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H2YDEA

Boosting the hydrogen transition in the Atlantic Area ports

Deliverable D5.1.4

HYDEA case studies for Spain

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DOCUMENT INFORMATION

GRANT AGREEMENT NUMBER	EAPA_0057/2022
PROJECT ACRONYM	HYDEA
WORK PACKAGE	WP 5
RELATED ACTIVITY	ACT 1
DELIVERABLE REFERENCE	D5.1.4
TITLE	HYDEA case studies for Spain
STATUS	Published
AUTHOR(S)	Victoria León Carpintero
DELIVERY LEAD	ENERGYLAB
FILE NAME	D.5.1.4_HYDEA case studies for Spain

DOCUMENT HISTORY

VERSION	DATE	DESCRIPTION	REVIEWER
0.0	30/06/2025	Initial outline case study 1 and 2 by ITG	Victoria León
0.1	14/11/2025	Initial outline case study 3 by Ghenova	Ghenova Ingeniería
0.2	26/11/2025	First review case study 3	APS
0.3	27/11/2025	First release by Ghenova	Ghenova Ingeniería
0.4	11/02/2026	Revision of case study 1 and 2 by HIVE	Cian Moran
0.5	04/03/2026	Release of case study 1 and 1 by ITG	Victoria León
0.6	05/05/2026	Revision of case study 3 by FEM	Lennaig Mellaza
0.7	29/05/2026	Release of case study 3	Ghenova Ingeniería
1.0	15/6/2026	Final release	Victoria León

EXECUTIVE SUMMARY

The objective of this deliverable D5.1.4 HYDEA case studies for Spain, is to present the results of the 3 case studies developed in Spain.

The project's primary objective is to accelerate the adoption of hydrogen in Atlantic Area ports. Central to this effort is the development of a Decision Support Tool (DST), which will provide a framework for evaluating hydrogen applications and supporting strategic decision-making in various port scenarios. The DST will be informed by data gathered from comprehensive assessments of selected case studies across the Atlantic Area. Building upon an initial list of opportunities outlined by Project HYDEA (D.4.4.1), each partner has now committed to a specific case study, chosen to align with their expertise and the interests of the participating port.

This document contains the detailed description of the case studies to be developed in the ports of Spain, with contributions of Port of Sevilla, EVO, Port of Vigo and Energylab.

The main topics to be developed are the following:

- Dual combustion H_2/diesel for vessels.
- Retrofit of heavy duty vehicles - dumper.
- Onshore Power Supply for vessels (OPS).

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ABBREVIATIONS AND ACRONYMS

H_2 – Hydrogen
CO_2 – Carbon dioxide
ETS – Emissions Trading Scheme
EU – European Union
CAPEX – Capital Expenditure
OPEX – Operational Expenditure
GHG – Greenhouse gas
IMO – International Maritime Organization
FCEV – Fuel Cell Electric Vehicle

1 Case study #1: Dual combustion H_2/diesel for vessels

1.1 Introduction

At present, there is a commitment from the international community to reduce atmospheric emissions generated by human activity.

Transport accounts for 25% of global emissions (IEA, 2023) and maritime transport in particular accounts for 3% of global CO_2 emissions (Organisation, 2021). The decarbonisation of the maritime sector is particularly challenging, and their share of emissions could increase by up to 5-8% by 2050, due to the faster decarbonisation of other sectors compared to the maritime/naval sector (e.g. automotive) (Shipping, 2021).

One of the most recent commitments is the preliminary agreement reached by the member countries of the European Union regarding emissions produced in the maritime sector. This agreement covers two sections that are intended for ships with a gross tonnage of more than 5,000 tonnes:

- To include maritime transport in the emissions trading scheme (ETS), which came into force in January 2024. This agreement provides for a gradual introduction into the scheme between 2024 and 2027. It will be 100% applicable to journeys between ports within the EU and 50% applicable to journeys between EU ports and third countries. (European Climate Commission, n.d.)

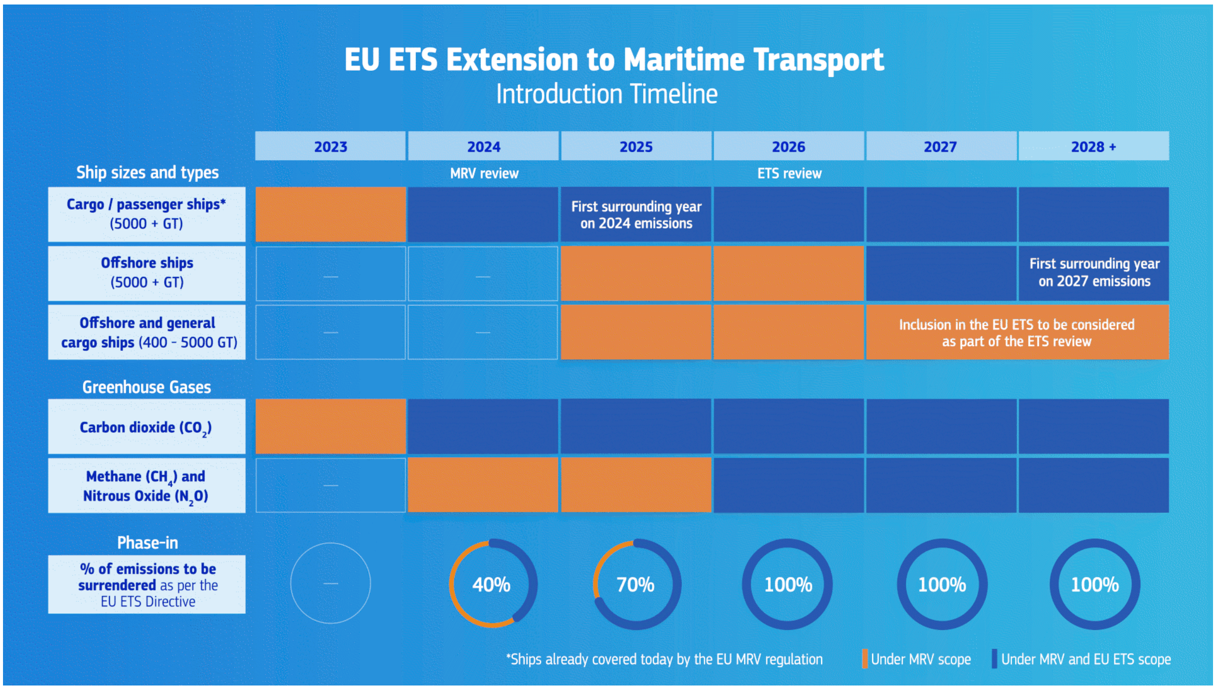

Figure 1 Emissions Trading Scheme (ETS) calendar

- A commitment to reduce emissions in the maritime sector, to be implemented between 2025 and 2050. The goal is to achieve an 80% reduction in emissions produced by the sector by 2050. The intermediate targets are as follows (European Council, 2023):

Emission reduction percentage (%)	Target year
2	2025
6	2030
14,5	2035
31	2040
62	2045
80	2050

Table 1. EU emissions reduction target

Given the global outlook and particularly these agreements within the European Union, it is worth examining the options currently available for achieving more sustainable and environmentally friendly maritime transport.

Vessels such as ferries and catamarans, which frequently operate on short and medium routes, traditionally rely on diesel engines, a fossil fuel whose emissions contribute to climate change and air pollution, affecting both marine ecosystems and the health of nearby communities.

This case study focuses on the transition of a catamaran or passenger ferry from a conventional diesel propulsion system to a diesel-hydrogen hybrid solution. The choice of hydrogen as an energy supplement is justified by:

- Its ability to reduce emissions in maritime applications where total electrification (batteries) is unfeasible due to limitations in range or infrastructure.
- The potential for local production using renewable energies (offshore wind, solar), taking advantage of the natural resources of coastal regions such as Galicia.
- Its technical flexibility, as it can be used in fuel cells (for electrical energy) or in mixtures with diesel (dual combustion), adapting to the needs of the vessel.

Furthermore, the adoption of this technology in passenger ships would not only contribute to environmental sustainability but could also serve as a pilot project to scale up its use in other fleets, positioning Atlantic ports as benchmarks in low-carbon maritime innovation.

1.2 Partners

This case study was prepared by two partners of the Hydea project: EnergyLab, acting as lead partner, and the Port of Vigo, as supporting partner.

EnergyLab specializes in research, development and innovation (R+D+i) activities focused on the production, storage, distribution and utilization of green hydrogen derived from renewable sources and waste recovery through biological and thermochemical processes. The centre is engaged across the entire hydrogen value chain, providing support to the industrial sector in order to optimize and advance these technologies. EnergyLab is actively involved in several regional, national, and European associations that foster the green hydrogen economy, including the Galician Hydrogen Association

(AGH2), the Spanish Hydrogen Association (AeH2), the Spanish Technological Platform for Hydrogen and Fuel Cells (PTEHPC), and the European Clean Hydrogen Alliance.

