Boosting the hydrogen transition

in the Atlantic Area ports

Deliverable D.4.4.1.

Opportunities of H_2 application in HYDEA ports

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EXECUTIVE SUMMARY

The objective of this deliverable **D.4.4.1 Opportunities of H_2 application in HYDEA ports** is to identify potential case studies for the integration of hydrogen technologies within the HYDEA ports. These case studies are based on each port's unique characteristics, functions, existing and planned infrastructure, the industrial environment of their surrounding areas, as well as their strategic plans.

This report summarizes the opportunities for the development of the H_2 economy identified in HYDEA ports, considering their alienation with the H_2 value chains. This identification of opportunities was carried out jointly with the ports through direct interviews. The focus areas include mobility, logistics, energy supply, and potential hydrogen production and distribution. Results provided a deeper understanding of the current situation of ports, evaluating their technological maturity, future vision, and interest in implementing hydrogen-based solutions in their daily operations.

Among the most prominent opportunities for hydrogen integration are:

- **Production and distribution points**: Ports have the potential to become strategic hubs for green hydrogen production through electrolysis plants. These facilities would enable both internal consumption and distribution of hydrogen to nearby industrial sectors.
- **Mobility in heavy-duty vehicles and ships**: Replacing fossil fuels with hydrogen in container trucks and vessels would reduce emissions during port operations, enhancing energy efficiency and lowering the port's carbon footprint.
- **Integration into port cargo handling equipment:** Implementing hydrogen-based technologies in port cargo handling equipment, such as cranes and internal transport vehicles, would also contribute to improving the port's sustainability.
- **Refueling stations**: To make the transition from fossil fuels to hydrogen feasible, it is essential to implement these refueling points within the port, as they will facilitate refueling and improve sustainable mobility within the port.

The implementation of these technologies is expected not only to provide environmental benefits by reducing CO_2 emissions but also to enhance energy efficiency through the adoption of advanced and sustainable technologies.[1] Furthermore, HYDEA ports could play a strategic role in the hydrogen supply chain, facilitating regional distribution and contributing to the development of a broader hydrogen economy.

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ABBREVIATIONS AND ACRONYMS

APB	Bilbao Port Administration
APDL	Douro, Leixões and Viana do Castelo Ports Administration
APG	Gijón Port Administration
APS	Sevilla Port Administration
APV	Vigo Port Administration
CCI	Chamber of Commerce and Industry
DWT	Deadweight Tons
GHEP	Galway Harbour Enterprise Park
GHG	Greenhouse Gas
ha	Hectare
HVO	Hydrotreated vegetable oil
Km	Kilometers
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MRE	Marine Renewable Energies
NOx	Nitrogen Oxides
OPS	Onshore Power Supply
PL	Port of Leixões
SFP	Synthetic Fuels Plant
SOx	Sulfur Oxides
TEU	Twenty-foot equivalent unit
ZAN	Negotiated Development Zone

SYMBOLS

CO_2	Carbon oxide
H_2	Hydrogen

1 INTRODUCTION

The maritime industry, a global trade powerhouse, relies on ports as vital hubs in the international logistics network. Yet, the environmental toll of port operations, notably their significant contributions to greenhouse gas (GHG) emissions and local air pollution,[1] has escalated into a pressing concern.

As the maritime industry charts a course towards cleaner energy sources to combat environmental challenges, hydrogen emerges as a unique frontrunner. This document explores the methodology for identifying hydrogen opportunities in port activities, underlining its distinctive role in advancing decarbonization efforts, countering climate change, and bolstering the sustainability of port operations.

1.1 Importance of Identifying Hydrogen Opportunities

Climate change profoundly threatens global ecosystems, economies, and communities.[2] One of the primary drivers for exploring hydrogen opportunities in port activities is the urgent need to decarbonize the maritime sector. By transitioning to hydrogen, ports can significantly reduce their carbon footprint, mainly when hydrogen is produced from renewable sources. This offers a clean energy alternative that emits only water vapour when used in fuel cells. [3]

Hydrogen helps reduce carbon emissions and addresses other pollutants, such as nitrogen oxides (NOx) and sulfur oxides (SOx), which contribute to local air quality issues and environmental degradation.[4,5]

Sustainability in port operations extends beyond environmental considerations to include economic and social dimensions. Hydrogen offers several benefits that enhance the overall sustainability of port activities. When this energetic vector is produced locally (in-situ) employing only renewable sources, including water electrolysis, it reduces dependence on imported fossil fuels and enhances energy security.[6] Storing hydrogen (liquid or gas) protects against energy supply disruptions, price volatility and is also a potential solution to face planned growth of renewable energies and their associated intermittency, thus contributing to provide stability in the electric grid.

The adoption of hydrogen technologies can stimulate economic growth by creating new markets and job opportunities in the hydrogen value chain, including production, distribution, maintenance, and final applications. In this context, ports that lead to hydrogen adoption can attract environmentally conscious customers and partners, enhancing their competitive advantage.

Investing in hydrogen technologies fosters innovation and positions ports as leaders in transitioning to a low-carbon economy. Also, collaborations with technology providers and research institutions (i.e. Universities) can drive advancements in hydrogen applications, further reducing costs and improving performance.

Ports are often located near urban areas, where the concentration of industrial activities and transportation can lead to significant environmental and health impacts. The adoption of hydrogen technologies can address issues like air quality and noise pollution. In this context, hydrogen fuel cells emit no harmful pollutants, reducing the impact of acid rain and other environmental degradation. Implementing hydrogen technologies that operate more quietly than internal combustion engines can improve port workers' and nearby residents' quality of life.

Governments and international organisms are increasingly enacting stringent regulations to reduce emissions and promote sustainable practices in the maritime sector.[7] Ports that proactively adopt hydrogen technologies can ensure compliance with these regulations and avoid potential penalties. Furthermore, ports can access funding opportunities and incentives that support the transition to cleaner energy sources by aligning with national and international policy goals, such as the European Union's Green Deal and various national hydrogen strategies. [8,9]

Hydrogen transition involves important stakeholders, including government agencies, industry partners, technology providers, and local communities. Identifying hydrogen opportunities in port activities can promote cross-sector collaboration, promoting synergies that enhance the overall impact of hydrogen adoption. Collaborative efforts can lead to shared infrastructure, joint research initiatives, and coordinated policy support, accelerating the development and deployment of hydrogen technologies.

In the long term, adopting hydrogen technologies can position ports as integral components of a broader hydrogen economy. As hubs of economic activity and energy distribution, ports can facilitate the scaling up of hydrogen production and utilization, supporting broader industrial and transportation sectors. This strategic positioning can ensure that ports remain relevant and competitive in a rapidly evolving global energy landscape.

The methodology outlined in this work provides a comprehensive framework for assessing the feasibility and benefits of hydrogen adoption. By advancing decarbonization efforts, mitigating climate change, enhancing sustainability, addressing environmental and health impacts, supporting regulatory compliance, promoting cross-sector collaboration, and securing long-term strategic benefits, hydrogen can play a transformative role in the future of port operations.

Through their proactive engagement and strategic planning, the ports of Vigo, Sevilla, APDL (Ports of Douro, Leixões and Viana do Castelo), Brest, Galway, Gijón and Bilbao located within a strategic region as the Atlantic area (see Figure 1), can lead the way in this transition, setting a benchmark for other ports worldwide.

1. Port of Vigo (APV).
2. Port of Sevilla (APS).
3. Administração dos Portos do Douro, Leixões e Viana do Castelo (APDL).
4. Port of Brest
5. Port of Galway
6. Port of Gijón
7. Port of Bilbao

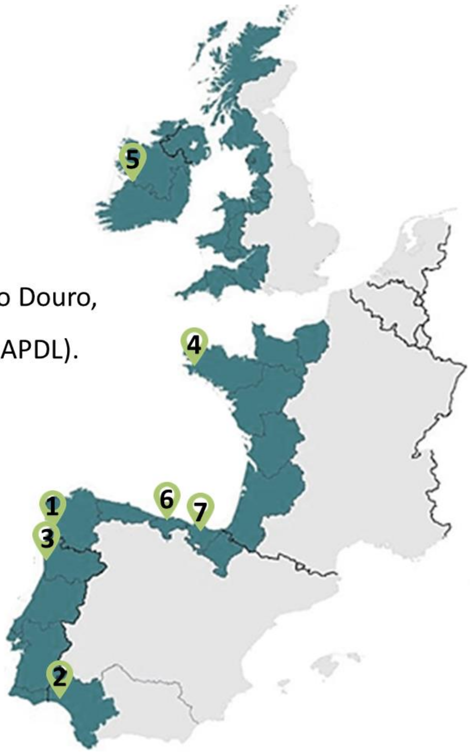


Figure 1. Atlantic ports included in HYDEA project.

2 POTENTIAL ANALYSIS IN ATLANTIC PORTS: KEY QUESTIONS AND ANSWERS

The interviews and the content of the questions aim to reflect the special features of each port in the Atlantic region that make them interesting for implementing hydrogen technologies and related activities. Each question was designed to provide key information on specific points that are closely related to strategic aspects important for identifying the potential for developing this type of technology.

The questions are numbered, and a description of the rationale behind each question is provided. The situation of each port is approached objectively, but the conclusions drawn will undoubtedly present a subjective perspective from each interviewee.

2.1. Interview questions and their importance

1. **Overview of the port:** *Request a general description of the port's infrastructure, including main activities, specific features, and services.*

A detailed description of port infrastructure and main activities is crucial for identifying and capitalising hydrogen opportunities in the Atlantic region. It provides a foundation for understanding the current capabilities and potential areas for improvement, engages key stakeholders, supports strategic planning, and enhances ports' competitiveness and sustainability.

Understanding ports' infrastructure and main activities is fundamental when identifying opportunities for hydrogen development. Ports serve as critical hubs for global trade, logistics, and transportation, and their infrastructure and activities influence their potential for adopting and benefiting from new technologies like hydrogen energy.

Port infrastructure encompasses many physical assets, including docks, terminals, storage facilities, and transport connections. This infrastructure determines the capacity of a port to manage diverse types of cargo and vessels, which in turn affects its operational efficiency and economic viability. Understanding the current state of port infrastructure provides insights into the **existing capabilities and potential areas for improvement**. Hydrogen infrastructure, such as refueling stations and storage tanks, requires significant space and investment, and ports with robust infrastructure are better positioned to accommodate these developments.

Furthermore, a port's main activities and services indicate its operational dynamics and economic impact. Ports engage in various activities, including cargo handling, passenger transport, logistics services, and industrial operations. Each of these activities presents unique opportunities and challenges for hydrogen integration. For example, cargo handling operations, especially those involving heavy machinery (i.e. cranes) and vehicles, can benefit from hydrogen fuel cells as a cleaner alternative to diesel engines, thereby reducing GHG emissions and improving air quality.

Moreover, understanding the main activities of a port helps identify the key stakeholders and their roles in the port ecosystem. Stakeholders such as port authorities, shipping companies, logistics providers, and industrial operators play crucial roles in adopting new technologies. Engaging these stakeholders early in the process and understanding their needs and concerns is essential for successfully implementing hydrogen projects. For instance, shipping companies may require assurances about the availability and reliability of hydrogen refueling infrastructure. At the same time, industrial operators may be interested in using hydrogen as a feedstock for their processes.

2. **Road traffic and fuel:** *Inquire about the type of road traffic present in the port and its fuel source.*

Investigating the type of road traffic and its fuel sources within port environments is critical in identifying the potential for hydrogen-based solutions in the Atlantic region's ports. This inquiry provides essential insights into the operational dynamics, environmental impact, and strategic opportunities for reducing carbon emissions and enhancing sustainability.

Road traffic within and around ports significantly affects their overall operational efficiency and environmental footprint. Ports are typically **high-traffic areas** with a constant flow of vehicles, including trucks, buses, forklifts, cranes and other machinery. Each of these vehicle types has different energy requirements and operational patterns. For instance, heavy-duty trucks are often used for transporting goods to and from the port, while smaller vehicles may be involved in internal coordination and passenger transport. Understanding the composition and volume of road traffic helps assess the energy demand and the potential for integrating alternative fuels like hydrogen.

The fuel sources used by these vehicles are a key factor in determining the environmental impact of port operations. Traditional **diesel and petrol-powered vehicles contribute significantly to greenhouse gas emissions**, air pollution, and noise, all of which are major concerns in densely populated port areas.[10,11] By identifying the current fuel sources, we can evaluate the potential benefits of transitioning to cleaner alternatives such as hydrogen. Hydrogen fuel cells produce zero emissions at the point of use, offering a significant reduction in pollutants and GHG compared to conventional fuels. This transition can greatly improve air quality in and around ports, contributing to better health outcomes for workers and nearby communities.

Moreover, the type of road traffic and its fuel sources indicate the logistical and economic considerations involved in port operations. Shifting to hydrogen would require establishing new refueling infrastructure, including hydrogen production, storage, and dispensing facilities. Understanding the current fuel logistics helps in planning these infrastructure developments, ensuring they are feasible and economically viable.

Examining road traffic and fuel sources also provides insights into stakeholders' readiness and willingness to adopt innovative technologies. Their current practices and future regarding vehicle fleets and fuel usage are crucial for determining the pace and scale of hydrogen adoption. Engaging with these stakeholders through inquiries about fuel usage and traffic patterns helps identify potential challenges and areas where support or incentives might be needed. By comparing the current costs and emissions associated with conventional fuels to those of hydrogen, stakeholders can make informed decisions about investments in hydrogen infrastructure and vehicles. This analysis can highlight the long-term savings and environmental advantages, strengthening the case for hydrogen adoption.

Inquiring about the type of road traffic and its fuel sources in ports is essential for identifying opportunities for hydrogen integration. It engages key stakeholders, supports strategic planning, and helps build a compelling case for the transition to cleaner, hydrogen-based solutions.

3. Load in/Load out equipment and energy: *Ask about the auxiliary material used for loading and unloading goods, as well as its predominant energy source.*

This inquiry offers crucial insights into current practices, energy consumption, and potential areas for improvement in terms of efficiency and sustainability.

Auxiliary materials and equipment such as cranes, forklifts, reach stackers, and conveyor belts are pivotal to the efficient handling of cargo in ports. These tools facilitate the smooth transfer of goods from ships to storage areas and onto transportation vehicles, significantly impacting the overall operational efficiency of the port. By identifying the specific types of equipment in use, we can better understand the energy demands associated with these operations. For instance, cranes and forklifts powered by diesel engines are robust and provide high power output, but they also contribute to emissions and noise pollution. Conversely, electrically powered equipment, while quieter and cleaner, may have limitations in terms of power and battery life. Understanding the equipment in use helps to evaluate the feasibility and benefits of transitioning to hydrogen-powered alternatives, which can offer both high power and zero emissions.

Secondly, the energy sources for auxiliary port equipment significantly affect the environmental impact of port operations. Diesel and fossil fuels, commonly used, contribute heavily to greenhouse gas emissions and air pollution, particularly near urban areas where air quality is a concern. Switching to hydrogen, which emits only water vapor, can drastically reduce emissions. Assessing current energy sources helps evaluate the environmental benefits of adopting hydrogen, aiding ports in achieving sustainability goals and improving air quality for nearby communities.

Moreover, understanding the energy sources and usage patterns of auxiliary equipment is critical for evaluating operational efficiency and reliability. Ports rely on continuous and efficient operations to handle large volumes of cargo, and any disruptions can lead to significant economic losses. Hydrogen fuel cells provide a stable and reliable power source, which can reduce downtime and enhance the efficiency of port operations. By inquiring about the predominant energy sources, we can determine how hydrogen can contribute to improving the reliability and performance of auxiliary equipment, thereby optimizing port operations.

Furthermore, engaging port authorities and operators about their use of auxiliary materials and energy sources helps identify key stakeholders and their roles in port operations. These stakeholders are crucial in the adoption of new technologies. Their existing practices, plans, and openness to innovation play a vital role in the successful implementation of hydrogen projects. By fostering dialogue with these stakeholders, we can address their concerns, gather support, and ensure a smooth transition to hydrogen technologies.

