



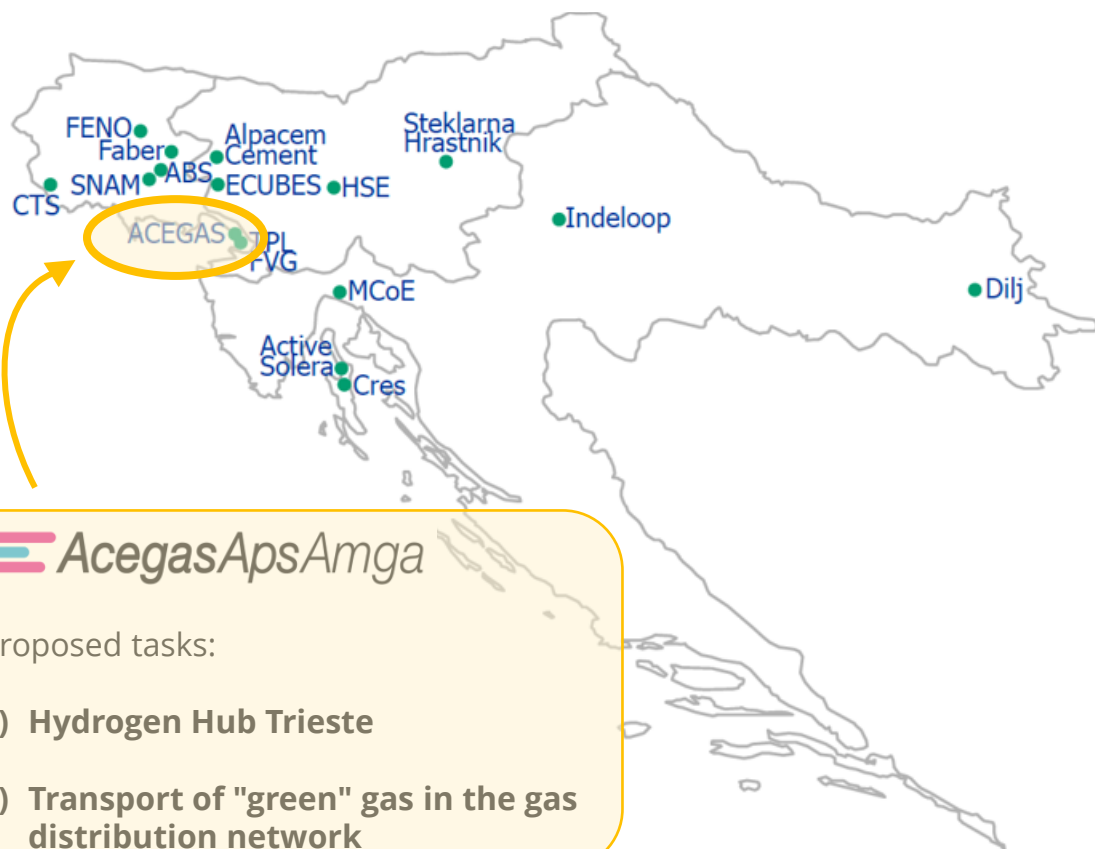
North Adriatic Hydrogen Valley (NAHV)



The project has activated **17 testbed application** in their related ecosystems, clustered in 3 main pillars – **the hard-to-abate industries and the energy and transport sectors.**

These act as **real-life cases for piloting global hydrogen markets**, moving from TRL 6 to TRL 8 by the end of the project.

4 fuel cell applications in the energy and transport sectors will be demonstrated. Testbeds will then be scaled up to the industrial level as replicable model, contributing to the decarbonization of the 3 territories by harnessing renewables to improve system resilience, security of supply and energy independence,



Transport of "green" gas in the gas distribution network

Experimental evaluation of the suitability of the Trieste distribution network for the introduction of **hydrogen-natural gas mixtures** in 3 steps:

- 1) Definition of criteria for verifying the main components of the distribution network
- 2) Direct verification of materials used for hydrogen transport
- 3) Technological Qualification (TQ) of the existing network

Main goals

- Decarbonizing the uses of civil gases
- Reduction of carbon footprint of cities
- Use existing gas infrastructure
- Involvement of customers and sellers



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