The Port of Vigo Authority, is a public body with its own legal personality and assets, integrated into Spain's state-owned port system. It operates under the Ministry of Transport and Sustainable Mobility through Puertos del Estado, which coordinates all Spanish ports of general interest. While enjoying managerial and operational autonomy, the Port aligns its activities with national regulations and strategic directives. The Port of Vigo plays a central role in the regional economy, moving over four million tons of cargo each year. It is recognised as a pioneer in the Blue Growth strategy, with more than 46 initiatives covering logistics, fisheries, shipbuilding, and blue energy. At the European level, it coordinates the port segment of the Energy Transition Partnership (ETP) and, since 2022, has led Pillar I of the Atlantic Strategy, "Ports as Gateways and Hubs for the Blue Economy," a mandate it will hold until 2026. In addition, through its collaboration with Energylab and its membership in the Galician Hydrogen Association (AGH2), the Port reinforces its leadership in sustainability and the Blue Economy.

1.3 Location

The Port of Vigo is a port within the Atlantic Ocean with a privileged geography, in a natural estuary with deep sheltered waters, operational 24/7/365 meant to be the economic-logistics centre of reference in the Spanish Northwest, managing goods with an industrial value over 12,000M€, serving an area of more than 8 million people.

The Port of Vigo handles over four million tons of freight annually, including containers, vehicles, and bulk cargo, alongside Europe's leading fishing port for fresh and frozen seafood. It also supports shipbuilding and repair activities and maintains strong logistics and intermodal connections with Europe, Africa, and the Americas.

Comprised by various terminals and sections, the section most relevant to this case study is the cruise terminal:

The cruise terminals have all the necessary services for embarking, disembarking, luggage handling and passenger assistance. They hold an annual average of 100 calls and 200,000 passengers, along with days when up to four large cruises arrive at once and more than 12,000 visitors pass through.

In accordance with the Law on State Ports and the Merchant Marine (Ley 2/2011), the Port Authority is responsible for planning, managing, and operating port facilities; overseeing maritime traffic and safety; granting concessions and authorizations; coordinating port services; administering the maritime-terrestrial public domain; maintaining infrastructure; managing environmental responsibilities; and promoting the development, competitiveness, and innovation of port activities.

1.4 Use cases that the case study covers

The use case that this case study covers is Hydrogen based fuels for vessels, shadowed in blue in the table below.

This use case covers the implementation of dual-fuel (H_2-diesel) engines for ships, specifically for short-haul passenger vessels. The technology is expected to reduce emissions and improve energy efficiency compared to traditional diesel engines.

USE CASES	DESCRIPTION
Import/Export of H_2, ammonia and methanol	Handling logistics, storage, transport and distribution for hydrogen-based products
H_2 storage, distribution and infrastructure: H_2 refuelling station	Development of storage and refuelling infrastructure for port operations
H_2 FC application for vehicles and equipment	Use of hydrogen fuel cells for port vehicles and equipment
Production of H_2 from marine and other renewable energies	Hydrogen production from renewable energy sources, such as offshore wind or solar power
Supply of alternative green fuels from H_2 (methanol, ammonia)	Production of green fuels (methanol, ammonia) from hydrogen for maritime decarbonization
Hydrogen based fuels for vessels	Use of hydrogen-based fuels (ammonia, methanol) for powering vessels.
H_2 based electrical power production for port consumption	Hydrogen used for electricity generation to meet port energy needs

Table 2 **Most relevant use cases of the project.**

1.5 Topic and objectives

In the field of emissions reduction/decarbonisation in maritime transport, there are various technologies and fuels that are candidates to lead the decarbonisation of the sector. Beyond the level of technological maturity, when discussing the maritime sector, it is important to consider the limiting factors when choosing the most appropriate option for the case in question. These limiting factors include, among others:

- High power demand: generally proportional to the size and gross tonnage of the vessel and its use.
- Autonomy: This factor is more dependent on the use of the vessel, although it is a very important factor to consider, nevertheless.
- Corrosive environment: There are solutions that are well suited to land-based applications but which, when working in a corrosive environment such as the marine environment, have significant additional costs due to the use of anti-corrosion alloys and materials and/or more frequent maintenance.
- Cost of the solution: The costs associated with its deployment can be a decisive limiting factor when adopting any technology, including initial investment costs or CAPEX, including the costs of the necessary infrastructure, possible economies of scale that can reduce the costs of the technology in the naval field, operating costs or OPEX, and competition with conventional technologies, among others.

Once the limiting factors to be considered have been mentioned, the option chosen in this case is to use hydrogen to partially replace diesel in combustion (dual combustion or dual fuel). The reasons for choosing this solution over others were:

- Minimum number of modifications to the vessel / lower CAPEX: Choosing this option, as in all cases, involves making a series of changes to the vessel (if installed on an existing vessel). However, due to the way it is implemented, these modifications are minimal in this case. What is needed to partially replace diesel with hydrogen is:
    - Changes to the engine: This is the most complex part. It involves installing injectors in the engine intake that mix hydrogen with the air entering the combustion chamber. This also involves installing associated electronics to regulate the amount of hydrogen to be injected at any given moment.
    - Hydrogen storage: In order to carry out the replacement, a tank or bottle rack must be installed on board to store the hydrogen to be injected. The dimensions of this tank will depend on the desired range of diesel for H_2 replacement.
    - Distribution: All intermediate elements between storage and hydrogen injectors.
- Widely developed technology: The level of maturity of this type of system is high and has already been tested by various companies, such as CMB Tech and Volvo Penta with the development of dual engines for use in the naval sector. Some examples of boats where this technology has been implemented include the Hydroville (CMB Tech, n.d.), the Hydrocat (CMB Tech, n.d.) and the Hydrotug (CMB Tech, n.d.).
- Performance level: When performing a partial replacement, the aim is to inject the necessary amount of hydrogen to achieve the same power and torque that would be achieved with 100% diesel use. Therefore, in terms of performance, there should be no difference compared to a conventional engine.

In addition to all the above, the main reason for making this change to the vessel is to reduce GHG emissions. Hydrogen combustion offers a clear advantage over fossil fuels because it avoids carbon emissions. However, for the hydrogen's promise of producing only water and heat to hold true, the air–fuel ratio must be carefully studied and controlled. Without proper management, the high-temperature environment can lead to the formation of NOx emissions, reducing the environmental benefit.

Considering these factors, the case study contemplates that the higher the level of diesel replacement, the greater the proportional reduction in harmful emissions produced during combustion.

In the case under study, the target replacement is 50%, so emissions based on carbon-based products would be reduced by this percentage.

1.5.1 Case study scenario

The technical and operational characteristics of the maritime mobility application for which the business case has been developed are described below.

The base case on which the business case is developed is the conversion to dual fuel (diesel – H_2) of a passenger ferry approximately 20 metres in length.

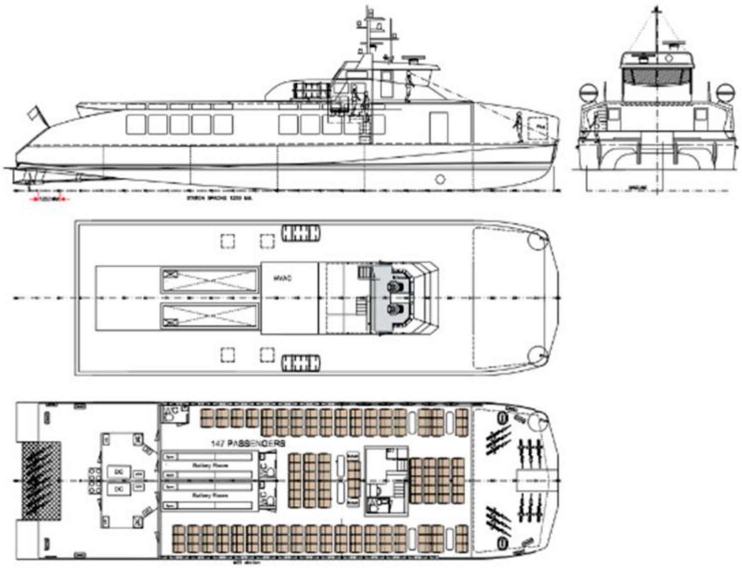

Figure 2 Passenger ferry drawing (source Nazemian, Amin & Boulougouris, Evangelos & Aung, Myo Zin. (2023). A Systematic Series Development and Calm Water Resistance Prediction for a Fast Catamaran Ferry Utilizing Machine Learning Tools.)