In conclusion, asking about the auxiliary materials used for loading and unloading goods, as well as their predominant energy sources, is essential for identifying opportunities for hydrogen integration in ports. This inquiry provides valuable insights into operational dynamics, environmental impact, and economic considerations, facilitating strategic planning for a sustainable transition. By addressing these aspects, ports in the Atlantic region can enhance their efficiency, reduce emissions, and improve their overall sustainability and competitiveness.

4. Terminal equipment and energy source: *Investigate the types of cranes or other equipment used in port operations, and the energy source used for their operation*.

Investigating the types of **cranes and equipment** used in port operations, alongside their energy sources, is crucial for identifying opportunities to integrate hydrogen technologies into port infrastructure. This inquiry provides insights into **operational efficiency, energy demands, and environmental impact**, leading to cleaner and more sustainable energy solutions.

Cranes and heavy machinery, such as gantry cranes and reach stackers, are vital to port cargo handling. While effective, **diesel-powered equipment** contributes significantly to emissions and air pollution. Understanding the equipment in use allows for assessing hydrogen-powered alternatives. The energy sources powering the harbor's equipment directly impact the port's environmental footprint. Assessing the current **energy mix** reveals the potential environmental and operational benefits of transitioning to hydrogen.

Operational reliability is another crucial factor. Hydrogen fuel cells provide consistent, uninterrupted power, reducing downtime compared to traditional fuels. This inquiry also enables a thorough economic evaluation, as hydrogen adoption can result in long-term cost savings. Additionally, this inquiry **engages critical stakeholders**, including **port authorities,** equipment **manufacturers,** and **logistics operators**. Understanding their practices and openness to innovation is vital for successfully implementing hydrogen solutions.

5. Industry and port environment: *Determine the industries present in the port's vicinity and their interaction with port activities*

Recognition of the economic environment of the port and their interactions with portuary activities is essential for identifying potential **synergies, economic drivers, and opportunities for hydrogen** integration. This question provides insights into the port's broader ecosystem, highlighting how **industrial sectors depend on and influence port operations** while also revealing opportunities for cleaner and more sustainable practices.

Firstly, industries in the port's vicinity—such as manufacturing, logistics, energy, and fisheries—are often heavily intertwined with the port's operations. These industries rely on the port to import and export raw materials, goods, and fuel, while ports depend on them for economic activity and job creation. By investigating this, we can better understand the **flow of goods, the types of cargo being handled**, and the energy demands of both the port and its surrounding industries.

Although the data suggest many of these **industries are high energy consumers** and contributors to emissions,[7,11,12] primarily if they rely on traditional fuels like coal, oil, or natural gas. Identifying the **energy sources** used by these industries can uncover opportunities for integrating hydrogen as a cleaner alternative. **Hydrogen could power industrial processes** and provide cleaner fuel for transportation and machinery, especially in energy-intensive sectors like manufacturing or chemical production, particularly economic activities that are facing an evident increasing regulatory pressure to meet sustainability targets.

Furthermore, understanding the interaction between industries and the port helps to identify **logistical and economic dependencies**. Sectors frequently using the port's services—transport, warehousing, and energy production—may already be engaged in forward-looking discussions about clean energy solutions. By understanding their current practices and plans, we can determine their **readiness to adopt hydrogen technologies** for **on-site production**, **vehicle fuel**, or **industrial applications**.

Finally, this engagement also helps highlight **opportunities for collaboration**. The presence of industries with **similar energy needs** or environmental goals can create the foundation for joint ventures or **hydrogen hubs,** where both the port and local businesses could benefit from shared hydrogen infrastructure, creating a more resilient and sustainable **energy network**.

6. **Refueling infrastructure:** *Inquire about refueling stations available in the port, including electric charging points, their operation, and availability.*

Information related to **refueling infrastructure**, including **electric charging stations**, is essential for understanding the current energy landscape in port operations and assessing opportunities for hydrogen technology integration. This inquiry reveals gaps and areas where **alternative fuels** like hydrogen could enhance efficiency and improve sustainability.

Ports with **well-established electric vehicle infrastructure** may find it easier to expand into hydrogen refueling, especially as both energy solutions require similar investments (related to power capacity) in charging and refueling stations.[13]

Hydrogen fuel's rapid refueling capability compared to electric vehicle charging could offer significant advantages in maintaining continuous operations. Investigating current refueling options provides a clearer picture of how **hydrogen could enhance operational efficiency** by reducing delays associated with refueling. By examining these aspects, we can better assess the feasibility and requirements for integrating hydrogen refueling into the port's infrastructure.

This inquiry also **highlights the role of stakeholders** in the port ecosystem, including energy **providers, equipment operators, and logistics companies**. Their collaboration and willingness to invest in hydrogen refueling infrastructure are essential for successfully adopting new technologies.

7. **Energy and environmental challenges:** *Identify the main energy and environmental challenges that the port is currently facing.*

Addressing the main energy and environmental challenges that a port is facing is crucial for understanding limitations and pressures that shape its operations. Firstly, **ports are energy-intensive environments**,[14–17] relying on various fuel sources to power equipment, machinery, and vehicles. A key challenge many ports face is the reliance on fossil fuels, this general dependence leads to **high energy costs** and significant carbon emissions.

Secondly, ports often face environmental challenges, including air pollution, noise, and water contamination. Understanding the environmental challenges, such as regulatory pressure to reduce emissions or improve air quality, can help frame hydrogen technology as a viable solution for meeting these targets while maintaining operational efficiency.

Moreover, ports **must adapt to increasingly** stringent environmental regulations to hold back emissions and adopt greener technologies. These regulations constitute operational and financial challenges, as ports may need to upgrade equipment or **invest in new infrastructure**. **Hydrogen technology,** with its zero-emission potential, **can assist in meeting these regulatory demands**, ensuring ports comply with future environmental standards.

Lastly, this inquiry helps to understand stakeholder’s concerns about energy and environmental challenges allows for the development of targeted strategies to reduce emissions, and again, improve energy efficiency.

8. Consideration of Hydrogen Technologies: *Ask if they have ever considered incorporating hydrogen technologies into their operations.*

Asking whether a port has considered incorporating hydrogen technologies into its operations is essential for understanding its **readiness to transition** towards cleaner energy solutions. This inquiry sheds light on the port's awareness of hydrogen as an alternative fuel, its openness to innovation, and the potential barriers to adopting such technologies.

Firstly, considering hydrogen technologies indicates a proactive approach to addressing energy and environmental challenges. If the port has explored hydrogen solutions, it suggests that decision-makers actively seek ways to enhance operational efficiency, reduce emissions, and comply with evolving environmental regulations. This inquiry can reveal the motivations behind the consideration of hydrogen, such as cost savings, sustainability goals, or partnerships with industry leaders in clean energy.

Secondly, it is crucial to understand the port's level of knowledge and familiarity with hydrogen technologies. If they have conducted feasibility studies or engaged in pilot projects, this reflects an existing foundation that could facilitate the transition. Conversely, if they have not yet considered hydrogen, this presents an opportunity for education and dialogue regarding hydrogen's benefits and practical applications in port operations.

Moreover, exploring their considerations can uncover potential barriers to adoption, such as financial constraints, lack of infrastructure, or concerns about the technology's reliability. Identifying these barriers allows stakeholders to develop targeted strategies, facilitating a more conducive environment for hydrogen integration.

Additionally, this inquiry promotes engagement with critical stakeholders, including port authorities, energy providers, and logistics companies. Understanding their interest in hydrogen technologies can help build a collaborative framework for sharing knowledge, resources, and best practices. Such collaboration is vital for developing a comprehensive hydrogen strategy that aligns with the port's operational goals and the regional energy landscape. Finally, hydrogen technologies should be considered, aligning with broader trends toward decarbonization and sustainability in the maritime and logistics sectors. By assessing the port's interest in hydrogen, stakeholders can better position themselves to align with global efforts to reduce carbon emissions and promote cleaner energy sources.

9. Projects Related to Hydrogen: *Investigate the existence of projects related to the use of hydrogen in the port and their impact on operations.*

The aim is to evaluate the strategic vision of ports regarding the adoption of emerging technologies and their **capacity to face future energy challenges**. This inquiry seeks not only to identify the use of clean technologies but also to examine the port's ability to effectively integrate innovation into its operations.

Hydrogen not only represents an energy alternative but also a turning point in how ports manage their operational efficiency and resilience to fluctuations in the energy market. By understanding whether a port has implemented hydrogen projects, it is possible to determine the extent to which it is prepared to lead in sectors such as port mobility or energy supply to vessels, areas where regulatory pressure and sustainability expectations are continually increasing.

From a strategic perspective, this question also provides insights into **collaboration opportunities** and available public and private funding sources, such as European funds for energy transition. Hydrogen projects often require alliances between public and private actors due to their complexity and scale. Investigating whether the port participates in these initiatives allows for the identification of potential synergies and government policies that could accelerate their adoption. This knowledge is crucial for fostering collaborations that strengthen the port's position as a leader in the global energy transition.

Ultimately, this inquiry not only assesses the port's capacity for adaptation and innovation but also offers a glimpse into strategic opportunities that can drive its sustainable and competitive development. This question serves as a valuable tool for understanding how the port positions itself against regulatory pressures and global market demands, and how these emerging technologies can transform its operational future.

10. Areas for Implementation of Hydrogen Technologies: Inquire about specific areas within the port where hydrogen technologies could be particularly beneficial.

The main objective of this deliverable is to identify the **key areas** where **hydrogen can provide effective solutions** within port operations. By understanding these areas for improvement, opportunities for efficiency can be detected by identifying where hydrogen can be implemented in operational processes. For example, its incorporation in internal transportation and heavy machinery can lead to reduced operational costs and increased productivity.

Furthermore, this understanding is essential for **establishing effective decarbonization strategies**. Identifying key areas for hydrogen application allows ports to develop plans that reduce their carbon footprint, thereby contributing to their sustainability goals.

The introduction of hydrogen technology also fosters innovation. By determining the areas where this technology can be applied, it opens the door to research and development initiatives, which may include collaborations with academic institutions and technology companies. These partnerships are crucial for developing innovative solutions that enhance both infrastructure and port operations.

Moreover, identifying specific areas for hydrogen implementation facilitates the creation of strategic synergies with other industry players and public sector entities. These collaborations can accelerate the adoption of hydrogen technologies and improve access to financing and resources, which are essential for the success of these projects.

Finally, understanding the areas where hydrogen technology can be introduced enables ports to anticipate market trends and future industry needs, ensuring that they are better prepared to adapt to a constantly evolving environment.

11. Strategic Focus on Sustainability: Determine the port's strategic focus on sustainability and long-term energy efficiency.

Asking ports about their approach to sustainability and long-term energy efficiency is crucial in a context where the pressure to **reduce GHG emissions** and promote sustainable practices is increasing. This question not only allows for the assessment of ports' ability to adapt to regulatory demands but also reveals their commitment to transitioning toward a greener economy.

Understanding a port's stance on sustainability provides a comprehensive perspective on its strategies for managing its environmental footprint. As central elements in logistics, ports have a significant impact on the global supply chain. Therefore, their ability to integrate clean technologies, such as hydrogen, is fundamental. This not only means decarbonizing their own operations but also supporting the sustainability of their partners' operations.

Additionally, this approach can uncover the initiatives that ports are undertaking to improve their energy efficiency and identify opportunities for innovation and collaboration.

Finally, this question is essential for anticipating how ports plan to address future challenges related to climate change and stakeholder expectations. A clear focus on sustainability is not only attractive to investors and business partners, but it also positions the port as a leader in the energy transition, which is essential for its competitiveness in an increasingly demanding market.

3 INFORMATION OF HYDEA PORTS

3.1 Spanish Atlantic area

3.1.1 Port of Vigo (APV)

Interviewee: **Elisa Romero González**, Sustainability and European project management technician in Puerto de Vigo.

The Port of Vigo is one of the most important ports in the Spanish Atlantic coast, especially in terms of trade, fishing, and cruise passengers, particularly specialized in both container and ro-ro traffic. Administered by the Port Authority of Vigo (APV), the port's infrastructure development and land maintenance are diligently managed by APV. Most port traffic operates under concession agreements, wherein private companies are granted rights to utilize specific port facilities in exchange for their investment and upkeep of these facilities.

Several distinct zones divide the port, including a Ro-Ro terminal, a free economic zone area, a ship repair dock, shipyards Beiramar, cold storage Beiramar, a fishing port, cruise facilities, commercial quays, a container terminal, and a marina zone (see Figure 2). Currently, only the container and the commercial quays are connected inside the port, which necessitates making the remaining connections externally.

Figure 2. Map of the Port of Vigo. A: Ro-Ro terminal, B: free economic zone area; C: ship repair dock; D: shipyards; E: cold storage; F: fishing port; G: cruise facilities; H: commercial quays; I: container terminal; and J: Marina.

The Ro-Ro terminal is specialized in traffic related to the automotive sector and, to a lesser extent, other general cargo, whose operations are carried out by rolling means. It is characterized by a high volume of vehicular traffic, predominantly featuring diesel-powered vehicles such as cars and trucks, significantly contributing to the port's overall emissions (see Figure 3).

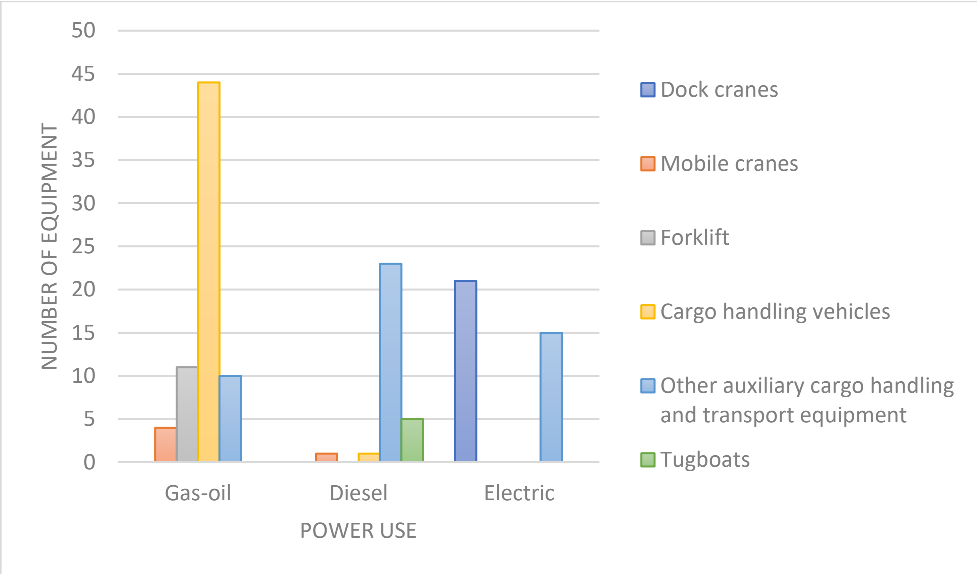


Figure 3. Vigo port's equipment and their power use. Based on the data provided in the 2022 annual report.[18]

In contrast, the commercial wharf area utilizes principally electric cranes owned by concessionaires, aligning with the port's sustainability goals by minimizing reliance on fossil fuels and reducing emissions. However, despite the presence of electric charging points within the port, these have never been operational, underscoring the need for maintenance or upgrades to facilitate the transition to electric vehicles. In terms of ship refueling, vessels continue to rely on tanker trucks, which contributes to local pollution through vehicle emissions and the risk of fuel spills, further increasing the port's carbon footprint.

This issue is further compounded by several shipping companies operating in the Ría de Vigo, providing ferry services that use diesel as fuel. These ferries facilitate transportation to the Atlantic islands, as well as to the towns located on the opposite side of the estuary. Due to their efficiency in terms of time and cost, these ferries have become the preferred means of crossing the estuary, resulting in a significant increase in the number of users over the past nine years.