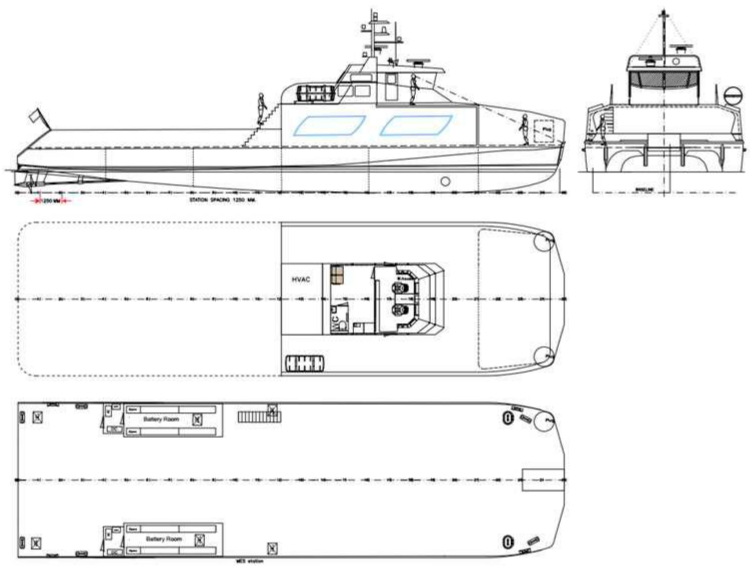

Figure 3 Passenger ferry drawing (source Nazemian, Amin & Boulougouris, Evangelos & Aung, Myo Zin. (2023). A Systematic Series Development and Calm Water Resistance Prediction for a Fast Catamaran Ferry Utilizing Machine Learning Tools.)

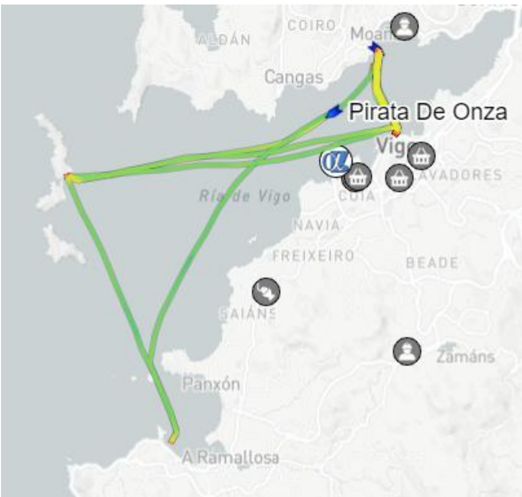

Figure 4 **Ferry's route (Source: MARINE TRAFFIC)**

This type of vessel is currently operated by various shipping companies, as is the case in the Vigo estuary (see Figure 4), where they run both estuary transport services between the towns of Vigo, Moaña and Cangas, and services to the Cíes Islands on the Vigo–Cies/Ons route, among others. The Vigo-Moaña route, which operates around 30 trips per day, has been selected as the base route due to its greater demand for autonomy.

The main details for the vessel are summarised below:

Number of passengers	150 (Vigo-Moaña) and 250 (Vigo-Cíes/Ons)
Engine	2 Volvo Penta D16-MH
Engine size (per engine)	16 L
Engine power (per engine)	551 kW
Engine consumption (per engine)	100 kg/h
Gasoil tank	4000 L
Gasoil consumption	250 g/kWh
Length of vessel	21,45 m
Beam	7,30 m

Table 3 **Passenger ferry technical details**

1.5.2 Indicators to be studied

The following key indicators will be assessed as part of this case study:

- Techno-economic indicators
  - Percentage of H_2 / diesel mix to feed the engine (2 scenarios considered, 30% and 50% of hydrogen of the total energy supplied)
  - Fuel storage: volume, mass and footprint of storage based on consumption and autonomy.

  - Redesign of the propulsion system to fit the H_2/diesel mix.
  - CAPEX, comparing the 2 scenarios at 30% and 50% of H_2 in the fuel mix.
  - OPEX, analysing the current state of the diesel market and comparing the 2 scenarios at 30% and 50% of H_2 in the fuel mix.

- Environmental indicators
  - Reduction of Green House Gases emissions.
  - Volume of water to produce the H_2 utilised in the vessel.

- Social indicators
  - Employment changes with the need of qualified staff to operate and maintain the system.
  - Improvement of life quality through improved air quality.

1.6 Case study implementation timeline

The implementation of the HYDEA case study at the Port of Vigo is planned over a five-year span, ensuring a viable transition toward dual-fuel hydrogen propulsion for short-distance passenger vessels.

The roadmap is structured into four progressive phases, from feasibility analysis to operational replication, and is aligned with EU maritime decarbonisation objectives and the HYDEA Decision Support Tool (DST).
This phased approach minimizes technical risks, allows progressive adaption of port infrastructure, and creates a replicable model for other Atlantic ports aiming to decarbonize their maritime transport.

PHASE	YEARS	KEY ACTIVITIES	MILESTONES	KPIs
1. Concept & Feasibility	1	- Operational and technical feasibility study (30 %–50 % H_2 substitution) - Assessment of local renewable H_2 production potential. - Safety and regulatory review.	- Feasibility and risk assessment reports. - Pilot operational plan. - Baseline emissions inventory completed.	Go/No-Go Investment decision; selection of optimal substitution scenario.
2. Detailed Design & Engineering	2	- Engineering design for retrofit and H_2 refuelling infrastructure. - Procurement of long-lead components. - Permitting and regulatory compliance. - Crew training	- Detailed design package approved. - EPC contract awarded. - Regulatory approvals secured.	Design validated.

3. Conversion & Infrastructure	3-4	- Retrofit of pilot ferry to dual-fuel (H_2–diesel) system. - Construction and commissioning of H_2 refuelling station. - Integration and operator certification.	- Retrofit completed. - H_2 infrastructure completed. - First operational trip in dual-fuel mode.	Verified operational performance; emissions reduction > 40%.
4. Pilot Operation & Replication Strategy	5	- Full pilot operation and performance monitoring. - Data collection (technical, economic, environmental). - Replication strategy for fleet expansion. - Guideline for other ports	- Final evaluation report delivered. - Business case for replication validated.	Sustained ≥50% CO_2 emissions reduction achieved and documented.

Table 4 Estimated timeline for implementation of dual combustion vessels.

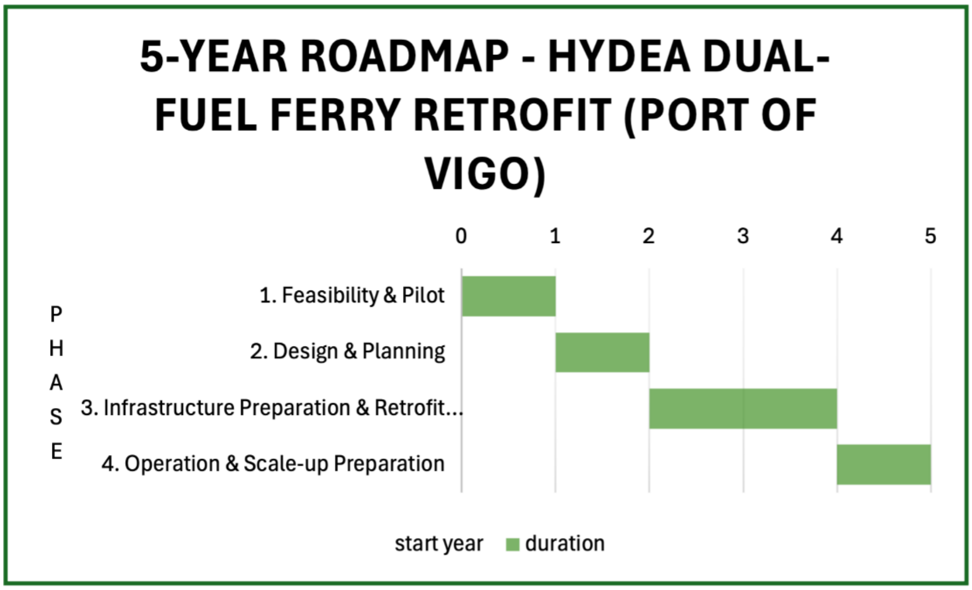

Figure 5 Roadmap for the implementation of dual-combustion vessels at Port of Vigo

1.7 Conclusions

The dual-fuel H_2–diesel approach represents a practical and scalable pathway for decarbonising short-distance maritime transport. This case study aims to analyse the effect of partial hydrogen substitution in terms of CO_2 emissions reduction while maintaining vessel performance and operational reliability.

2 Case study #2: Retrofit of heavy-duty vehicles - dumper

2.1 Introduction

Ports are critical logistics hubs in the global transport system, enabling the large-scale movement of goods and connecting international economies. However, these activities generate significant greenhouse gas (GHG) emissions and air pollutants due to the intensive use of diesel-powered machinery, including heavy-duty vehicles, cargo handling equipment, and support vessels.

Port decarbonization is therefore a strategic priority – not only to comply with climate targets but also to improve local air quality and public health while maintaining operational competitiveness.