In response to these challenges, the APV is committed to managing air quality to ensure a sustainable environment. It has implemented several measures to control emissions and enhance environmental quality: enforcing mandatory environmental and safety regulations such as speed limits and covering ships during maintenance; publishing Environmental Best Practice Guides on its website to raise awareness among users; upgrading internal roads to reduce truck traffic; and installing continuous air quality monitoring systems with new sensors to track pollutants (2023 Sustainability report). Additionally, the port has introduced a fleet of electric and hybrid vehicles (two electric vehicles, nine hybrids, and seven vehicles that could be either gasoline or hybrid, out of a total of 28 new vehicles), uses exclusively renewable energy for its facilities, and has been calculating and registering its carbon footprint since 2014.

A further strategy being explored for the port's decarbonization is the incorporation of biofuels into port activities. The APV is considering the integration of hydrogen technologies through two hydrogen initiatives. The first one, Julio Verne projects, involves the installation of a hydrogen refueling station. Located outside the port area near the Ro-Ro terminal, this station will play a crucial role in transitioning port traffic from fossil fuels to hydrogen, thereby reducing greenhouse gas emissions from high-usage vehicles like trucks and auxiliary cargo handling equipment.

Initially, the Julio Verne on-site hydrogen refueling station will serve as a pilot project, allowing the port to test a small internal fleet of hydrogen-powered vehicles and equipment. This phased approach will enable the port to assess performance, gather valuable data, and refine its strategy. Based on these findings, the port can then expand its hydrogen infrastructure, potentially adding more refueling stations and increasing the deployment of hydrogen-powered equipment in high-emission areas such as the Ro-Ro terminal and commercial quays.

Figure 4. Possible location of the H_2 refueling station of the Julio Verne project.

Another initiative involving the Port of Vigo is the Green Bay Vigo project, which focuses on developing and deploying technologies for electric propulsion systems and battery energy storage for the maritime sector. As a complement of this project, the use of hydrogen technologies will be developed, generation and storage, as a sustainable solution for the decarbonization of land transport and its application in the maritime sector with the development of hydrogen vehicles for goods transport and vessels with hydrogen fuel cells. This initiative will have several significant impacts: environmentally, it will reduce emissions, promote renewable energy use, and lower noise pollution; economically, it will boost the local economy, revitalize the industry, create high-quality jobs, and open new markets for automotive and naval companies; socially, it will enhance tourism by offering eco-friendly transport options and foster the development of advanced technologies to improve sector competitiveness.

The Vigo region's port environment is a hub of diverse and thriving industries, excelling in fishing, automotive manufacturing, industrial machinery, biotechnology, pharmaceuticals, and logistics. These industries stand to gain significantly from the integration of hydrogen in various applications. For example, the fishing and logistics industries can lower emissions by adopting hybrid or hydrogen fuel cell vehicles or/and vessels. At the same time, the biotechnology, pharmaceutical, and food sectors can utilize hydrogen to energize their operations.

3.1.1.1 Conclusions

The Authority of the Port of Vigo (APV) is poised to make significant strides in sustainability through the strategic adoption of hydrogen technology. Transitioning from fossil fuels to hydrogen presents a transformative opportunity to reduce emissions, improve air quality, and enhance energy efficiency across various port operations.

After understanding the operation of the port and its division into zones, as well as its activities, several development opportunities have been identified to enhance the efficiency and sustainability of the port. Incorporating hydrogen technology in mobility at the APV involves transitioning from the current reliance on diesel and gasoline vehicles, which significantly contribute to emissions of harmful gasses, to hydrogen-powered alternatives. This shift promises to reduce emissions, enhance air quality, and support a move towards a more sustainable, less fossil-fuel-dependent economy.

Additionally, integrating hydrogen into port logistics can optimize the operation of machinery and equipment used in daily activities. Hydrogen-powered equipment for cargo handling and transportation within the port will not only lower emissions but also improve energy efficiency.

The development of an on-site hydrogen production point through the "Julio Verne" project's hydrogen station will facilitate local hydrogen generation and distribution, thereby reducing dependence on fossil fuels and supplying vehicles in the port and surrounding areas. To support this, establishing a hydrogen distribution point will allow the port to leverage existing infrastructure and future hydrogen production to become a key distribution center in northern Spain.

In the interim, until local hydrogen production meets demand, setting up an additional hydrogen import point is essential. This approach ensures a continuous and adequate supply to satisfy the needs of both transportation and local industries, facilitating a smooth transition to hydrogen fuel.

Overall, these initiatives will not only advance the Port of Vigo's sustainability objectives but also position it as a leader in the maritime industry's shift towards cleaner energy solutions. By embracing hydrogen technology, the Port of Vigo is taking significant steps towards a more sustainable and environmentally responsible future.

3.1.2 Port of Seville (APS)

Interviewee: **Elisa Oyonarte**, Head of Innovation and European Projects.

The Port of Seville, Spain's only inland maritime port, is a key strategic hub for the European Union. It offers seamless multi-modal transport through sea, rail, and road connections, serving a 200-kilometer hinterland and linking with major regional transport hubs. As part of the Trans-European Transport Network (TEN-T), the port is crucial to both the Mediterranean and Atlantic Corridors, leveraging the navigable Guadalquivir River for inland navigation. To reach the port, ships must navigate the 90 kilometers of the Guadalquivir Euroway E.60.02, a journey that typically takes 5-6 hours to reach the port's access lock. This lengthy voyage is offset by the significant reduction in heavy road traffic.

Figure 5. Guadalquivir Euroway E.60.02

It hosts a range of industrial, logistical, and commercial port activities, along with some nautical sports and other activities related to port-city interaction, though on a smaller scale. The port is divided into six different areas: port operations, complementary activities (such as ro-ro terminal, railway terminal or free trade zone), logistic area, linked management areas (commercial, industrial or logistic enterprise), port-urban use area and green areas.

The reliance on fossil fuels, particularly for road traffic and cargo machinery, has posed a significant challenge in terms of sustainability and emission reduction. To address this issue and move towards a more sustainable model, the Port Authority of Seville (APS) has implemented a series of strategic measures aimed at reducing fuel consumption and minimizing its carbon footprint.

One of the main actions has been the complete renewal of its vehicle fleet, replacing the traditional cars with hybrid or electric models. To facilitate the transition to electric mobility, the APS has invested in the installation of charging stations for electric vehicles at several strategic points throughout the port, thereby promoting greater use of clean technologies.

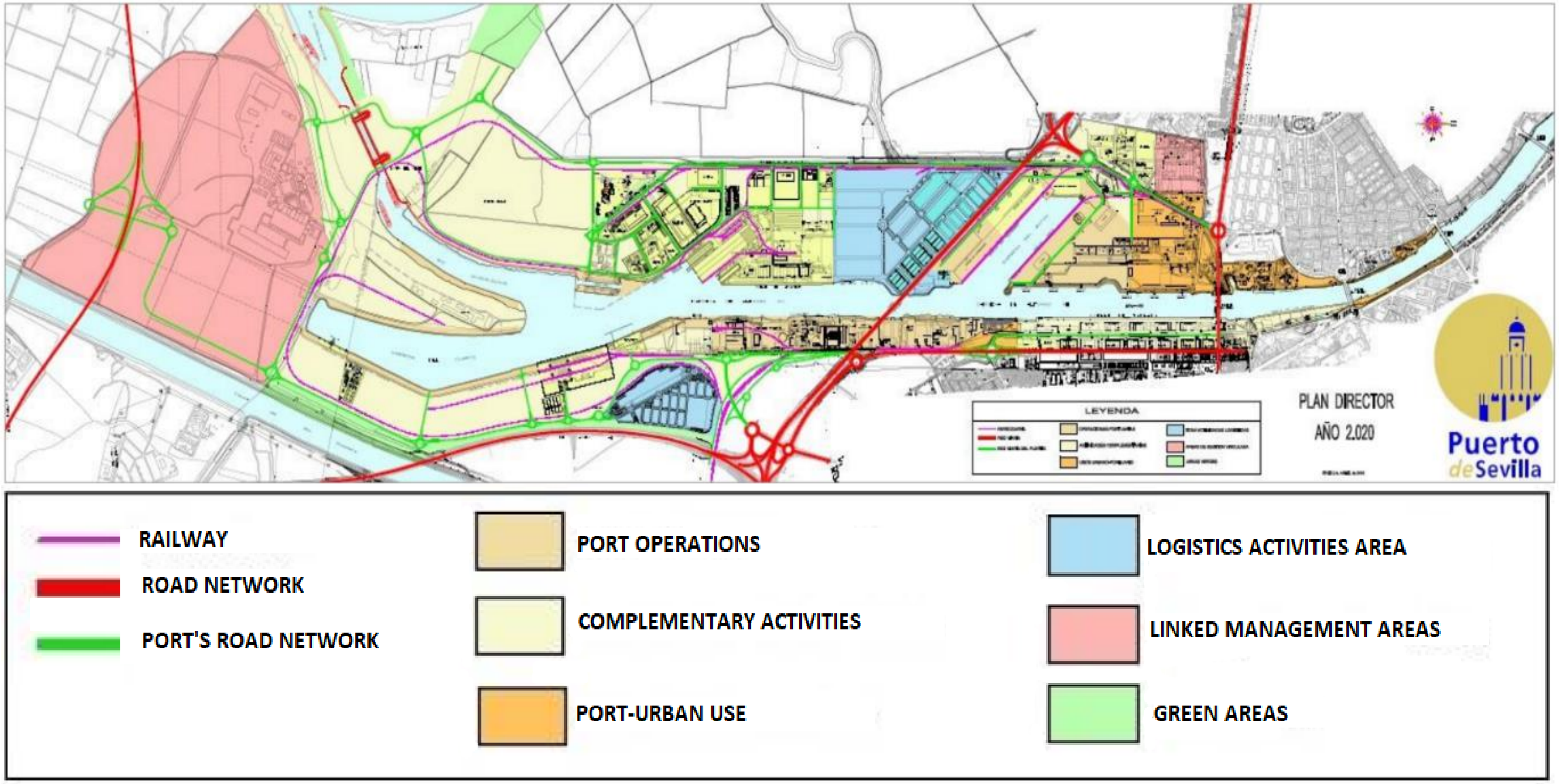


Figure 6. Map of the port of Seville.

Additionally, the use of electric auxiliary cargo machinery has been encouraged over equipment that runs on gasoline or diesel. The quay cranes have been fully electrified, leaving only mobile cranes and tugboats still dependent on fossil fuels (see Figure 7).

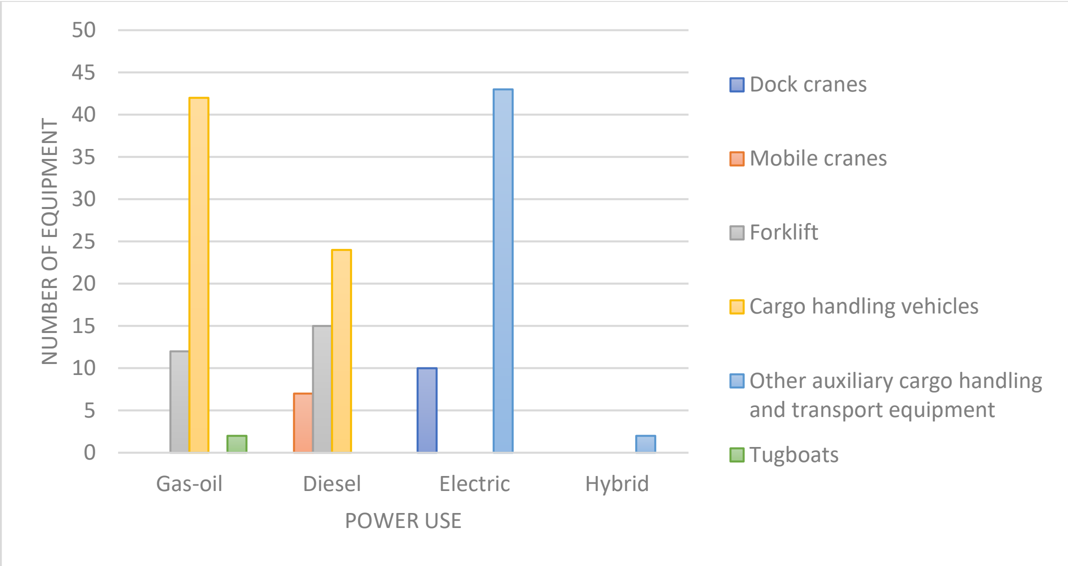


Figure 7. Seville port's equipment and their power use. Based on the data provided in the 2022 annual report.[19]

As part of its strategy for decarbonizing maritime transport, APS plans to implement the OPS (Onshore Power Supply) system. This system allows vessels to connect to the shore power grid while docked, enabling them to operate without needing to activate their generators and auxiliary engines. The adoption of this measure significantly reduces noise and pollutant emissions and allows the energy required for vessel operations to come from renewable sources generated by systems installed at the port.

In line with its environmental protection strategy, APS is considering the use of green hydrogen to achieve 100% renewable energy and advance the decarbonization of the port by incorporating it into daily port operations. One of the studies being considered focuses on integrating hydrogen into the OPS system.

APS is working on two significant hydrogen projects, both essential to its goal of advancing sustainable energy solutions. The first one, the Ignis project, involves establishing a facility for processing and storing green ammonia, produced from nitrogen obtained through cryogenic air separation and electrolytic hydrogen generated through water electrolysis. This electrolysis process splits water into hydrogen and oxygen using an electric current, with each phase of the project designed to generate hydrogen at a capacity of 350 MW, totalling 1.05 GW across all three phases.

The second initiative, the Alener H2 Plant project, which will be situated in the port's industrial area, focuses on the production, storage, and distribution of green hydrogen, utilizing 1 MW PEM technology.

The plant will be supported by a 2 MW photovoltaic solar installation and a 1 MWh energy storage system, designed to meet the needs of industrial, residential, and mobility sectors.

The industry in the Seville port area will benefit significantly from these projects, as it will be able to utilize the produced hydrogen for its processes. By integrating hydrogen into their operations, local businesses can reduce their carbon footprint and enhance their environmental performance. Additionally, the availability of green hydrogen can drive innovation and foster growth in sectors such as metalworking and renewable energy, further strengthening the industrial base of the Seville port area.

3.1.2.1 Conclusions

The Port of Seville is embarking on a significant sustainability initiative with a comprehensive hydrogen strategy. Central to this effort is the establishment of the Alener plant on port grounds, which will position the facility as a leading producer of green hydrogen in southern Spain. This plant will not only produce and store hydrogen but also facilitate its distribution, supporting both port operations and surrounding businesses by providing energy and auxiliary systems. This dual function will contribute to a reduction in environmental impact across the port area.

The hydrogen production plant will also act as a distribution hub, converting hydrogen into ammonia to enable safer transport by both sea and land. This step is crucial for ensuring the efficient and secure delivery of hydrogen to various users. Concurrently, a feasibility study will be conducted to evaluate the potential for integrating hydrogen into the onshore power supply (OPS) system. This study aims to determine the viability of generating electricity from hydrogen, further enhancing the port's sustainability efforts.

In addition to these advancements, integrating hydrogen into ship propulsion systems is expected to significantly reduce emissions along the 90-kilometer route on the Guadalquivir River to the Port of Seville. This integration represents a substantial step forward in decreasing the environmental footprint of maritime operations, aligning with the port’s broader sustainability goals.

In summary, the Port of Seville’s hydrogen strategy will significantly advance its sustainability objectives. By improving energy efficiency, facilitating cleaner transportation, and supporting local businesses, the port is poised to become a leader in green energy adoption.

3.1.3 Port of Bilbao (PB)

Interviewee: **José Luis García-Mochales** (Innovation Department Manager) and **Nagore Ardanza Urtiaga** (Bilbao PortLab coordinator).

The strategic location of the Port of Bilbao makes it a key link with the main ports of Northern Europe as well as the Atlantic. Its main activity focuses on handling a wide variety of goods, with liquid bulk being the most prominent, accounting for 60% of its total operations. Crude oil for refining is the main product in this category. Furthermore, the port ranks third in Spain in terms of both imports and exports.

The port area is divided into six distinct zones: liquid bulk terminals, solid bulk terminals, container terminals, the Ro-Ro zone, and the passenger station (see Figure 8). A significant portion of its surface area, 38 %, is dedicated to industrial companies from sectors such as energy and wind power, which use the docks to manufacture or transform materials into final products.