This transition is supported by several regulatory and strategic frameworks:

- IMO & Paris Agreement: Net-zero GHG emissions by 2050, with a 20-30% reduction by 2030 (baseline 2008).
- EU Fit for 55: Mandates a 55% reduction in GHG emissions by 2030 (baseline 1990), including stricter fuel use in maritime logistics (FuelEU Maritime).
- Local impact: The maritime sector contributes ~3% of global CO_2 emissions; within ports, logistics operations represent around 60% of on-site emissions.

This case study focuses on converting diesel-powered dumpers (a high emission asset class used for bulk cargo handling) into dual-fuel vehicles aiming to:

- Reduce GHG emissions from intensive operations.
- Enable on-site green hydrogen use.
- Develop a scalable pathway for other heavy-duty port vehicles.

The study addresses the operational, economic, and technical aspects of implementing hydrogen dumpers, including cost analysis, storage and refuelling infrastructure, and potential impacts on port efficiency and productivity. The experience of this case provides a replicable model for other ports seeking to move toward sustainable and competitive logistics while contributing to global decarbonization goals.

2.2 Partners

This case study was prepared by two partners of the Hydea project: EnergyLab, acting as lead partner, and the Port of Vigo, as supporting partner.

EnergyLab specializes in research, development and innovation (R+D+i) activities focused on the production, storage, distribution and utilization of green hydrogen derived from renewable sources and waste recovery through biological and thermochemical processes. The centre is engaged across the entire hydrogen value chain, providing support to the industrial sector in order to optimize and advance these technologies. EnergyLab is actively involved in several regional, national, and European associations that foster the green hydrogen economy, including the Galician Hydrogen Association (AGH2), the Spanish Hydrogen Association (AeH2), the Spanish Technological Platform for Hydrogen and Fuel Cells (PTEHPC), and the European Clean Hydrogen Alliance.

The Port of Vigo Authority, is a public body with its own legal personality and assets, integrated into Spain's state-owned port system. It operates under the Ministry of Transport and Sustainable Mobility through Puertos del Estado, which coordinates all Spanish ports of general interest. While enjoying managerial and operational autonomy, the Port aligns its activities with national regulations and strategic directives. The Port of Vigo plays a central role in the regional economy, moving over four million tons of cargo each year. It is recognised as a pioneer in the Blue Growth strategy, with more than 46 initiatives covering logistics, fisheries, shipbuilding, and blue energy. At the European level, it coordinates the port segment of the Energy Transition Partnership (ETP) and, since 2022, has led Pillar I of the Atlantic Strategy, "Ports as Gateways and Hubs for the Blue Economy," a mandate it will hold until 2026. In addition, through its collaboration with Energylab and its membership in the Galician Hydrogen Association (AGH2), the Port reinforces its leadership in sustainability and the Blue Economy.

2.3 Location

The Port of Vigo is a port within the Atlantic Ocean with a privileged geography, in a natural estuary with deep sheltered waters, operational 24/7/365 meant to be the economic-logistics centre of reference in the Spanish Northwest, managing goods with an industrial value over 12,000M€, serving an area of more than 8 million people.

The Port of Vigo handles over four million tons of freight annually, including containers, vehicles, and bulk cargo, alongside Europe's leading fishing port for fresh and frozen seafood. It also supports shipbuilding and repair activities and maintains strong logistics and intermodal connections with Europe, Africa, and the Americas.

Comprised by various terminals and sections, this case study most relevant section will be the commercial quays:

The commercial quays in Port of Vigo are devoted to breakbulk and project cargo. The recent enlargement works developed have entailed an increase of the berthing line. The main traffic through these quays are granite, timber, minerals, scrap, and salt, besides liquid and solid bulk traffics namely cement asphalt, fuel for bunkering operations or chemical products.

In accordance with the Law on State Ports and the Merchant Marine (Ley 2/2011), the Port Authority is responsible for planning, managing, and operating port facilities; overseeing maritime traffic and safety; granting concessions and authorizations; coordinating port services; administering the maritime-terrestrial public domain; maintaining infrastructure; managing environmental responsibilities; and promoting the development, competitiveness, and innovation of port activities.

2.4 Use cases that the case study covers

The use case that this case study covers is H_2 FC application for vehicles and equipment, shadowed in blue in the table below.

This use case covers the implementation various H_2 based technologies in a heavy duty vehicle, a dumper in particular. The technology is expected to reduce emissions and improve energy efficiency compared to traditional diesel engines.

USE CASES	DESCRIPTION
Import/Export of H_2, ammonia and methanol	Handling logistics, storage, transport and distribution for hydrogen-based products
H_2 storage, distribution and infrastructure: H_2 refuelling station	Development of storage and refuelling infrastructure for port operations
H_2 FC application for vehicles and equipment	Use of hydrogen fuel cells for port vehicles and equipment
Production of H_2 from marine and other renewable energies	Hydrogen production from renewable energy sources, such as offshore wind or solar power
Supply of alternative green fuels from H_2 (methanol, ammonia)	Production of green fuels (methanol, ammonia) from hydrogen for maritime decarbonization
Hydrogen based fuels for vessels	Use of hydrogen-based fuels (ammonia, methanol) for powering vessels.
H_2 based electrical power production for port consumption	Hydrogen used for electricity generation to meet port energy needs

Table 4 Most relevant use cases of the project.

2.5 Topic and objectives

In efforts to decarbonise maritime activities, the vehicles used for bulk cargo handling in port operations play a crucial role in reducing the overall carbon footprint.

The intensive use of diesel in this kind of operations, especially in heavy machinery, lorries and generators, has significant impacts in terms of greenhouse gas (GHG) emissions, operating costs and long-term sustainability.

The transition from diesel to clean energy responds to the need to reduce emissions, comply with stricter regulations, improve operational efficiency and reduce costs, as well as meet the demands of investors and communities. This process is key to the sustainable development of the sector and its alignment with global climate change objectives.

The limiting factors of the implementation of H_2 technologies in this application include, among others:

- Corrosive environment: considering the closeness of the sea for these operations, we can assume that the vehicle will be exposed to a corrosive environment, which implies an additional cost due to the use of anti-corrosion alloys and materials and/or more frequent maintenance.
- Cost of the solution: The costs associated with its deployment can be a decisive limiting factor when adopting any technology, including initial investment costs or CAPEX, the costs of the necessary infrastructure, possible economies of scale that can reduce the costs of the

technology in the naval field, operating costs or OPEX, and competition with conventional technologies, among others.

This case study specifically analyses the transition of port dumpers, vehicles that are essential for bulk cargo handling, from conventional diesel engines to hydrogen-based propulsion systems. The choice of hydrogen as an energy vector is justified by:

- Its potential to decarbonise intensive operations where direct electrification is complex.
- The possibility of producing it locally using renewable energies, taking advantage of the port's privileged coastal location.
- Its versatility for dual applications (pure hydrogen or diesel-H_2 blends).
- Mature technology: hydrogen fuel cells have reached a high level of maturity and start to be commercially implemented in various applications, including heavy duty vehicles such as the Volvo HX04 and XCMG's EHSL552F.

Beyond all the benefits already mentioned, the primary motivation for modifying this vessel is emissions reduction. Unlike fossil fuels, hydrogen combustion generates only water and heat as by-products. By switching from diesel to hydrogen, greenhouse gas emissions can be significantly reduced.

2.5.1 Case study scenario

The case study focuses on heavy-duty dumpers operating within the Port of Vigo. These vehicles present high energy demand and intensive duty cycles, making them good candidates for testing hydrogen-based retrofitting strategies.

The study is built upon the operational profile of a standard heavy-duty dump truck currently running on conventional diesel, with the following technical parameters:

Parameter	**Value/Description**	**Relevance**
Vehicle Type	Heavy-Duty Dump Truck (40-50 Ton Class)	Represents the primary cargo-moving asset.
Engine Configuration	6-Cylinder Diesel Engine	Standard configuration for this class of vehicle.
Engine Power	≈300–450 Net Power (kW)	Range appropriate for high-load hauling.
Annual Operating Hours	≈4,000–5,000 hours	Accounts for multi-shift, continuous port operations.
Duty Cycle	Start-Stop/High-Load Cycle: Short-distance hauling, long idle times, and frequent high-torque requirements (lifting/dumping).	Critical for analysing engine efficiency across various fuel mixtures.

Fuel Consumption (Base)	≈30–40 Litres per hour (under load)	High consumption validates the economic benefits of fuel switching.

Table 5 **Dumper technical details**

The study assesses three technological pathways:

- Dual-fuel hydrogen-diesel conversion,
- Dual-fuel methanol-diesel, and
- Full hydrogen fuel cell electric vehicle (FCEV) replacement.

For each pathway, the project evaluates technical feasibility, infrastructure needs, performance impacts, and environmental benefits. This structured assessment supports evidence-based investment decisions for the port's decarbonization strategy.