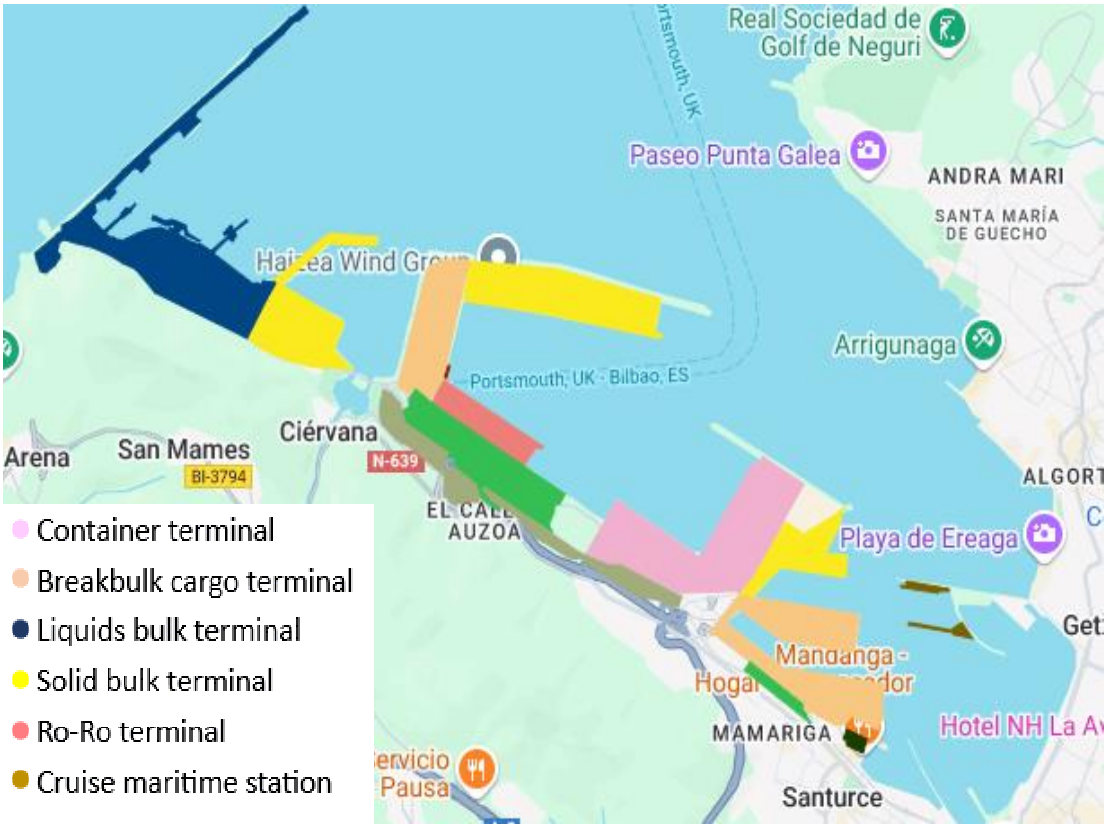


Figure 8. Structure of the docks and terminal of Bilbao port.

Most roll-on/roll-off traffic is governed by concession agreements, with diesel fuel being the predominant energy source. Bulk terminals, which are among the most active areas, utilize over 350 units of auxiliary loading machinery, predominantly powered by diesel fuel, with the exception of electrically powered forklifts. In contrast, port cranes, which are located in separate areas of the port, operate exclusively on electrical energy (see Figure 9). Additionally, mobile cranes at the port are hybrid, using both diesel and electric power, while tugboats rely solely on diesel fuel for their operations.

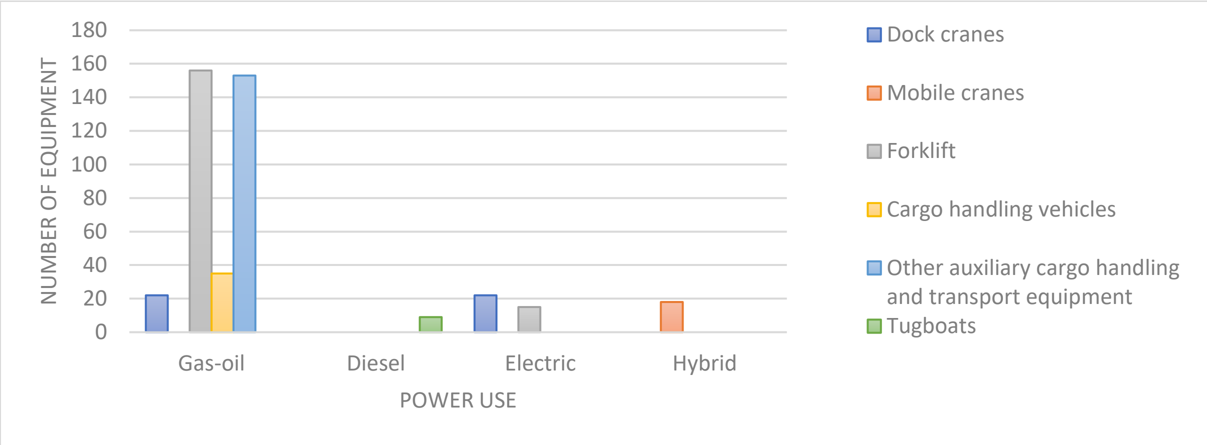


Figure 9. Seville port's equipment and their power use. Based on the data provided in the 2022 annual report.[20]

Among the port's services is the ferry line operating between Bilbao and Portsmouth. One of the vessels on this route is powered by liquefied natural gas (LNG), reducing CO_2 emissions per passenger by 46 %. To support this vessel, an LNG refueling station has been integrated into the port.

In terms of sustainability, the Port of Bilbao is advancing its Energy Transition Plan, which includes several key initiatives. Since 2021, the Port Authority of Bilbao (APB) has implemented a strategy focused on sustainability by renewing its vehicle fleet with units powered by alternative fuels. This updated fleet now features electric cars, hybrid vehicles, those powered by LPG (liquefied petroleum gas), and plug-in hybrids, resulting in over 70 % of the fleet using alternative fuels. This partial replacement of the fleet with more efficient vehicles reduced the port's overall emissions by 15 % compared to 2022. Additionally, as part of the Energy Transition Plan, the implementation of engine upgrades for vessels has led to a 26 % reduction in fuel consumption.

Building on these advancements, the next major initiative is the BilbOPS project, which will focus on the electrification of docks. This project aims to achieve a 20 % share of renewable energy in the port's total energy consumption by 2026, with an increased target of 50 % by 2028. As part of this initiative, 11 electrical supply points for ships will be implemented between 2025 and 2026. Additionally, a wind and photovoltaic park will be developed to supply this electrical demand, further advancing the port's commitment to sustainable energy solutions.

In addition to the efforts described previously, the port is implementing other sustainable initiatives. These include the transition to LED (light-emitting diode) lighting technology, which will significantly reduce energy consumption and associated emissions, as well as the incorporation of photovoltaic panels in some of the port facilities.

To support these goals, the incorporation of hydrogen (H_2) technologies could be a valuable approach to enhance the transition to cleaner energy sources. Following this idea, the APB is involved in different hydrogen projects. Among these initiatives is a project within the Basque Hydrogen Corridor and focuses on constructing a synthetic fuels plant (SFP). This facility is expected to start operating by late 2025 or early 2026. It will produce synthetic fuels through the combination of CO_2, captured from refinery emissions, and hydrogen generated by a 10-megawatt electrolyzer, which will be installed at a nearby Petronor facility. The plant is projected to achieve an annual production capacity of 2,000 tons of synthetic fuel, contributing significantly to regional sustainability objectives.

The subsequent phase of the project, slated to begin in 2027, will involve the construction of a large-scale production facility. This phase will also incorporate a high-capacity electrolyzer with a rating of 100 megawatts, aimed at enhancing hydrogen production capabilities and supporting the broader goals of the hydrogen corridor.

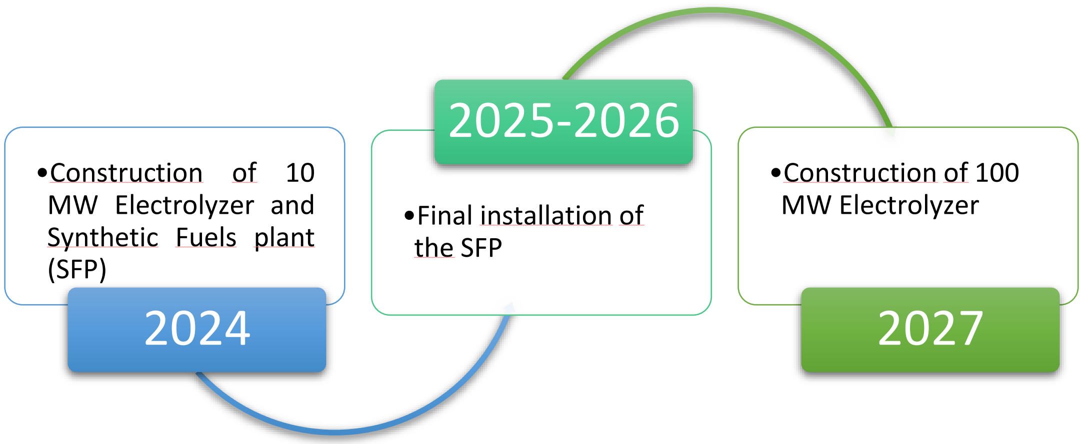


Figure 10. Stages of the Basque Hydrogen Corridor involving the Port of Bilbao.

In parallel, the APB, in collaboration with the Port of Amsterdam, is engaged in the development of a key initiative to establish a European renewable hydrogen corridor. This project aims to create a sustainable energy supply chain between Southern and Northern Europe, facilitating the production, storage, and transport of green hydrogen. The corridor aligns with EU decarbonization goals, particularly in the maritime sector, and is designed to support the energy transition across industries. By enhancing hydrogen infrastructure, both ports are positioned as central nodes in Europe's emerging hydrogen economy, contributing to industrial decarbonization and energy security.

These two corridors aim to enhance the infrastructure for hydrogen production and distribution across Spain and Europe, facilitating its integration into various sectors. The surrounding industries, of the port are particularly interested in adopting hydrogen technologies. Notably, steel mills, the port itself, cement manufacturers, and shipping companies, are exploring hydrogen for applications such as methanol mobility. This growing interest underscores the potential impact of the hydrogen corridor on regional industrial practices and sustainability efforts.

3.1.3.1 Conclusions

The Port of Bilbao is demonstrating a notable interest in hydrogen technologies as part of its broader sustainability strategy. This focus underscores its commitment to reducing emissions and enhancing operational efficiency. Hydrogen technologies can be applied at several key points within the port, showcasing their potential to significantly impact various operational areas.

One of the primary initiatives is the establishment of a hydrogen production plant at Petronor, which will position the Port of Bilbao as a central hub for hydrogen production and storage in northern Spain. This facility will enable the port to produce and store hydrogen locally while also serving as a distribution center for this renewable fuel, facilitating its use throughout the region and supporting the energy transition of both the port and neighboring industries.

In terms of mobility, it could be feasible and beneficial to the environment to introduce hydrogen technology into the ferry lines between Bilbao and Portsmouth. Given that one of the three ferries on this route already utilizes liquefied natural gas (LNG), transitioning to hydrogen could further enhance sustainability by reducing CO_2 emissions. The existing LNG refueling infrastructure at the port could be adapted to support hydrogen refueling, making the transition to cleaner fuel a practical option.

Additionally, the Port of Bilbao is engaged in the development of a European renewable hydrogen corridor in collaboration with the Port of Amsterdam. This project aims to establish a sustainable energy supply chain between southern and northern Europe, facilitating the production, storage, and transport of green hydrogen. The port's involvement in this corridor highlights its pivotal role in advancing hydrogen infrastructure at a European level and contributes to broader goals of industrial decarbonization and energy security.

In summary, the Port of Bilbao's engagement with hydrogen technologies spans multiple areas, including production, distribution, and potential applications in maritime transport. These initiatives not only advance the port's sustainability goals but also position it as a leader in the adoption of clean energy solutions, driving the transition towards a hydrogen economy in Europe. ▯

3.1.4 Port of Gijón (APG)

Interviewee: **Ainhoa Puebla**, Director of Subsidies and Projects at the Port Authority of Gijón.

The Port of Gijón, located on the northern Cantabrian coast of Spain, is a significant maritime access point that facilitates connections with over 200 international ports through an extensive network of regular routes. Its strategic location makes it a key node for maritime traffic between the Iberian Peninsula and Northern Europe. It focuses its main activity on the handling of solid and liquid bulk, containers, and general cargo. It particularly excels in the management of solid bulk, positioning itself as the leading receiver of this type of goods in Spain, with coal and iron ore as its main imports. Although it is not specialized in cruise operations, the port also provides services for these vessels and their passengers, ensuring proper attention to this type of traffic.

The port facilities include a fishing dock, a container terminal, multiple terminals for solid bulk materials, strategically located throughout the port according to the type of raw material, a liquid bulk terminal, a ro-ro (roll-on/roll-off) terminal, and a regasification plant (see Figure 11).

Figure 11. Map of the Port of Gijón.

Road traffic within the port is classified into several types. Heavy-duty vehicles include trucks for transporting containers and bulk materials, as well as tanker trucks for liquid bulk. Internal handling equipment, such as mobile cranes and forklifts, are essential for port operations. Service and maintenance vehicles, along with buses and passenger cars, complete the vehicle fleet.

Fuel supply at the port is dominated by fossil fuels, primarily diesel and gasoline, used in trucks, heavy machinery, and service vehicles. However, there is a growing adoption of alternative fuels and new technologies, such as compressed natural gas (CNG), liquefied natural gas (LNG), and electricity for electric vehicles, in response to the need to reduce the carbon footprint.

Regarding the equipment used in the port for cargo handling, a diverse range of machinery can be found. This includes electric dock cranes and diesel-powered mobile cranes located at various points of the port, as well as reach stackers and straddle carriers for transporting and stacking containers. There is also specialized equipment for bulk handling, such as conveyor belts and electric hoppers for handling solid bulk. Additionally, there are auxiliary equipment like diesel-powered or hybrid forklifts and diesel-powered tugboats (see Figure 12).

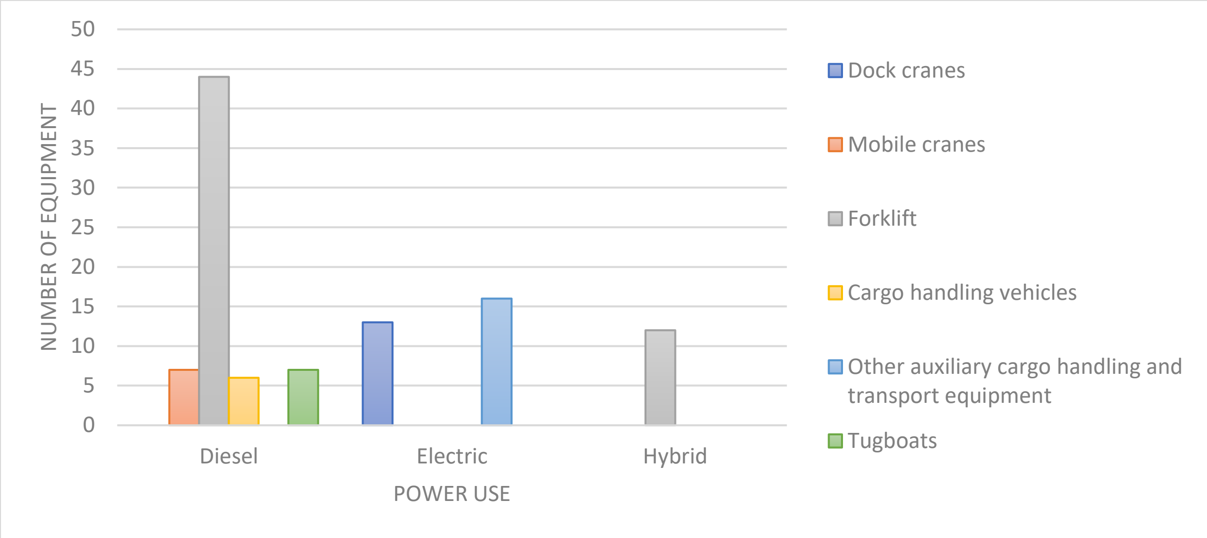


Figure 12. Port equipment and its power use. Based on the data provided in the 2022 annual report.[21]

The reliance on fossil fuels, such as diesel, remains significant in much of the port's machinery and vehicles. The APG has proposed a plan to control and reduce greenhouse gas emissions from its activities, aiming to align with the new energy model established by the Paris Agreement. This plan includes managing GHG, water pollution, waste management, air quality, noise, and biodiversity protection.