2.5.2 Indicators to be studied

The following key indicators will be assessed as part of this case study:

- Techno-Economic Indicators:
  - Conversion scope and infrastructure requirements (refuelling systems, engine modifications).
  - Vehicle performance (power, torque, efficiency, range, refuelling time).
  - Durability, maintenance, and operational reliability
  - CAPEX (retrofit kits, refuelling station) and OPEX (fuel, maintenance, incentives).
  - Implementation complexity and scalability within the port fleet.

- Social Indicators:
  - Workforce impacts: skill development, specialized training needs.
  - Health and safety improvements: reduction of emissions and noise.

- Environmental Indicators:
  - Life cycle GHG emission reductions compared to diesel baseline.
  - Resource intensity (e.g., water consumption for H_2 production).
  - Air quality improvements in port surroundings.

2.6 Case study implementation timeline

The implementation roadmap for hydrogen dumper conversion at the Port of Vigo spans five years. The roadmap is structured into four progressive phases that integrate infrastructure development, fleet conversion, and scaling.

PHASE	YEARS	KEY ACTIVITIES	MILESTONES	KPIs
1. Feasibility & Pilot	1	- Baseline operational and emission data collection. - Risk assessment. - Pilot retrofit (1–2 dumpers).	- Feasibility report. - Safety training completed. - Pilot evaluation.	CO_2 baseline established; initial H_2 substitution achieved.
2. Design & Planning	2	- Engineering design for H_2 refuelling (350–700 bar). - Permitting and procurement. - Staff training.	- Design package approved - Engineering, Procurement and Construction contract awarded.	Regulatory and technical readiness achieved.
3. Implementation	2–4	- Hydrogen production and storage infrastructure. - Commission refuelling station. - Convert 30–50% of fleet.	- Station operational. - Fleet integration completed.	≥40% fleet-wide diesel reduction, ≥30% fleet-wide CO_2 reduction.
4. Evaluation & Scale-up Preparation	4–5	- Performance monitoring and feedback. - Cost-benefit and emission evaluation. - Roadmap for 100% fleet conversion.	- Final evaluation report. - Business case for scale-up validated.	Operational performance verified; scaling plan approved.

Table 6 **Total Estimated Dumper Project duration: 5 years**

This structured timeline allows the port to de-risk technological adoption, optimize investments, and set the stage for full fleet decarbonization. This 5-year roadmap outlines the phased implementation of hydrogen technologies for the port's dumper fleet, aligning with the port's decarbonization targets and the infrastructure roll-out planned under Proyecto Julio Verne.

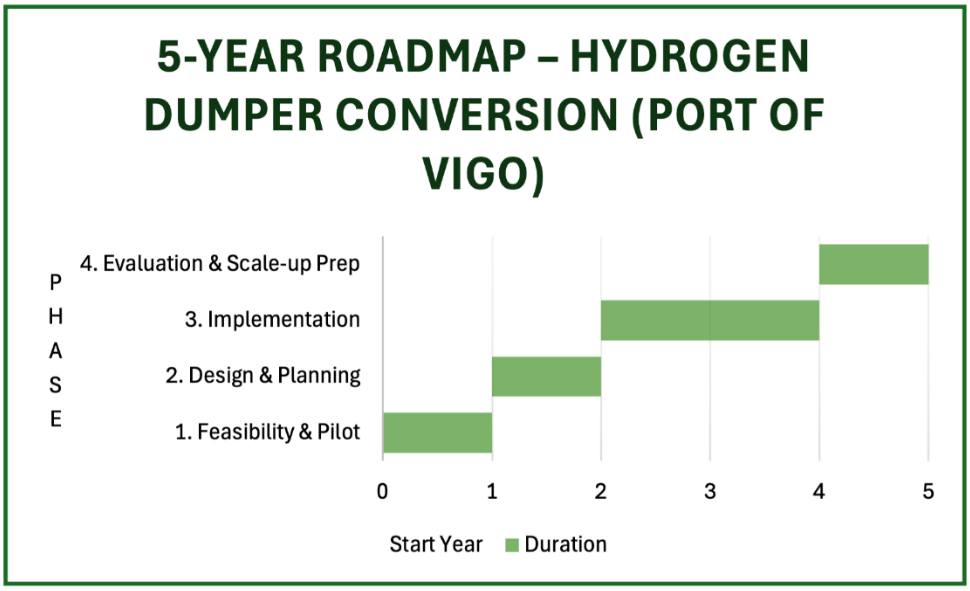

Figure 5 **Roadmap for the hydrogen dumper conversion at Puerto de Vigo**

2.7 Conclusions

The three scenarios evaluated for dumper conversion provide viable alternatives for decarbonizing bulk cargo handling within the Port of Vigo. This case study analyses the impact of these pathways: substituting diesel with hydrogen or methanol and replacing internal combustion engines (ICE) with hydrogen fuel cells.

3 Case study #3

3.1 Introduction

The HYDEA project aims at accelerating the deployment and integration of green hydrogen-based technologies with marine and other renewable energies in the Atlantic Area ports, with the ultimate goal of energy efficiency and contributing to a decarbonised energy economy.

This objective will be achieved through decision-making processes grounded in the specific strategic frameworks of each port. Consequently, each port authority will define case studies aligned with its operational requirements and long-term strategic ambitions.

For the Autoridad Portuaria de Sevilla (APS), the case study that has been selected contributes to reducing greenhouse gas (GHG) emissions and advancing the decarbonization of port operations. Building on initiatives already implemented at other quays, the proposed project focuses on deploying an Onshore Power Supply (OPS) system to deliver electrical power to vessels alongside. The installation is planned for the Muelle del Centenario, which primarily accommodates container vessels and ro-ro ships.

3.1.1 General Objective of the Case Study

The main objective of this case study is to equip the main docks of the Port of Seville with all the necessary infrastructure to enable the supply of electrical power to vessels berthed at the port, ensuring that this energy originates from renewable sources. These vessels will remain at berth with their auxiliary engines switched off, being fully powered by this new shore-side electricity supply system.

This document, as a preliminary step, analyses the different options that can be considered to define the origin of this electrical energy supply. Green hydrogen is explored as the primary energy vector for powering the OPS system, either through on-site production via electrolysis or through external supply. The use of hydrogen-based generation enables the OPS to operate independently from the conventional electrical grid, contributing to a truly renewable and low-carbon shore power solution.

3.1.2 Justification of the Initiative at the Port of Seville

As the only inland maritime port of general interest in Spain, the Autoridad Portuaria de Sevilla (APS) possesses unique operational characteristics that make it a strategic node for maritime–fluvial transport and logistical connections within Andalusia. However, this inland configuration also means that port operations take place in an urban environment, near residential areas, where emissions derived from port activities have a direct impact on local air quality.

Within the framework of the HYDEA project, the implementation of an Onshore Power Supply (OPS) system goes beyond a standard grid connection by integrating green hydrogen technologies as a clean energy source. As illustrated in Figure 1, the system is designed with a hybrid architecture that includes

a source selector switch. This allows the port to choose between the conventional electrical grid and a hydrogen-powered motor (or fuel cell) to generate the electricity required by the vessels.
This synergy between hydrogen and OPS is critical for achieving true zero-emission berthing. By utilizing green hydrogen to power the OPS, the port can:

- Decouple from the carbon intensity of the national grid, ensuring that the energy supplied to the ship is 100% renewable.
- Provide a flexible energy solution that can operate during peak demand or grid constraints.
- Drastically eliminate local pollutants: By replacing fossil-fuelled auxiliary engines with hydrogen-generated electricity, the system removes emissions of SOX, NOX and particulate matter directly protecting the health of the surrounding residential areas.

Furthermore, this initiative strengthens the port's commitment to the HYDEA project goals, positioning the Port of Seville as a pioneer in the transition toward a hydrogen-based maritime economy and reducing the environmental footprint on the Guadalquivir estuary.

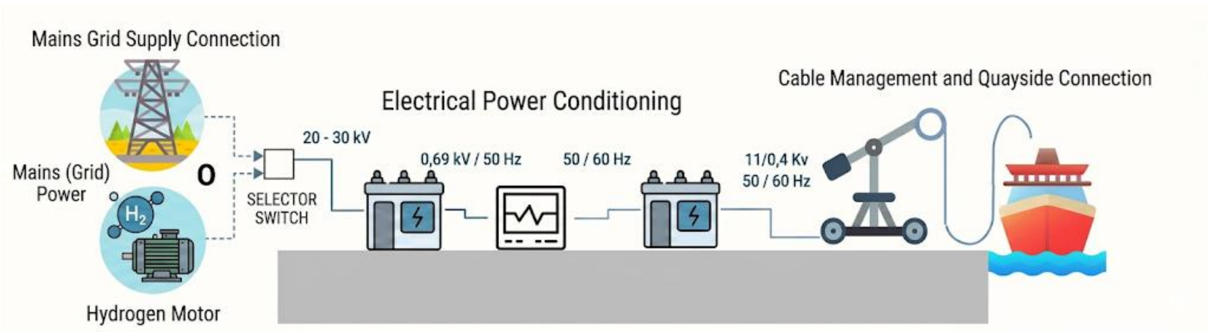

Figure 6: Shore-to-ship electrical connection scheme

Furthermore, this initiative enhances the port's environmental image among citizens and logistics operators, strengthening its commitment to sustainability and to reducing the impact of its operations on the urban and natural environment of the Guadalquivir estuary.

3.1.3 Alignment with European Decarbonization Policies

The proposed installation of an OPS infrastructure at the Port of Seville is fully aligned with European, national, and regional policies aimed at the decarbonization of maritime and port transport.

At the European level, the project aligns with the objectives of the European Green Deal and the EU Sustainable and Smart Mobility Strategy, which promote the electrification of ports and the reduction of maritime transport emissions. Likewise, the recently adopted FuelEU Maritime Regulation and Directive (EU) 2023/1804 on the deployment of alternative fuels infrastructure establish the mandatory implementation of OPS systems in major ports before 2030.

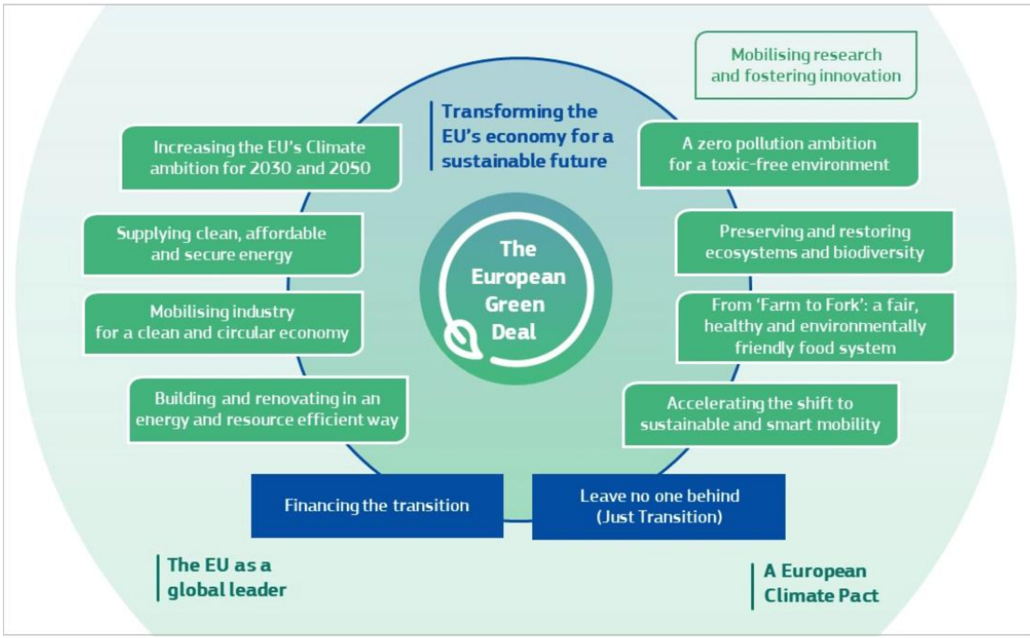

Figure 7: European Green Deal elements

At the national level, the initiative is consistent with Spain's Sustainability Strategy for the State Port System (Puertos del Estado) and the National Integrated Energy and Climate Plan (PNIEC) 2021–2030, which include the electrification of docks as a key measure for emissions reduction.

At the regional level, the project contributes to the objectives of the Andalusian Energy Strategy 2030, focused on increasing the share of renewable energy and improving energy efficiency in the transport and logistics sectors.

Overall, the implementation of the OPS system powered by green hydrogen in the Port of Seville, represents a holistic approach to port decarbonization. This strategy transcends a simple technical upgrade; it is a pioneer action deeply aligned with the HYDEA project's goals to integrate hydrogen-based technologies across all port operations. By combining shore-to-ship power with hydrogen, the port directly contributes to climate change mitigation and a just energy transition. This comprehensive alignment ensures that the decarbonization of the maritime–fluvial interface is supported by a local, sustainable energy carrier, reinforcing the port's role as a leader in the transition toward a hydrogen-based logistics ecosystem.

3.2 Case study description

Once the case study objective has been defined and framed within current energy policies, APS proposes three scenarios—employing different technologies and alternatives—for the OPS solution case study. The first scenario is based entirely on renewable hydrogen as the energy supply. The second scenario consists of a direct connection to the national electrical grid. The third scenario combines hybrid solutions, such as a photovoltaic plant as the primary electricity generator, complemented by battery systems and hydrogen engines to meet demand and cover peak loads.

3.2.1 Location

The case study is located at Muelle del Centenario, within the Port of Seville, in southern Spain.

The area considered in this study is situated within the state-owned land managed by the Port of Seville, located in the municipality of Seville, in the Province of Seville, Andalusia, Spain.

Figure 8: Port of Seville location

Managed by the Port Authority of Seville, the Port of Seville is Spain's only inland seaport. It is situated within one of the country's main metropolitan areas, with more than one and a half million inhabitants in its surroundings, and at the core of the cargo-generating region of southern Spain. It is a fully multimodal port with both maritime and land connections and, across its 850 hectares, it offers extensive space for logistics and industrial development.

It is a strategic hub for the European Union and comprises five concessioned port terminals and three public quays, more than 4,000 meters of berthing line, one million square meters of warehouse space, and a cruise terminal located in the city centre.

The scope of the case study is limited to the area of Muelle del Centenario within the Port of Seville, as shown in the following figure.

This river terminal has two berthing lines of 728 meters, a surface area of 179,889 square meters, and a draft of 7 meters. It features 78 connections for refrigerated containers and a maximum capacity of 373,000 TEUs/year.

Total surface area	179,889	m2
Railway (5 tracks of 750m)	28,145	m2
Maximum capacity	373,000	TEUs/year
Berthing lines	1	
Linear meters	728	m
Draft	7	m
Ro-Ro ramps	1	
Reefer connections	78	
Offices	531	m2
Repair and maintenance warehouse	392	m2