To tackle these challenges, the port is adopting various strategies, including investments in renewable energy sources such as solar panels and wind turbines, as well as the electrification of docks and vehicles. Additionally, the APG has optimized lighting and climate control systems across its facilities by implementing more efficient technologies like LED lighting and low-energy climate control systems.

Moreover, the port is exploring the feasibility of hydrogen technologies, although it has not yet initiated formal projects in this area. Its interest in these technologies is evident through its involvement in various hydrogen-related projects. One of the key upcoming projects is Musel Greenmet, scheduled to begin in 2025. This project involves the development of a plant for the production of green hydrogen and methanol (MeOH), with operations anticipated to begin in 2027. The project will be executed in two phases: the initial phase will feature a 50 MW electrolyzer for green H_2 production, which will support an e-methanol plant with an annual output of 100.000 tons. The second phase will expand the plant's capacity to 100 MW, and it is estimated that the green methanol will reduce up to 175.000 tons of CO_2 annually, significantly benefiting the environment.

Furthermore, another project of interest is the Julio Verne project, focusing on the use of hydrogen to supply vessels and vehicles, and including the establishment of a H_2 refueling station. Lastly, the H2PORTS project, which focuses on integrating hydrogen technologies into the port's cargo handling equipment, involves the APG as an observer. Although the APG does not actively participate, it stays informed about the project's advancements, allowing it to stay abreast of developments and consider applying these innovations in future projects.

3.1.4.1 Conclusions

The Port of Gijón is demonstrating a strong commitment to adopting hydrogen technologies, aiming to enhance its environmental performance and operational capabilities. A key element of this strategy is the Musel Greenmet project, which will establish a cutting-edge facility for producing green hydrogen and e-methanol. This initiative is expected to make a significant impact on regional sustainability goals by substantially reducing CO_2 emissions and promoting the use of cleaner energy sources.

In conjunction with this, the development of the Julio Verne hydrogen station will provide crucial refueling infrastructure for hydrogen-powered vessels and vehicles. This advancement will support the port's transition to hydrogen-based technologies and further reduce greenhouse gas emissions across its operations.

Moreover, integrating hydrogen technologies into port logistics will address the current dependence on diesel for loading and unloading processes. By adopting hydrogen-powered equipment, the port anticipates a considerable reduction in CO_2 emissions, enhancing both its environmental performance and operational efficiency.

The future use of hydrogen-derived e-methanol for maritime mobility, once the e-methanol plant is operational, will offer a sustainable and efficient energy source for navigation. This initiative aligns with the port's broader goals of minimizing environmental impact and advancing cleaner energy solutions.

Overall, these initiatives collectively underscore the Port of Gijón's dedication to sustainability. By leveraging hydrogen technologies, the port is not only improving its operational efficiency but also contributing to the global transition towards a more sustainable energy future.

3.2 Portuguese Atlantic Area

3.2.1 Port of Douro, Leixões & Viana do Castelo (APDL)

Interviewee: **Filipe Martins** (Innovation Manager and Datacenter Program Manager) and **Hugo Lopes** (Director of Development and Sustainability).

The APDL (Administration of the Ports of Douro, Leixões, and Viana do Castelo, SA) is a public limited company responsible for managing the Ports of Leixões, Viana, and the Douro Navigable Waterway. Its main objectives are the economic utilization, conservation, and development of these ports and waterways. This includes exercising port authority functions and any other competencies or prerogatives that may be assigned to it.

3.2.1.1 Port of Leixões

The Port of Leixões (PL), located in Matosinhos, is one of the largest and most advanced ports in Portugal. The PL manages a wide range of port activities, such as container handling, bulk cargo operations, and cruise ship services. It also provides comprehensive logistics solutions, warehousing, and state-of-the-art cargo handling operations.

It comprises two main terminals (North and South), capable of handling various types of cargo and features a modern cruise terminal, making it a complex infrastructure that manages a wide range of activities including logistics services.

Figure 13. Map of Leixões Port

The most significant activities in terms of cargo volume are carried out at the following terminals: Cargo bulk and liquid, containers, RO-RO, and the oil terminal.

The liquid bulk handled is mainly destined for the Petrogal Refinery located in Leça da Palmeira, as well as CEPSA. In addition to the Oil Terminal, there are other suitable locations for handling different types of liquid bulk like asphaltic products and fuel oil. The Port has an Oil Terminal, concessioned to Petrogal - Petróleos de Portugal, S.A., built on the submerged breakwater, with a length of 700 meters and a height of 15 meters above sea level, also serving as protection for the port entrance. The terminal is connected to the Petrogal Refinery via pipelines and has three berths with capacities of 100.000, 27.000 and 6.000 DWT respectively.

The north terminal has a quay with a berthable length of 360 meters and a depth of -10m (Z.H.L.), equipped with 2 quay cranes with a capacity of up to 35/42 tons (on the spreader/under the beam). Its yards cover a total area of 6 hectares and are equipped with 4-yard cranes with a capacity of 35/42 tons (on the spreader/under the beam), allowing for the storage of 3,500 TEUs. The handling capacity of this terminal is 170,000 TEUs per year. For container handling, it also has 2 reach stackers and 3 front forklifts. Additionally, this terminal includes a refrigerated container parking area with 72 power outlets and 10 semi-trailers for internal container transport.

There is also a quay at this terminal, 145 meters long in the North-South direction, with a depth of -6m (Z.H.L.), which is not part of the concession.

The South Container Terminal has a quay with a berthable length of 540 meters and a depth of -12m (Z.H.L.), equipped with 4 quay cranes with the following capacities: two cranes of 40/2x30/75 tons (on the spreader single/twin-lift/under the beam), one crane of 40/2x20/65 tons (on the spreader single/twin-lift/under the beam), and one crane with a capacity of 35/45 tons (on the spreader/under the beam). Its yards, with a total area of 16 hectares, are equipped with 14-yard cranes with a capacity of 35/45 tons (on the spreader/under the beam). Additionally, it has 7 reach stackers and 6 front forklifts, allowing for storage of 14.100 TEUs.

The handling capacity of this terminal is 600.000 TEUs per year. The terminal also includes a refrigerated container parking area with 544 power outlets and 28 semi-trailers for internal container transport. Furthermore, there is a quay at this terminal, 100 meters long in the North-South direction, with a depth of -11m (Z.H.L.), located at the eastern end of Dock No. 2, which is not part of the concession.

The Ro-Ro Terminal is located at Dock 1 North, with a depth of -10m, providing roll-on/roll-off cargo loading and unloading services at the Port of Leixões. This terminal offers suitable conditions for berthing Ro-Ro vessels with a stern ramp, featuring a fixed platform incorporated into the quay. The platform is 21m long, has a maximum width of 22m, and a slope of 7.7%.

The terminal's maximum load capacity is 80 tons and 24 tons per axle. Additionally, it has a parking area for approximately 100 trailers.

The PL experiences significant road traffic, primarily involving **heavy vehicles that transport goods** to and from the port, with most of this traffic relying on traditional fossil fuels such as diesel. In addition, the port utilizes a wide range of equipment, including gantry cranes, mobile cranes, forklifts, and automated systems. While most of this equipment operates on electricity and fossil fuels (diesel), the area surrounding the port is home to a robust industrial presence, including food processing, manufacturing, and petrochemical industries. These industries are closely linked to port operations, particularly in the handling of raw materials and finished products.

In order to reduce the consumption and traffic of trucks and wheeled vehicles within the port, a single refueling station will be installed at the port's entrance (northeast area according to the image in the general description of the port – Figure 13). The installation of a single station requires heavy transport to pass through a control point, where only machinery authorized under strict controls can access the port area. This will eliminate older trucks and vehicles, whose emissions are significant compared to newer models. This, for now, is the strategy mentioned in the interview to promote the decarbonization of port activities related to passenger and cargo transport by land. No comments were made regarding river transport.

A particular feature mentioned is the presence of unused infrastructure previously dedicated to oil refinery processes. The potential of this type of structure for the implementation of space dedicated to hydrogen generation or for possible large-scale storage is highlighted.

Given this context, the port faces challenges related to emission management, energy efficiency, and the mitigation of air and water pollution.[14] To address these challenges, the Port of Leixões is exploring the potential integration of hydrogen technologies to reduce carbon emissions. Although specific hydrogen projects have not yet been implemented, feasibility studies are currently underway.

The authorities remarked that there's no physical space in the port and the port's vicinity. Hydrogen production, storage, and distribution imply large spaces and important logistic deployment, and the administration must take into consideration safety and regulatory concerns. Following a techno-economic evaluation, which essentially resulted in negative results regarding the implementation of hydrogen and related technologies, the port administration has opted for a gradual transition.

This transition moves from current emissions towards neutrality, eventually reaching the "green" classification through the implementation of electrification as the main solution.

It is noted that for applications where electrification is not the most viable option for obvious reasons, liquid biofuels will be used to address the transition, utilizing existing infrastructure and taking advantage of technological developments made so far.

3.2.1.2 Port of Douro

The Port of Douro is a fluvial port extending along the Douro River in northern Portugal. It is primarily oriented towards river navigation, with facilities for managing tourist vessels, small cargo operations, and recreational services. It is well-known for its docks and berths dedicated to river transport and tourism, particularly the Douro River cruises. The main activities include managing tourist traffic, particularly river cruises, and limited cargo transport operations.

The port provides berthing services for tourist boats, small fluvial cargo handling, and logistical support for recreational activities.

Road traffic related to the port is relatively low, given its focus on fluvial and tourist activities. However, there is movement of vehicles transporting passengers and supplies to the boats. The vehicles operating in the port area typically use fossil fuels, although the scale of road traffic is limited. Given the port's focus on tourism and recreational activities, it uses light equipment such as small cranes and mooring systems. The equipment used for port operations is limited compared to commercial ports and most of that equipment operates in electricity and fossil fuels diesel).

The Port of Douro's surroundings are characterized by industries related to tourism, including hotels, restaurants, and river cruise operators. There is also interaction with small-scale viticulture and wine production in the Douro region. The main challenges include the sustainable management of fluvial tourism, preserving the natural environment of the Douro River, and minimizing pollution caused by boat traffic.

Although the port is more focused on tourist activities, it has begun to consider the use of hydrogen technologies, particularly to reduce the environmental impact of tourism and recreational operations There are no active hydrogen projects at the port, but they could be considered in future initiatives, especially in the context of sustainable tourism, for example, potential areas include the propulsion of tourist vessels and energy generation for port facilities.

The Port of Douro has a strategic focus on sustainability, with initiatives aimed at preserving the natural environment of the river and promoting environmentally friendly tourism, however there is no mention anywhere in the strategic documents regarding the use of hydrogen related technologies.

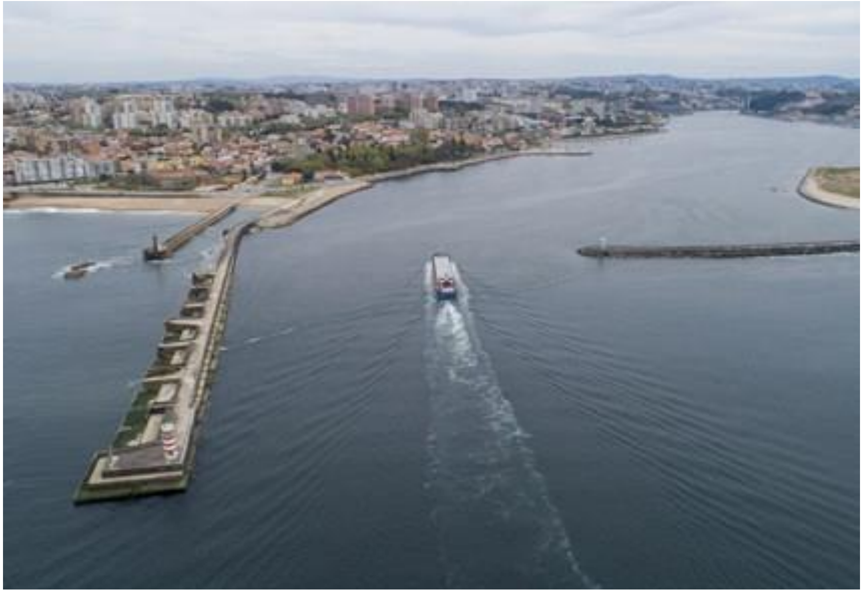


Figure 14. Port of Douro.

3.2.1.3 Port of Viana do Castelo

The Port of Viana do Castelo is a versatile port located in the northwest of Portugal. It is equipped to handle various types of cargo, including solid bulk and general cargo, and is renowned for its significant fishing activity. The port also hosts shipyards vital for shipbuilding and repair. Key activities include bulk handling, fishing, and shipbuilding. The port also sees relevant traffic linked to the tourism industry.

The port offers stevedoring, warehousing, and general port services, including support for fishing and maritime transport.

The port manages moderate road traffic, primarily related to transporting goods to local industries and shipyards. Tourism and fishing also contribute to traffic. Road traffic generally relies on fossil fuels, predominantly diesel.

The port is equipped with mobile cranes, forklifts, and other necessary equipment for handling bulk and general cargo. Specialized equipment is also used in the shipyards. The operation of these machines depends mainly on electricity and fossil fuels.

Surrounding the port are industries related to shipbuilding, fish processing, and light manufacturing. These industries depend on the port for receiving raw materials and exporting finished products. The port faces challenges in reducing emissions, managing shipyard waste, and conserving marine resources.

Although not yet implemented, the port has started considering hydrogen technologies as part of a broader strategy to improve sustainability and reduce its carbon footprint. There are no active hydrogen-related projects, but these are being considered for future sustainability initiatives.

The port is committed to a strategic focus on sustainability, emphasizing the need to preserve marine resources and reduce the environmental impact of its operations.

Figure 15. Port of Viana do Castelo

3.2.1.4 Conclusions

Based on the information provided regarding the ports of Douro, Leixões, and Viana do Castelo, the integration of hydrogen technologies in the Portuguese port sector, while considered, **is not yet a priority.** Each of these ports demonstrates varying degrees of readiness and focus on sustainability, with **electrification and biofuels being the main strategies for decarbonization.** However, hydrogen-related technologies remain largely in the conceptual or exploratory stages.

At the Port of Leixões, one of Portugal's largest and most advanced ports, the primary focus has been on **transitioning towards a "green" port through electrification.** Despite initial considerations of hydrogen as a decarbonization strategy, a recent techno-economic evaluation has led to a negative outlook on the immediate feasibility of hydrogen-related technologies. Instead, the port administration has opted for a gradual approach focused on electrification, citing the lack of space for hydrogen production, storage, and distribution as a significant barrier. **For applications where electrification is not feasible, the port plans to rely on liquid biofuels**, leveraging existing infrastructure.

At the Port of Douro, a riverine port with a strong emphasis on tourism and recreational activities, hydrogen technologies are still in a nascent stage. While sustainability is a key priority, particularly in reducing the environmental impact of tourism, there are currently no active hydrogen projects. **The potential for hydrogen in this port is recognized**, especially in applications such as **boat propulsion** and energy generation for port facilities, but these remain future considerations rather than immediate implementations.

Similarly, at the Port of Viana do Castelo, which focuses on shipbuilding, fishing, and general cargo, hydrogen technologies are being considered as part of broader sustainability efforts. **However, no active projects have been initiated.** The port is committed to improving sustainability, particularly in reducing emissions and conserving marine resources, but hydrogen remains an idea for future exploration rather than a current strategy.

In conclusion, while the potential for hydrogen technologies in Portuguese ports is acknowledged, the **immediate focus is on electrification and biofuels**. Hydrogen is seen as a long-term solution, with ongoing feasibility studies but no large-scale implementations. Key challenges include the physical space required for hydrogen infrastructure, economic viability, and the readiness of current technologies. For now, the region is pursuing more established decarbonization methods, with hydrogen expected to play a more significant role in the future as technologies and infrastructure mature.

3.3 French Atlantic Area

3.3.1 Port of Brest (PBREST)

Interviewee: **Fabienne Vallée** (Innovation & development in the maritime sector) and **Thibault Marzin** (Technical support).

The port of Brest is the most westerly major port in the Brittany region. The port offers its customers easy access at any time, deepwater docks, efficient modern equipment, and quick service and quality.

In the port, six areas can be distinguished: a general cargo terminal equipped to manage various types of goods, including machinery and industrial equipment; a bulk cargo terminal for handling both solid and liquid bulk materials; a container terminal that provides efficient loading and unloading services; a fishing port, that supports the seafood industry with facilities for landing, processing, and distributing products; a cruise terminal that accommodates cruise ships and offers amenities for passengers and vessels; and finally, an industrial area for manufacturing and logistics operations, contributing significantly to regional economic activities.

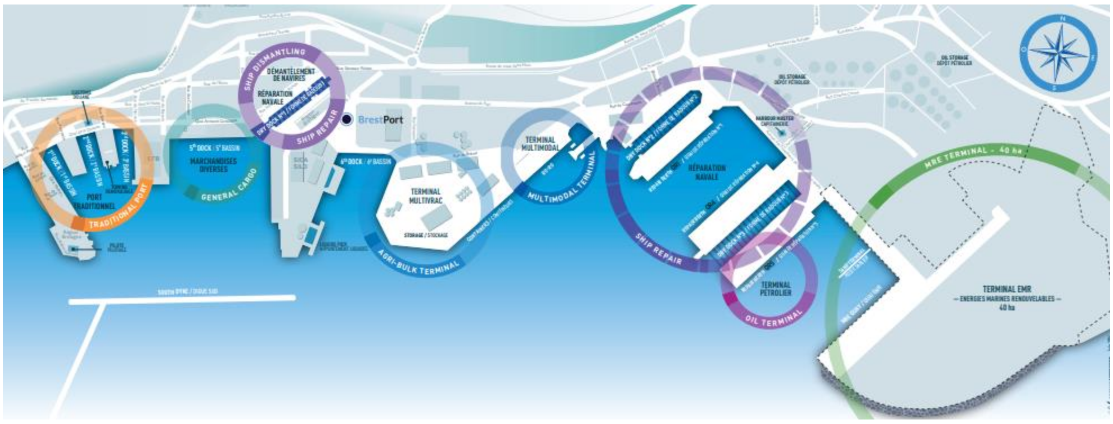


Figure 16. Map of terminals of Brest Port.

The Port of Brest is a multi-activity port: marina, commerce (~100 containership commercial calls per year), fishing, industry and passenger ships (~25 cruise ships commercial calls per year). Most notably, it offers significant naval repair facilities (~60 ships per year) which set it apart from many other ports. As port authority, the Brittany Region delegates management of the port to the company BrestPort, a joint venture between the Région Bretagne, Brest Métropole and the Chamber of Commerce and Industry (CCI) Finistère.

Extract from the Brest Port Business Plan:

"Brest Port bases its positioning as a cutting-edge port on four major pillars that underpin all its activities:

• Shifting usage patterns from historical markets, stabilising agri-food activities and reducing conventional hydrocarbon traffic in the long term.

• Affirming the strategic role of energy and transition to energy sovereignty for the development of marine renewable energies (MRE).

• Accelerating decarbonization of transportation, using railways, new fuels, sail propulsion, dockside power supply, etc.

• Increased industrial land tension, within the framework of the Negotiated Development Zone (ZAN).

The entrepreneurial port model of Brest Port relies on diversifying business activities, promoting technological innovation, developing the offshore renewable energy sector, public-private partnerships, providing incubation for maritime companies, maritime tourism, and committing to sustainability. By adopting this proactive and visionary approach, Brest Port can strengthen its position as a key player in the maritime sector while contributing to regional economic development and the transition to a more sustainable future"

Port activity generates significant truck traffic mainly for regional distribution, with only one company planning to acquire three hydrogen trucks. Heavy handling equipment like mobile cranes has the potential for hydrogen use, but current market offerings are immature, and consumption would be low.

Decarbonizing Brest's fleet with hydrogen would require significant volumes. Hydrogen generators could be an alternative to direct quay electrification, and hydrogen welding, though little known in naval repair, offers decarbonization potential. Most of the vehicles are currently fuelled with diesel, even though there are some electric buses and EVs in the city.

Table 1 shows the types and number of different vehicles that operates in port's activities compared with the total amount in the city of Brest.

Table 1. Number of vehicles that operate in the port and city of Brest.

Vehicle	Number in the Port of Brest	Number in the City of Brest
Trucks	34	1027
Garbage Truck	-	31
Bus	-	371
Utility vehicle	14	14.000
Private vehicle	50	115.500
Handling equipment (type to be detailed later)	83	

Regarding auxiliary material and energy usage, the cranes are the main equipment used by Brest Port for goods loading and unloading. There is currently other handling equipment, such as stackers which use diesel too. However, this type of handling equipment is operated by other stakeholders working at the port of Brest. Authorities say that currently they don't have any information, but they are investigating. Moreover, note that BrestPort plans to buy a 650 T boatlift that uses diesel (2026/2027).

The investigation related to the Port equipment and energy sources concluded that the port purchases 15 GWh of electricity composed by:

- 50% is dedicated to powering Brest Port clients (Damen's naval shipyard, Brest fish auction facilities, AMB reefers, Boluda's tugs, MRE manufacturers, etc.)

- 50% is dedicated to powering Brest Port's own equipment/scope of activities (see table 2):

Table 2. Equipment with its energy source and needed.

Brest Port Activity	Equipment	Energy source	Energy need
Naval repair facilities	7 Cranes on rail	100% Electrical grid	150 MWh/yr
	6 air compressors	100% Electrical grid	500 MWh/yr
	50 water pumps: Docks drying, water cooling, firefighting, ballasting	100% Electrical grid	2,000 MWh/yr
	400 kVA Onshore Power Supply 440 V / 60 Hz	100% Electrical grid	150 MWh/yr

Commerce Facilities (Multi bulk Terminal)	4 cranes on rail with hoppers	100% Electrical grid	300 MWh/yr
	11 compressors	100% Electrical grid	+200 MWh/yr
	˜10 Bucket lifts, ~50 conveyors, ~100 filters, etc	100% Electrical grid	1,000 MWh/yr
Miscellaneous	6 mobile cranes	Diesel + electricity for motor heating and starter battery recharging	unknown

Note that a specific detailed study has been conducted by ***Manifeste*** to qualify/quantify Brest Port's energy consumption (deliverables in French).

Regarding to the refueling infrastructure of the port and the port environment the data shared by the authorities indicates that there is a lacks electric charging points at the port (Table 3):

Table 3. Refueling infrastructures of the port.

Owner	Type	Fuel	Volume (m^3)	Use
COP	Refueling station	Diesel	/	boats
AMB	Tank	Diesel	5	Handling equipment
AMB	Tank	Diesel	3.2	Handling equipment
Brest Port	Tank	Diesel	?	Private/Utility vehicles
AS24	Refueling station	Diesel	/	Trucks
Total Energies	Refueling station	Diesel	/	Trucks/Private/ Utility vehicles
Guyot	tank	Diesel	250	Trucks/handling equipment

The new FuelEU Maritime Regulation aims to increase the use of renewable and low-carbon fuels to reduce GHG emissions from the transport sector. The regulation sets a carbon intensity limit for the energy used onboard by ships arriving in or departing from a European port, and an obligation to connect to OPS facilities while in European ports, via Article 5.

"From 1 January 2030, a ship at berth in a port of call under the jurisdiction of a Member State shall connect to onshore power supply and use it for all energy needs while at berth."

This article applies only to containerships and passenger ships over 5.000 GT. At present, this new obligation for ship owners is scheduled to come into effect on January 1, 2030.

The new AFIR Regulation aims to increase the deployment of alternative fuels infrastructure, and especially to encourage the use of OPS for ships docking at maritime ports throughout the EU, via Article 9.

"Member States shall ensure that a minimum shore-side electricity supply for seagoing container and passenger ships is provided in maritime ports."

This article perfectly complements Article 5 of the FuelEU Maritime Regulation as it applies only to containerships and passenger ships over 5.000 GT.

This new obligation aims at TEN-T ports (Brest Port is one of the 8 TEN-T French maritime ports) is scheduled to come into effect on January 1, 2030. It is important to note that this obligation is subject to a certain number of annual commercial calls and that the port's electrical facilities must be able to meet 90 % of demand in terms of the number of commercial calls. These new regulations will have a direct impact on the Port's electrical grid, where passenger ships - mainly cruise ships - and containerships dock at port.

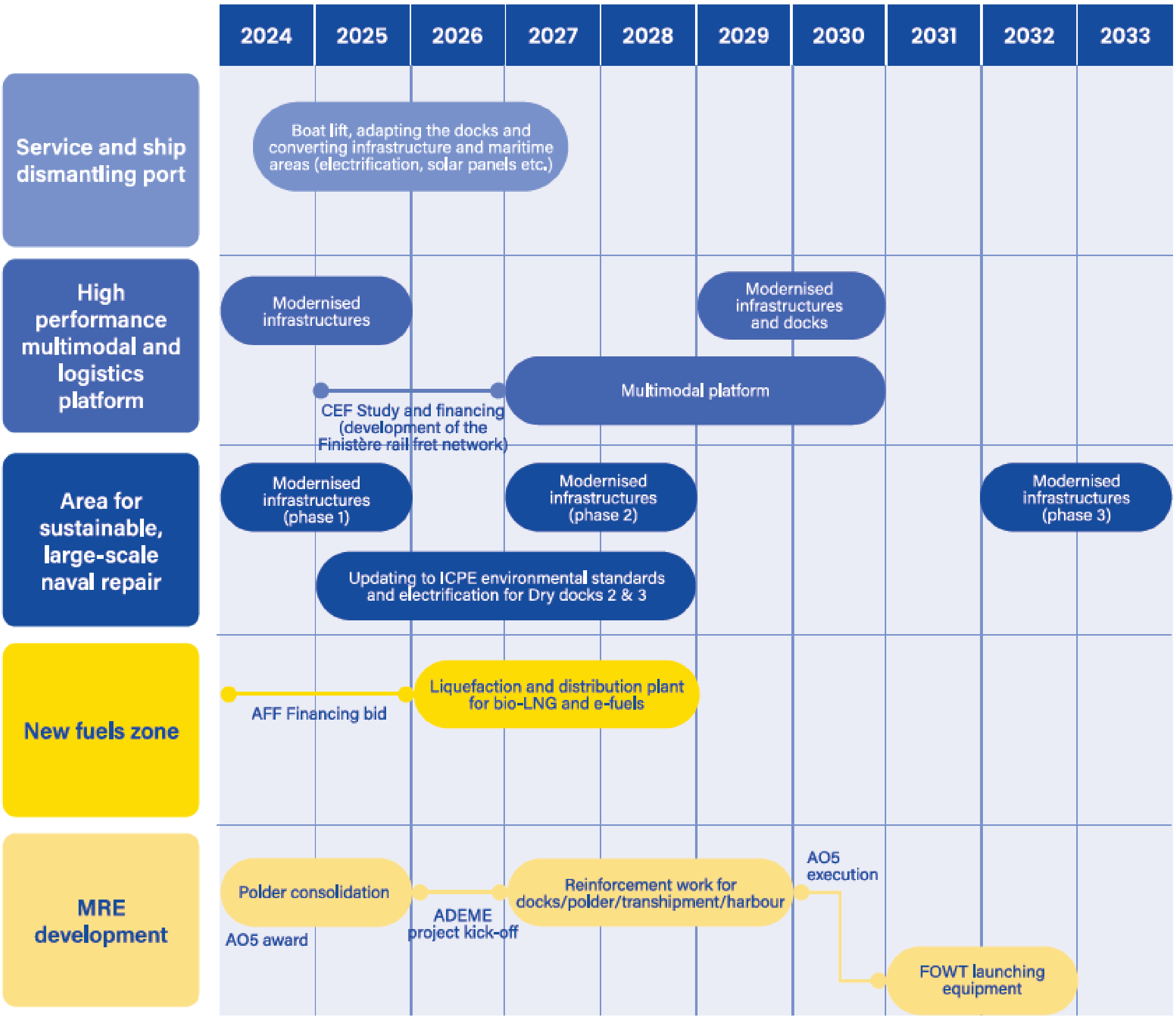
Brest Port wants to meet the requirements of these two regulations. It should be noted that ship repair is not subject to these new obligations and must not be taken into consideration regarding the calculation of the number of calls.

Potential solutions proposed by the authorities to overcome some of the main challenges in the next few years, are the following:

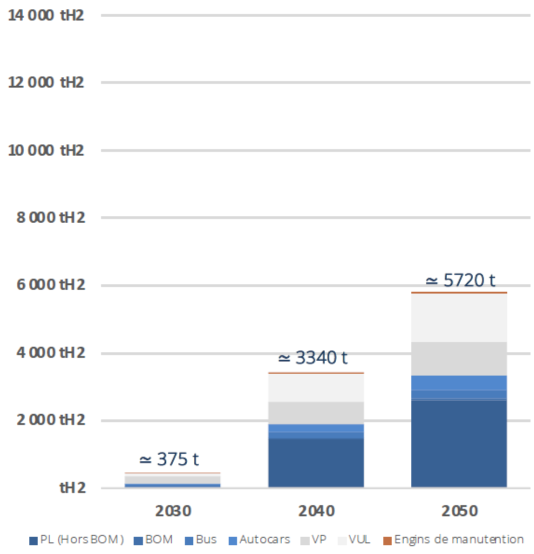
- **Development of a service port** fitted with a new 650-tonne boat lift and the capacity to accommodate medium-sized ships on pontoons. This facility will provide access to the sea for industrial players involved in energy or ecological transitions.
- **The multimodal and logistics platform**, integrated into the RTE-T network, consolidates the business around its two main activities of agricultural raw materials and containers. As part of a more low-carbon logistics strategy, the platform will prioritize rail transport, low-carbon shipping lines and the handling of organic products.
- **Sustainable ship repair**, leveraging Dry docks 2 and 3, equipped with tools unique in Europe, keystones of the Port of Brest's activity. However, given that these docks are over fifty years old a significant modernization effort is required.
- **Fuel services**, operating from a dedicated quay, will transition away from road hydrocarbons to less carbon-intensive alternatives (bio-LNG, H_2, etc.).
- **Hosting marine renewable energy (MREs) on the new polder**. This facility will support national energy sovereignty, capable of addressing industrial challenges in float assembly, while aligning with broader initiatives in decarbonized industries and port cooperation.

Table 4 provides an organized summary of the solutions previously discussed, as proposed by the authorities to address the port's key challenges. Each solution is accompanied by an implementation plan, detailing the necessary actions and timelines.

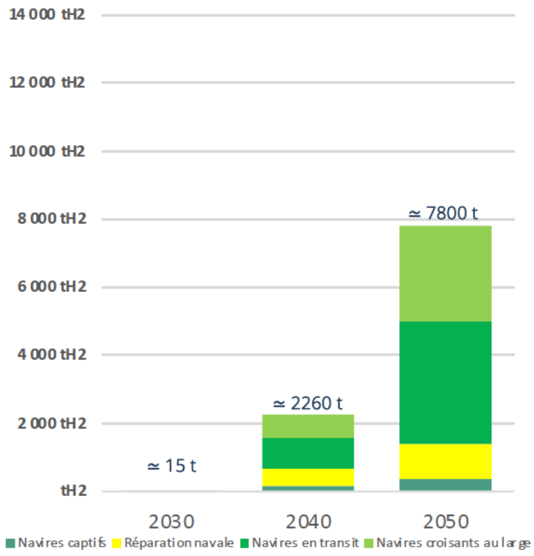
Table 4. Proposed solutions by the authorities and planning for their implementation.