Table 7: TMG Key Data

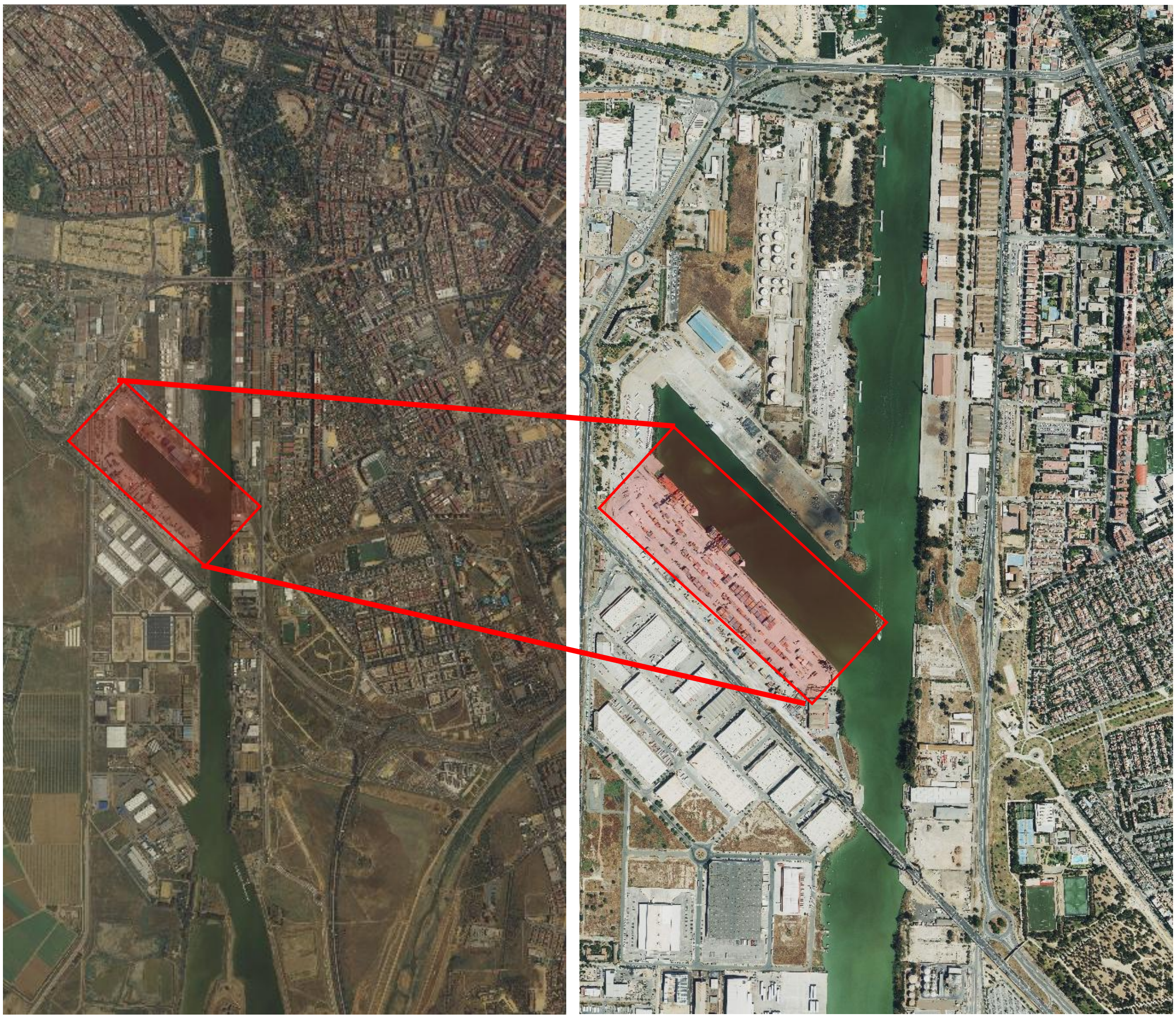

Figure 9: Location of Muelle del Centenario

The design of the infrastructure represents one of the case study's main challenges. Implementing an OPS system requires adequate space for electrical equipment, power conversion systems, and — in the case of hydrogen-based solutions — dedicated areas for gas storage, compression, and handling.

Key aspects to consider are:

- Availability of space within the port area for the installation of electrolyzers, compressors, storage tanks, engines, and auxiliary systems.
- The handling, storage, and distribution of compressed or liquid green hydrogen involves specific safety risks that must be addressed in the project design. These include the risk of leaks in high-pressure systems, explosion hazards in enclosed spaces, and compliance with ATEX zoning regulations. ISO/TR 15916, IEC 60079)
- Proximity to the quay and accessibility for medium-voltage cabling and shore-to-ship connections.
- Integration with existing infrastructure, minimizing interference with ongoing port operations.

- Compliance with industrial safety regulations, particularly in hydrogen handling (ATEX-rated zones, ventilation systems, leak detection, and safety distances).
- For photovoltaic integration, assessment of rooftops, open yards, or adjacent plots with potential for solar array deployment, considering solar irradiation and shading conditions within the port environment.

3.2.2 Objectives and Scope

The implementation of an OPS system at the Port of Seville, in any of the configurations analyzed, will enable significant progress toward the decarbonization of port activities and the modernization of its energy infrastructure.
Below are the main expected outcomes in terms of sustainability, energy efficiency, and the port's strategic positioning.

3.2.2.1 Reduction of Emissions

The principal benefit derived from commissioning the OPS system is the **elimination of emissions** produced by **vessels' auxiliary engines** during their stay in port, contributing directly to **improved air quality** and a **lower carbon footprint** for port operations.

Expected results include:

Reduction of CO_2, NO_x, SO_x, and particulate matter (PM) emissions during vessel berthing operations.

Reduction of environmental noise and vibration, improving working and living conditions for port personnel and nearby residents.

Achievement of a significant reduction of operational emissions if powered through renewable hydrogen or photovoltaic-based energy sources.

According to standard maritime auxiliary engine emission factors, replacing conventional onboard generation with OPS power could prevent 2.594,38 tonnes of CO_2 annually [Huella de Carbono: Puerto de Sevilla. Año 2019].

3.2.2.2 Maritime Transport Decarbonization

The OPS solution serves as a strategic measure for maritime decarbonization, aligned with European directives such as: Regulation (EU) 2023/1805 – FuelEU Maritime, and Directive (EU) 2023/2413 – Alternative Fuels Infrastructure Regulation (AFIR), which progressively mandate the provision of **OPS connections** in all major **TEN-T network ports**.

This project positions the **Port of Seville** at the **forefront of the European port energy transition**, integrating **clean technologies** that can be expanded to future applications such as:

Use of renewable hydrogen as a common energy vector for vessels, port vehicles, and terminal machinery.

Cogeneration and trigeneration systems based on hydrogen engines for building climate control, reducing fossil fuel dependence.

Development of industrial synergies with nearby companies engaged in hydrogen production, storage, and distribution.

This comprehensive strategy supports the creation of a **sustainable energy ecosystem** around the port, strengthening its role as a **low-carbon logistics node**.

3.2.2.3 Promotion of Renewable Energy and Hydrogen Utilization

Adopting an OPS configuration powered fully or partially by renewable sources will drive the integration of photovoltaic generation and green hydrogen as key components of the port's future energy mix.

Expected benefits include:

Increased renewable energy share in the port's total electricity consumption.

Advancement of technological expertise and local know-how in hydrogen generation, storage, and fuel cell or combustion applications.

Creation of a modular and replicable infrastructure, enabling expansion to additional port services and facilities.

Moreover, the dual use of hydrogen — as a **fuel for power generation** and as a **thermal or mobility vector** — will facilitate the transition toward an **intelligent port energy model**, capable of optimizing power flows through **digital technologies and distributed storage systems**.

3.2.3 Identified Challenges

3.2.3.1 Hydrogen logistics

The **production, storage, and distribution** of hydrogen constitute a critical challenge — particularly in the cases involving **external supply (tube trailers)** or **on-site production**.
Main challenges include:

- Logistical planning to ensure continuous and safe hydrogen supply in coordination with H_2 providers.
- Determining the required storage capacity based on the expected electrical demand and vessel berthing frequency.
- Designing safe unloading and connection systems for hydrogen modules, optimizing both operational efficiency and safety.
- In Subcase A (external supply): accounting for transport-related costs and carbon footprint of delivered hydrogen.
- In Subcase B (on-site production): ensuring availability and management of demineralized water for electrolysis, including environmental considerations.

Furthermore, the economic and regulatory feasibility of incorporating a hydrogen refuelling facility for road transport fleets will be evaluated. Such integration could enhance the overall value proposition of the project, improve infrastructure utilisation rates, and contribute to the development of a broader hydrogen ecosystem within the port and its surrounding logistics area.

3.2.3.2 Electrical and Operational Regulations

The deployment of an OPS system must strictly comply with national and international standards governing shore-side electricity supply to vessels, particularly the IEC/ISO/IEEE 80005 series.

Regulatory and operational challenges include:

- Electrical and frequency compatibility between the port system and the various types of vessels (50 Hz / 60 Hz).
- Power management and coordination with the grid operator in the 100% grid-supplied scenario (Case 2).
- Permitting procedures and authorizations from relevant authorities, including the Port Authority, Maritime Captaincy, Industry Directorate, and electricity distributor.
- Safety certification of hydrogen installations, ensuring compliance with ATEX standards and the Spanish Regulation on the Storage of Chemical Products (RAPQ).
- Development of operation and maintenance (O&M) protocols, both for electrical systems and hydrogen production/combustion equipment.

For hybrid or off grid, the main challenge is the implementation of an Energy Management System (EMS) capable of dynamically prioritizing power sources according to availability and demand, while maintaining grid stability and power quality.

3.2.3.3 Preliminary Cost Considerations

From an economic standpoint, the main challenges relate to both the **initial investment (CAPEX)** and the **operational costs (OPEX)** associated with each technology.
Key cost drivers are:

- Cost of renewable hydrogen, whether purchased or produced on-site (dependent on electricity price and electrolyzer utilization factor).
- Investment in electrical and power generation equipment: transformers, converters, hydrogen engines, storage systems, and batteries.
- Civil works and integration costs, adapting port infrastructure and connection systems.
- Maintenance and component replacement, such as electrolyzer stacks or compressor units.

- Anticipated evolution of energy prices and CO_2 cost (EU ETS impact), directly influencing long-term competitiveness.

Although a detailed financial assessment is pending, it is expected that hydrogen-based alternatives will involve a higher initial investment, but offer significant potential for emission reduction and energy independence in the long term.

3.2.4 Partners

-AUTORIDAD PORTUARIA DE SEVILLA (APS): is the owner and promoter of this case study. As the managing body of the Port of Seville — the only inland maritime port of general interest in Spain — APS leads the strategic decision-making process for the implementation of the OPS system at Muelle del Centenario and is responsible for the overall coordination of the case study within the HYDEA project framework.

-CMA CGM Group is a global shipping company committed to freight transport lines from Seville to Africa and the Canary Islands, based at Centenario Quay in the Guadalquivir Maritime Terminal.
As a global player in maritime, land, air, and logistics solutions, **CMA CGM** has been heavily investing in decarbonizing its operations. A pioneer in the use of biofuels and the acquisition of LNG-powered vessels, **CMA CGM** continues to optimize operations, diversify its energy matrix, and support innovation to achieve carbon neutrality by 2050.