Regarding the consideration of the adoption of hydrogen technologies, authorities shared the perspective studies conducted by REDII, from the annual H_2 volume derived from interviews with port and city stakeholders (Figure 17).



Synthèse des volumes potentiels de consommations H2 pour des usages terrestres



Synthèse des volumes potentiels de consommations H2 pour des usages maritimes

Figure 17. Annual H_2 volume for lands uses at left, (Legend: PL: Trucks; BOM: Garbage trucks; Bus/Autocars: Bus; VP: Private vehicle; VUL: Utility vehicle; Engins de manutention: Handling equipment) and for maritime uses at right (Legend: Navires captifs: Captive ship (~190); Réparation Navale: Ship repair (~60/y); Navires en transit: Ship in transit (~700/y); Navires au large: Ship off shore (55,000/y))

Land use:

- The port activity generates significant truck traffic mainly for regional distribution. Few carriers are currently considering acquiring H_2 solutions, except for one company, who plans to acquire three trucks.

- Heavy handling equipment could represent an interesting potential for H_2 development due to the power requirements and the intensity of usage (e.g., mobile cranes), but the current market offering is not very mature, and the consumption volumes would be low.

- Utility and private vehicles used in the port can mostly be electrified, given their low mileage and usage intensity. Decarbonizing the fleet within the Brest metropolitan area through H_2 would involve significant H_2 volumes.

- H_2-powered garbage trucks are a relevant use case considering the limited range of electric solutions. Brest Métropole has already considered their acquisition, but supply issues still limit their deployment.

- Electric buses currently cover a large part of the metropolitan area's needs, but some intercity lines with longer distances and fewer stops could benefit from H_2 solutions.

- H_2 generators could provide an interesting alternative (temporary or not) to direct quay electrification in the port.

- H_2 welding is currently little known among naval repair actors, although it represents an interesting decarbonization lever for the sector. The potential could not be estimated due to the lack of consumption data.

- The area includes only two GHG-emitting industries. The main one is involved in a 20 MW cogeneration power unit project, which will reduce gas consumption by nearly 80 % from 2026. To date, no H_2 project has been shared.

Maritime use:

- Currently, the bunkering activity at the port of Brest is limited to approximately 3.000 m^3 of fuel per year for naval repair activities, 10.000 m^3 for bunkering ships in transit, and 40.000 m^3 for captive ships. Bunkering for fishing is marginal at 1.000 m^3.

- The fleet of captive ships (fishing vessels, service vessels) presents some usages (high power, high availability) and technical characteristics (boat length and engine power) that make it possible to consider converting to H_2 as fleets are renewed. The maturity of these considerations is still low, and to date, only Maritime pilots plan to convert a pilot boat by 2030.

- Even under optimistic scenarios for fleet conversion to H_2, consumption would remain low by 2050 at 400 t/year (approximately 15 % of the consumption associated with heavy trucks alone).

- Bunkering ships under naval repair also present H_2 consumption volumes. The "small" H_2 ships under naval repair will be few and with low consumption volumes. However, in accordance with IMO recommendations, some large-tonnage ships would take advantage of repair stops to recharge (assuming 2 bunkering stops per year for about twenty decarbonized ships by 2050).

- The H_2 consumption potential relies on bunkering ships in transit through the port. To date, less than 1 % of ships passing through Brest are bunkered at the port.

- Switching to alternative fuel would require more frequent recharges and could enable a new balance in port bunkering offerings. The maritime sector decarbonization roadmap also foresees a relocation of bunkering activities. Consequently, by developing an attractive bunkering offer in terms of price and services, the port could expand its ship refueling activities with H_2 (mainly e-fuel).

If a competitive bunkering offer is established and alternative fuels are deployed according to the maritime decarbonization roadmap, bunkering 1 % of ships in transit and 0’01 % of ships passing offshore would represent approximately 6.400 t/year of H_2 consumption (mainly for e-fuels).

The port is actively involved in various research and European projects, focusing on hydrogen (H_2) initiatives. These projects aim to advance hydrogen technology and its applications in port operations and transportation.

Key H_2 projects include:

1. **H2Port**: This project focuses on developing hydrogen technology specifically for port operations, enhancing the sustainability and efficiency of port activities.

2. **HYDROGEN LEADER**: Aims to advance hydrogen applications in both industrial and transport sectors, supporting the transition to cleaner energy sources.

3. **FCH JU (Fuel Cells and Hydrogen Joint Undertaking)**: Supports a range of hydrogen-related projects across Europe, including those involving the Port of Brest, to foster innovation and development in hydrogen technology.

4. **REDII Ports** – managed by the Région Bretagne, this Interreg North Sea Project aims to study the uses of alternative fuels in port areas between 2022 and 2025. Nine other ports are involved in the initiative and have identified technologies to develop with the ambition of pooling the results of studies. The ports of Brest and Saint-Malo recently joined the project to study the uses of hydrogen.

5. **H2 NS Ports Valley**

3.3.1.1 Conclusions

The Port of Brest, located in the French Atlantic region, stands at a pivotal moment in its transition towards sustainability and the adoption of hydrogen technologies. As a major maritime hub, the port has set its sights on reducing reliance on traditional hydrocarbons, diversifying its energy sources, and exploring renewable options. Hydrogen presents a significant opportunity for decarbonization in sectors where electrification may not be fully viable, particularly in heavy industrial and maritime applications. However, this shift also brings challenges that must be addressed for a successful and efficient transition.

Hydrogen offers clear potential to help the Port of Brest meet its decarbonization goals. One of the primary areas where hydrogen could be transformative is in the operation of heavy-duty equipment, such as cranes and stackers, which are currently powered by diesel. Hydrogen-powered alternatives could significantly reduce emissions in these operations, although the current market for such equipment is not yet fully developed. The port's ongoing projects, such as the REDII Ports initiative and the H2Port project, highlight its proactive approach to exploring hydrogen's potential. These European collaborations aim to foster the development of hydrogen technologies and identify practical uses in port activities, positioning Brest as a key player in hydrogen innovation.

On land, the port generates considerable truck traffic, much of which is currently dependent on diesel. While hydrogen-powered trucks are not yet widespread, there is growing interest in this area, with at least one company planning to acquire hydrogen trucks. As hydrogen technology matures, its application in logistics could expand, offering a cleaner alternative to diesel trucks. Additionally, utility vehicles, garbage trucks, and buses are also strong candidates for hydrogen adoption, particularly for routes that extend beyond the reach of electric vehicles. In the Brest metropolitan area, hydrogen buses could complement existing electric options, especially for longer intercity routes where electric solutions may be less practical.

Maritime operations also hold potential for hydrogen integration. The port's current bunkering activities are relatively limited, with small volumes of fuel used for ships under repair and transit vessels. However, the prospect of hydrogen bunkering is emerging, particularly as maritime regulations push for lower emissions and cleaner fuels. Captive ships, such as fishing vessels and service ships, are likely early candidates for hydrogen fuel conversion as their fleets are renewed. Though current hydrogen consumption is minimal, projections suggest that by 2050, hydrogen demand could grow significantly, especially if Brest positions itself as a competitive hydrogen bunkering hub for ships in transit. The port's role in the maritime decarbonization roadmap could allow it to expand it refueling services to include hydrogen, particularly as alternative fuels like e-fuels gain traction.

Despite these promising prospects, there are notable challenges to hydrogen adoption at the Port of Brest. The lack of dedicated hydrogen refueling infrastructure is a major hurdle. The port currently has no electric cargo terminals and refueling stations for hydrogen-powered vehicles and equipment are not yet in place. Developing this infrastructure will require substantial investment and close collaboration between public and private stakeholders. Additionally, the hydrogen market remains immature, particularly for heavy-duty applications like port equipment and large maritime vessels, meaning the transition will likely be gradual.

Hydrogen's potential to decarbonize the port's operations hinges on securing a reliable and sufficient supply. To meet the energy demands of the port's fleet, handling equipment, and maritime vessels, significant volumes of hydrogen will be needed. The idea of using hydrogen-powered generators as an alternative to direct quay electrification is being considered to reduce the port's carbon footprint. However, the feasibility of such a solution depends on both the availability of hydrogen and the economic viability of deploying these technologies on a large scale.

While both hydrogen and electrification present viable pathways for decarbonizing port operations, they each have distinct advantages and limitations. Electrification is already more mature and readily available for certain applications, such as utility vehicles, cranes, and even buses, especially in urban settings. The Port of Brest already relies heavily on electricity for powering various equipment, including cranes and compressors, which highlights its potential to further electrify operations. Electrification also benefits from a well-established infrastructure and lower energy costs compared to hydrogen, making it the more accessible option in the short term. However, electrification faces challenges in high-power, heavy-duty applications, such as large ships and industrial handling equipment, where hydrogen could offer a more efficient and scalable solution.

On the other hand, hydrogen holds promise for applications where electrification falls short, particularly in sectors requiring long-range, high-energy density, or rapid refueling. For instance, hydrogen-powered trucks, ships, and heavy port equipment could be more efficient than their electric counterparts, especially for long-haul transportation or maritime bunkering. Hydrogen also offers potential as a backup power source and could play a critical role in reducing the carbon intensity of port activities under future regulations. However, the hydrogen market is still in its infancy, and significant investments in infrastructure and technology are needed before it can rival electrification. In conclusion, while electrification may lead in the near term for many operations, hydrogen's potential to fill critical gaps suggests that a hybrid approach, utilizing both technologies, may offer the most effective pathway toward full decarbonization of the Port of Brest.

3.4 Irish Atlantic Area

3.4.1 Port of Galway (PG)

The Port of Galway, situated on Ireland's west coast, is a vital commercial hub with a rich history and ambitious future. It manages various maritime activities, including cargo handling, cruise services, and wind turbine operations. The port handles vessels up to 6.000 tonnes and is planning an expansion to accommodate larger ships and operate 24/7. The current equipment includes a Sennebogen crane powered by diesel, with third-party diesel cranes used occasionally. The port is divided into two key areas: the Inner Dock and the Galway Harbour Enterprise Park, which houses industries such as petroleum, bitumen storage, and wind turbine logistics.

Figure 18. Port of Galway.

With over 100 years of history, it currently faces significant limitations in its infrastructure. The port is tidal, with dock gates that are only open for 4 hours each day, and it can only accommodate vessels carrying up to 6.000 tons of cargo. As a result, the port regularly must turn away ships due to these constraints.

To address these issues, a live planning application has been submitted to relocate and expand the port to a new facility. This new port would operate 24/7 and accommodate larger vessels, carrying between 20.000 and 30.000 tons of cargo. Additionally, the new port would provide around 16 ha of new yards to better serve port users. Currently, the port handles a range of imports and exports, including petroleum products, bitumen, wind turbines, refuse-derived fuels, limestone, and scrap metal. It is also home to the Marine Institute's research vessels, cargo and ferry services to the Aran Islands, naval and fishing vessels, and foreign research ships. Furthermore, it accommodates cruise ships, although passengers must be tendered to shore, a situation that would improve with the new port facilities.

In terms of road traffic, the port relies heavily on trucks for importing and exporting cargo, with most trucks assumed to be powered by diesel. While the port cannot directly influence the fuel used by these trucks, HVO (hydrotreated vegetable oil) has recently been imported for fuel tanks on-site, and some HVO-powered trucks are used for distribution from the port estate.

Goods are loaded and unloaded using cranes, with the port owning and operating a single Sennebogen crane that runs on diesel. The port is exploring whether HVO can be used for this crane but is still awaiting a response. Third-party cranes, also diesel-powered, are used occasionally, particularly for wind turbine operations.

Figure 19. Evolution of the Port of Galway

The port estate is divided into two zones: the Inner Dock, which covers around 6.9 ha, and the Galway Harbour Enterprise Park (GHEP), which spans 16 ha. A portion of the Inner Dock is underutilized and is being master planned for urban regeneration, which will include housing, public spaces, and commercial developments. The remainder of the Inner Dock is used for car parking, small port operations, and other tenant activities. The GHEP is home to a range of operations, including two tank farms for petroleum and bitumen, a limestone warehouse, and extensive wind turbine storage areas. Other users include bus companies, a haulier, marine support services, an engineering company, a cable station, and a sailing club.

Refueling infrastructure at the port is minimal, with just two electric charging points at a petrol station on the port. The port is reviewing the possibility of adding more charging points in the short to medium term. Energy consumption at the port is relatively low, and while the port is transitioning to green fuels like HVO for its pilot boat, it believes that its capital would be better spent improving the estate to support renewable energy deployment. For instance, the port has invested 150.000 € to handle larger onshore wind turbines, a business that has become increasingly important. By mid-2024, around 450 MW of onshore wind turbines will have passed through the port estate.

The port has limited operations that could directly benefit from hydrogen technology, but it is part of a consortium aiming to facilitate hydrogen distribution to local users. The port's tenant base and proximity to Galway City make it an ideal location for a hydrogen distribution hub, and the port is open to accommodating such a facility, subject to planning approval.

While the initial hydrogen hub would be small, the proposed expansion of the port could support a larger distribution facility in the future. The port is also open to the idea of hosting electrolysers at the new site, though it is unlikely that the port will produce hydrogen or e-fuels at scale for export. Several users, including bus companies, could benefit from hydrogen, and the port's proximity to the railway station also makes it a strategic location for future hydrogen-powered train operations.

The Port of Galway has a long-standing vision of supporting the renewable energy sector, including the potential creation of a renewable energy campus on part of the estate. This campus could attract startups, research facilities, and both state and private entities engaged in the renewable energy sector. Overall, the port is focused on providing enhanced facilities for companies working in renewable energy rather than prioritizing its own energy usage, which is minimal. However, the port remains committed to transitioning to green fuels for its vehicles and machinery.

3.4.1.1. Conclusions

Although the Port of Galway is small compared to others, it is undergoing a strategic redevelopment aimed at overcoming its current limitations, such as tidal restrictions and its reduced capacity to accommodate large vessels. With the proposed expansion, the port will be able to operate 24/7 and handle significantly higher cargo volumes, improving not only its commercial competitiveness but also its ability to support the renewable energy sector.

While the port has expressed interest in participating in local hydrogen distribution, the direct applications of this technology in its current operations are limited. Moreover, large-scale hydrogen implementation does not appear feasible in the short term. However, its strategic location and proximity to Galway City give the port potential to become a local hydrogen distribution hub, provided that the necessary infrastructure projects are approved.

Despite its modest size, the port is committed to the transition to green fuels such as HVO and continues to explore opportunities to integrate renewable technologies. However, its primary focus is on providing advanced infrastructure for companies in the clean energy sector, rather than reducing their own energy consumption, which is relatively low.

With the planned expansion and the potential to develop a renewable energy campus, the Port of Galway has significant growth potential, not only in operational terms but also as a driver of innovation and collaboration in Ireland’s energy transition.

4 COMPARATIVE

This section provides a summary of the opportunities identified across the HYDEA ports. The primary initiatives are systematically categorized into five principal sectors: production, distribution, mobility, logistics, storage and conversion. This categorization underscores the strategic focus of each port's efforts in advancing hydrogen technology and enhancing sustainability.

Table 5. Summary of the opportunities identified found in each of the HYDEA ports.

PORTS	COUNTRY	Production	Distribution*	Mobility	LOGISTICS	STORAGE	Conversion
Vigo	Spain	●	●	●	●	●	
Seville	Spain	●	●	●	●	●	●
Bilbao	Spain	●	●	●	●	●	●
Gijón	Spain	●	●	●	●	●	
Leixões	Portugal	●	●	●	●	●	
Viana do Castelo	Portugal			●	●		
Douro	Portugal			●			
Brest	France		●	●	●	●	
Galway	Ireland		●	●			

*Import and export of hydrogen gas, liquid and derivative products (methanol, ammonia) by vessels.

5 GLOBAL CONCLUSIONS

The results obtained from all the interviews seem to suggest a common conclusion: the adoption of hydrogen as an energy vector and the implementation of related technologies does **not appear to be an easy solution to execute**. Various challenges are observed throughout the region, particularly in activities linked to port ecosystems.

Most interviewees made it clear that they are aware of the importance of decarbonizing port-related activities, as well as maritime transport and mobility, both for goods and passengers. In this context, there is an optimistic outlook regarding the decarbonization goals to be achieved. However, all agree that before hydrogen, its associated infrastructure, technologies, and other relevant aspects can be implemented, an intermediate transitional phase is required.

As outlined in deliverable "4.3.1: Identification of bottlenecks and possible measures" of HYDEA project, certain limitations—such as regulatory gaps, safety concerns, social acceptance, and, most notably, investment and operational costs—make the widespread adoption of these technologies a more medium-term prospect (10 years or more). At present, these technologies are largely in the research and development phase across the regions interviewed.

Nevertheless, the potential of hydrogen in the region is clear. Ports, in their various configurations and economic activities, agree that the path toward decarbonization is crucial. The creation of state policies to support these efforts is of utmost importance.

5.1 Opportunities identified

5.1.1 Spain

5.1.1.1 Port of Vigo

The Port of Vigo is one of the leading ports on Spain's Atlantic coast, handling a variety of activities including automotive and fishing logistics. The port has taken bold steps toward sustainability by exploring hydrogen technologies. One key project is the **Julio Verne hydrogen refueling station**, which aims to reduce emissions from **high-usage vehicles such as trucks and auxiliary cargo-handling** equipment. The station, initially set up as a pilot, will serve as a foundation for scaling hydrogen adoption across the port's transportation network. Vigo's ambition extends to turning the port into a **green hydrogen production hub**, serving not only port operations but also surrounding industries, including the fishing and automotive sectors.

Another major initiative is the **Green Bay Vigo project**, focused on developing hydrogen-powered vehicles and energy systems for **maritime transportation**. Moreover, with the increasing emphasis on green supply chains, hydrogen could drive the region's **automotive and logistics sectors**.

Opportunities:

- **Hydrogen production and refueling infrastructure**: The port has the potential to become a significant hydrogen distribution hub for northern Spain. Hydrogen production by **electrolysis** (AEM or PEM) and refueling on-site are the main opportunities identified for this port.
- **Sustainable mobility and logistics**: The introduction of **hydrogen-powered port vehicles** and equipment could set an example for other ports, reducing the use of diesel and lowering emissions.

5.1.1.2 Port of Seville

As Spain's only inland maritime port, the Port of Seville offers a unique set of opportunities for hydrogen integration. The port is exploring **green hydrogen production** through the **Alener H_2 plant** and plans to use this hydrogen to power various port operations, including auxiliary systems and energy generation for vessels. The **Onshore Power Supply (OPS)** system under consideration could use hydrogen to supply vessels with clean energy, further decarbonizing the port's activities.

Opportunities:

- **Hydrogen-powered OPS system**: Using hydrogen to power vessels docked at Seville could make the port a leader in **clean inland port operations**.
- **Green hydrogen production hub**: The Alener H_2 plant positions Seville as a key **hydrogen producer** in southern Spain.

5.1.1.3 Port of Bilbao

The port has embraced hydrogen technology through multiple projects, including its involvement in the **Basque Hydrogen Corridor**. One of the standout initiatives is the **Petronor electrolyzer** project, which will produce **hydrogen and synthetic fuels**.

Another promising development is the **BilbOPS project**, which will **electrify port docks** while considering **hydrogen as an alternative** fuel for vessels.

Opportunities:

- **Hydrogen production and distribution**: Bilbao's role as a key player in the hydrogen economy is strengthened by its **synthetic fuel plant and electrolyzer.**
- **Green maritime mobility**: The **hybrid ferry** linking Bilbao and Portsmouth, **powered by hydrogen**, presents an opportunity for emissions reduction in maritime transport.

5.1.1.4 Port of Gijón

The **Musel Greenmet project**, scheduled to begin in 2025, aims to develop a **green hydrogen production plant**, with plans for expanding capacity and producing large amounts of **e-methanol and e-ammonia.** This project is expected to contribute significantly to regional decarbonization goals, **reducing up to 175.000 tons of CO_2 annually**. The port is also exploring the **Julio Verne project** to provide hydrogen refueling for vehicles and vessels, further cementing Gijón's role in hydrogen mobility and logistics.

Opportunities:

- **Hydrogen production and distribution**: Gijón's green **hydrogen production** initiatives will contribute to **reducing emissions from port activities and nearby industries**.
- **Hydrogen-powered logistics and mobility**: Hydrogen could **replace diesel in cargo-handling vehicles and trucks,** enhancing the port's sustainability profile.

5.1.2 Portugal

5.1.2.1 Port of Leixões

The port has significant potential to repurpose unused infrastructure from oil refineries for **hydrogen production and storage**. While the port's current focus is on **electrification** as the primary decarbonization strategy, the possibility of hydrogen integration in the future remains strong, especially for **heavy-duty port equipment** that cannot easily be electrified.

Opportunities:

- **Future hydrogen infrastructure**: Repurposing refinery infrastructure could facilitate large-scale hydrogen production and distribution.
- **Hydrogen in heavy equipment**: Leixões could pioneer the use of hydrogen-powered cranes and cargo handling systems.

5.1.2.2 Port of Douro

Primarily a fluvial port focused on tourism, the Port of Douro sees **limited industrial activity** but has started to consider hydrogen as part of its **sustainability strategy**. While no formal projects are underway, the port could explore hydrogen-powered vessels for its **tourism operations** and **energy generation for its port facilities**.

Opportunities:

- **Sustainable tourism**: Hydrogen-powered vessels could offer a clean alternative for the port's tourism operations.

- **Low-emission port infrastructure**: Hydrogen could be integrated into the port's facilities for energy generation, reducing reliance on fossil fuels.

5.1.2.3 Port of Viana do Castelo

The Port of Viana do Castelo is renowned for its shipbuilding and fishing activities. Although there are no active hydrogen projects at the port, hydrogen is being considered as part of the port's **long-term sustainability plans**. Hydrogen could play a role in reducing emissions from the shipbuilding industry and port operations, potentially positioning the port as a **green shipyard** in the future.

Opportunities:

- **Green shipbuilding**: Hydrogen could be integrated into shipbuilding processes, reducing emissions from this industrial activity.
- **Sustainable port operations**: Hydrogen-powered equipment could be used for cargo handling and port logistics.

5.1.3 France

5.1.3.1 Port of Brest

Brest has identified hydrogen as an element in its decarbonization strategy, particularly for **heavy-duty equipment** like cranes and handling machines, which currently rely on diesel. Additionally, the port is exploring **hydrogen bunkering services** for vessels, positioning itself as a hub for maritime hydrogen refueling in the region. Brest's strong commitment to sustainability is also reflected in its energy transition plans, which include large-scale electrification projects and potential hydrogen generators as an alternative to direct quay electrification.

Opportunities:

- **Hydrogen-powered heavy equipment**: Brest could become a leader in hydrogen-powered port logistics, using **hydrogen to power its cranes and handling equipment**.
- **Hydrogen bunkering hub**: The port's focus on hydrogen bunkering services could make it a central node in Europe's maritime hydrogen network.

5.1.4 Ireland

5.1.4.1 Port of Galway

Galway is an essential commercial port on Ireland's west coast, and it is currently in the process of expanding its infrastructure. While the port has not yet adopted hydrogen technologies, future projects could incorporate **hydrogen-powered port equipment and vehicles,** especially as the port grows to accommodate larger vessels and increased traffic. Hydrogen could also play a role in **wind turbine logistics**, as the port already handles equipment for renewable energy projects.

Opportunities:

- **Hydrogen-powered port expansion**: As Galway expands, hydrogen could be integrated into new infrastructure, including vehicles and equipment.

- **Hydrogen in renewable energy logistics**: Hydrogen could be used in the transportation and installation of wind turbines, contributing to Galway's role in the renewable energy sector.

5.2 Potential case studies for hydrogen integration

- *Port of Vigo (Spain)*

Project: Julio Verne hydrogen refueling station & Green Bay Vigo project

Description: The **Julio Verne Hydrogen Refueling Station** is a pilot project aimed at serving port vehicles and auxiliary cargo-handling equipment. Over time, this refueling station will scale to serve a broader fleet of hydrogen-powered vehicles within the port, including trucks and potentially ships. This station sets a benchmark for hydrogen refueling infrastructure in maritime environments.

The **Green Bay Vigo Project** focuses on developing hydrogen-powered vehicles and systems, creating an important case study for the use of hydrogen in both logistics and maritime operations. The port's proximity two industrial sectors like the fishing and automotive industries amplifies the potential of using hydrogen to decarbonize these sectors as well.

This case study will demonstrate the viability of **hydrogen in heavy-duty transport** and **port logistics**. Additionally, it provides insight into **multi-sector hydrogen integration**, showing how hydrogen can be applied beyond the port to serve surrounding industries.

- *Port of Seville (Spain)*

Project: Alener H_2 plant & hydrogen in Onshore Power Supply (OPS)

Description: The **Alener H_2 plant** at the Port of Seville represents a significant opportunity to study the impact of localized **hydrogen production in a major inland port**. The plant will serve not only port operations but also surrounding industrial sectors, reducing their reliance on fossil fuels. This **OPS** system would allow ships to run on hydrogen while docked, significantly reducing emissions from maritime vessels.

The **Ignis Project** complements this by converting **hydrogen into ammonia for easier storage** and transportation, highlighting the potential for **hydrogen derivatives in port applications**. The Port of Seville is a perfect case study for **hydrogen-powered port operations and logistics**, as well as the use of hydrogen in **inland waterways** and **industrial decarbonization**. Its focus on the integration of hydrogen into OPS systems also offers lessons for reducing emissions from ships while at berth, a critical area for improving air quality near ports.

- *Port of Bilbao (Spain)*

Project: Petronor electrolyzer & synthetic fuels plant

Description: Bilbao's **Petronor electrolyzer** is one of the most ambitious hydrogen projects in Spain, aiming to **produce green hydrogen** to serve both local industries and the broader region. The electrolyzer, together with the synthetic fuels plant, will produce **2000 tons of synthetic fuel annually**. This hydrogen will be used to produce synthetic fuels by **capturing CO_2** from refinery emissions, making Bilbao a hub for **clean energy production**.

Additionally, the **BilbOPS project** will focus on the electrification of docks while evaluating hydrogen's potential in powering the port's **onshore power supply (OPS)** systems. Hydrogen-powered ferries operating between Bilbao and Portsmouth are also being developed as a **maritime mobility case study**.

Bilbao offers a comprehensive case study for **hydrogen production, storage, and distribution**. Its integration of hydrogen into both **industrial processes** and **maritime transportation** makes it a key example of how ports can become major players in the hydrogen economy, contributing to decarbonizing multiple sectors.

- *Port of Gijón (Spain)*

Project: Musel Greenmet project & Julio Verne hydrogen station

Description: The **Musel Greenmet project** at the Port of Gijón will be pivotal in demonstrating how hydrogen can be produced and applied at an industrial scale in a port environment. The project includes a **green hydrogen production facility** and a **methanol plant**, expected to produce over 100,000 tons of e-methanol annually, with operations beginning in 2027. This facility will contribute to **sustainable fuel production** and reduce CO_2 emissions by up to 175.000 tons annually, making it a key component of Spain's national decarbonization strategy.

The **Julio Verne Hydrogen Station** will serve as a **refueling hub** for hydrogen-powered vehicles and vessels, highlighting the role of hydrogen in **port logistics** and **maritime transport**. Gijón's strong focus on the decarbonization of its bulk cargo handling operations, which are highly energy-intensive, makes it an ideal testing ground for **heavy-duty hydrogen-powered equipment**.

This project serves as a comprehensive case study in **hydrogen fuel production**, **distribution**, and **application in maritime transport**, with a special focus on bulk cargo handling, e-methanol production, and sustainable logistics.

- *Port of Leixões (Portugal)*

Project: Future hydrogen feasibility studies

Description: Although the Port of Leixões has not yet embarked on any large-scale hydrogen projects, it presents an interesting case study for **hydrogen feasibility**. Given its **industrial infrastructure**, particularly the presence of unused refinery equipment, Leixões could easily convert this infrastructure to serve **hydrogen production and storage** purposes. Feasibility studies are already underway to evaluate how hydrogen can be integrated into the port's logistics, with a special focus on **port machinery** that cannot be fully electrified.

This case study will explore how existing industrial infrastructure can be repurposed for hydrogen, making Leixões an example for other ports facing similar challenges of space and investment. Its transition from fossil fuels to hydrogen, especially in heavy equipment, will provide valuable insights into the **economic viability and technical feasibility** of hydrogen in ports.

- *Port of Brest (France)*

Project: REDII ports initiative & hydrogen bunkering

Description: The **Port of Brest** is actively involved in the **REDII Ports Initiative**, which explores the use of alternative fuels like hydrogen in port operations. Brest is a key player in the European hydrogen landscape, particularly with its plans to implement **hydrogen bunkering services** for vessels. Hydrogen bunkering is seen as a critical solution for **maritime decarbonization**, and Brest is poised to become a leader in this area. Additionally, Brest's **H2Port project** is exploring the use of hydrogen to power **heavy-duty port equipment** like cranes and mobile handling machines, which are typically powered by diesel.

Relevance: Brest's focus on **hydrogen bunkering** and the integration of hydrogen into **heavy equipment** makes it a valuable case study for ports looking to service hydrogen-powered ships while also decarbonizing their logistics operations. It provides lessons in overcoming the challenges of hydrogen infrastructure development, particularly in terms of safety and storage.

- *Port of Galway (Ireland)*

Project: Hydrogen integration in port expansion

Description: The Port of Galway is in the process of a significant **expansion**, and while it has not yet initiated formal hydrogen projects, there is considerable potential to incorporate hydrogen technologies into its new infrastructure. With the expansion allowing for larger vessels and more extensive port operations, Galway could introduce **hydrogen-powered equipment** and **refueling stations** to serve its growing fleet. Additionally, the port could explore hydrogen's role in the **renewable energy logistics** sector, given its involvement in wind turbine handling.

Relevance: As Galway expands, it provides a real-time case study of how **hydrogen infrastructure** can be integrated into new port developments. This is especially relevant for other ports considering hydrogen as part of long-term expansion plan.

While hydrogen presents numerous opportunities for decarbonizing port operations, it is important to consider the advantages that **electrification** offers as a more **viable short-term alternative**. From an **infrastructure** perspective, electrification is already far more mature. Most ports already have access to electricity grids, and the transition to electric-powered port equipment—such as cranes, vehicles, and auxiliary systems—requires less significant investment compared to the new infrastructure needed for hydrogen production, storage, and distribution.

Costs are also considerably lower for electrification, with reduced energy prices and fewer maintenance requirements compared to hydrogen technologies, which remain expensive due to their nascent state and the specialized infrastructure they demand. Furthermore, the **speed of implementation** favors electrification, as electric vehicles and systems are readily available and already in use in several ports, while hydrogen projects require long lead times for research, feasibility studies, and pilot programs. Finally, **safety** concerns around hydrogen, particularly its highly combustible nature, mean that electrification may be a safer option for ports in densely populated urban areas or near hazardous industrial activities.

The Atlantic region's ports are at different stages of hydrogen integration, yet all present unique case studies for exploring the application of hydrogen technologies in maritime environments. From **hydrogen production hubs** like Bilbao and Gijón to **hydrogen refueling infrastructure** in Vigo and Brest, these ports offer valuable lessons in the challenges and opportunities associated with hydrogen adoption. The inclusion of hydrogen in **onshore power supply** systems, **port logistics**, and **industrial decarbonization** makes these ports central to Europe's push toward a **hydrogen economy**. The feasibility studies underway in ports like Leixões and Galway provide further insights into how hydrogen can be scaled across diverse maritime settings.

These ports not only serve as laboratories for hydrogen technology but also demonstrate the **multifaceted role of hydrogen** in the transition to greener, more sustainable port operations. As infrastructure, safety, and cost challenges are overcome, these case studies will provide a roadmap for the **global maritime industry** to follow in the decarbonization of logistics and transport.

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