To meet customer expectations, particularly regarding emissions in their supply chains, **CMA CGM** has developed low-carbon transport solutions and engages in decarbonization projects beyond its vessels, including ports where it operates. **CMA CGM** promotes the use of low-carbon fuels such as second-generation biofuels and offsets its emissions. This also includes the use of electrical power for vessels docked in ports, reducing the operation of auxiliary engines and thereby lowering GHG emissions, pollutants, and noise.

Boluda Corporación Marítima is a shipping company originating in 1837 with Naviera Fos. Today, it is one of the leading global maritime service companies, with operations in Europe, West Africa, Cape Verde, the Indian Ocean, and Latin America.

Through **Boluda Maritime Terminals,** they participate in port logistics and co-manage the **TMG Guadalquivir Maritime Terminal** (50% ownership with CMA CGM), serving transport lines to Africa and the Canary Islands from Seville.

Specializing in the transport of perishable goods, the terminals feature refrigerated connections to maintain optimal temperatures for both fresh and frozen cargo.

-GHENOVA, a consulting and engineering company, has been participating in and leading OPS projects since 2017. It began as a partner in the OPS MasterPlan led by OPPE – Puertos del Estado, conducting technical and economic feasibility studies for the implementation of OPS systems for cruise ships and RO-ROs in the ports of Cádiz, Huelva, and Seville.

In recent years, primarily driven by the EU “Fit for 55” package of measures, many ports have accelerated their investment and financing programs related to OPS. As a result of this demand, **GHENOVA** has been awarded the following public tenders**:**

- Drafting of the preliminary or basic construction project for a substation at the Port of Málaga and the implementation of OPS (Onshore Power Supply) systems to provide electrical power to ships in port (Cold Ironing), contributing to the decarbonization of the Port of Málaga.
- Technical assistance for the development of electrical supply to vessels (OPS) at Muelle Juan Carlos I Sur (Berth 0), Berths 1 to 5 to Tangier, and Berth 6 to Ceuta at the Port of Algeciras.
- Technical assistance for the development of electrical supply to vessels (OPS) at the Port of Tarifa.
- Technical assistance for the development of electrical supply to vessels (OPS) at Muelle Príncipe Felipe and the initial section of the Dique Norte at the Port of Algeciras.
- Technical assistance for the development of electrical supply to vessels (OPS) at Muelle Isla Verde Interior at Port of Algeciras.
- Technical assistance for the development of electrical supply to vessels (OPS) at Berths 7b and 8 to Ceuta, Port of Algeciras.
- Drafting of the execution project for the OPS system to supply electrical power to container ships at Muelle Transversal de Costa for Port of Valencia.
- Drafting of the preliminary project for the electrical supply network to container ships at Muelle Ferrazo for the Port Authority of Vilagarcía de Arousa.
- Drafting of the preliminary project for the electrical supply network to cruise ships at Muelle Espigón Exterior, Port of Ferrol, for the Port Authority of Ferrol and San Cibrao.
- Drafting of the execution project for the OPS system to supply electrical power to passenger vessels at the quays of the Puerto Exterior de Ciutadella de Menorca, Balearic Islands.
- Drafting of the preliminary project for the electrical supply network to cruise ships at Muelle de Tablada at Port of Seville, for the Port Authority of Seville.

-CLANTECH, an engineering company specialized in designing on-site gas generation plants, operates internationally with a presence in multiple countries and over 1,000 clients across approximately 19 countries.
In recent years, CLANTECH has executed the following notable projects:

- HRS TMB – BARCELONA: Located in the industrial heart of Barcelona, the hydrogen generation and dispensing station designed and integrated by Clantech for Iberdrola is one of the largest of its kind in the world.

- HRS 3EMOTION – DENMARK: Clantech was subcontracted for the design and integration of a hydrogen refueling station, which was constructed, commissioned, and delivered by the end of 2019.
- HRS MANOTERAS – MADRID: Clantech inaugurated Spain's first high-pressure hydrogen refueling station, enabling the complete refueling of a hydrogen vehicle (700 barg) in under 5 minutes.
- HRS – CHILE: The installation supplies two transport forklifts at 350 barg, dispensing a total of 2 kg of green hydrogen per day, generated using renewable energy from a photovoltaic facility located at the Las Tórtolas mining plant.

3.2.5 Proposed Case Studies

Once the project objectives are established and its alignment with current energy policies has been defined, APS propose three case studies employing different technologies and configurations for the OPS solution:

1. **Case 1 – 100% Hydrogen-Based Supply**
2. **Case 2 – 100% Grid-Connected Supply**
3. **Case 3 – Hybrid Configuration (Photovoltaic + Batteries + Hydrogen Engine)**

These configurations are designed to evaluate alternative pathways to achieve a technically and economically viable shore power system for the Port of Seville.

3.2.5.1 Case 1: 100% Hydrogen-Based Power Supply

The primary objective of this scenario is to assess renewable hydrogen as the energy vector for generating the electrical power required to feed the Onshore Power Supply (OPS) system to be installed in the port — that is, proposing a stand-alone (off grid) cold ironing solution based on hydrogen combustion.

As it may initially seem challenging to meet the full electrical demand using hydrogen alone, alternative scenarios are also considered to provide comparative and complementary insights. Two subcases are analyzed, differentiated by the origin of the hydrogen, i.e., whether it will be produced on-site within the port facilities or supplied by an external provider.

3.2.5.1.1 Subcase A: Hydrogen Supply via External Purchase

In this first subcase, the configuration is designed assuming hydrogen will be supplied by an external producer and transported to the port via **tube trailers**. The port installation will include the necessary equipment for **hydrogen storage** and the associated distribution infrastructure. Likewise, electricity generation from hydrogen will be assessed through a detailed study of the different generation technologies available, including Proton Exchange Membrane (PEM) fuel cells, Solid Oxide Fuel Cells (SOFC), hydrogen-fuelled internal combustion engines, and hydrogen-fired gas turbines, evaluating their energy efficiency, capital and operating costs, infrastructure requirements, reliability, and suitability for the specific needs of the facility.

Main advantages identified are:

- Simplified implementation, as no local production infrastructure is required.
- Reduced initial CAPEX and faster deployment timeline.
- Higher operational flexibility to adapt to fluctuating power demands.

Considerations and limitations of this solution are:

- The high electrical power demand implies a substantial hydrogen consumption, with significant fuel and logistics costs associated with external supply.
- Dependency on hydrogen availability and price from external markets.
- Safety and permitting requirements related to handling and unloading of compressed hydrogen modules.
- The need to allocate suitable space for temporary hydrogen storage and the associated logistics operations may constitute an additional constraint within the port area.
- The continuity of the electricity supply will depend on the reliability of the hydrogen supply chain; therefore, appropriate procurement and contingency mechanisms will be required to minimise the risk of supply disruptions.

3.2.5.1.2 Subcase B: On-Site Hydrogen Production

In this scenario, hydrogen is generated **locally** via an **electrolyzer** installed within or adjacent to the port area. This option involves a larger installation footprint compared with Subcase A, as it requires the inclusion of **electrolyzers, compressors, purification and auxiliary systems**.

Main advantages identified are:

- Full independence from external hydrogen logistics.
- Potential integration with renewable power sources (e.g., photovoltaics) for producing green hydrogen.
- Greater long-term sustainability and potential for energy self-sufficiency.

The challenges identified for the this solution are:

- Higher CAPEX due to production infrastructure.
- Need for demineralized water supply and treatment systems.
- Continuous monitoring and maintenance of electrolyzer stacks and auxiliaries.
- Compliance with ATEX safety standards and hydrogen handling regulations.

3.2.5.2 Case 2: 100% Grid-Connected Power Supply

This case study will provide the basis for the introduction of hydrogen as an alternative fuel for the generation of the electricity required by the port facilities. It represents a key enabling measure and a fundamental element in the port's decarbonisation strategy. Although the port currently procures electricity from renewable sources through its electricity supplier, the implementation of hydrogen-based power generation will further enhance energy independence, increase system resilience, and contribute to the long-term transition towards a zero-emission energy model.

In this scenario of business as usual, the OPS is powered **directly from the existing electrical grid**, connected through the **local distribution network** managed by the utility company.

Currently, all electricity supplied from the grid to APS is certified as originating from renewable energy sources.

The system will include the **transformers and converters** required to adapt the supply to the voltage and frequency levels demanded by vessels, in full compliance with **IEC/ISO/IEEE 80005** standards governing shore-to-ship electrical systems.
Main advantages identified are:

- Technical simplicity and high supply reliability.
- Predictable operational costs and low maintenance requirements.
- Easier integration with the existing port electrical infrastructure.

The limitations identified for this solution are:

- Lower decarbonization potential, as emissions depend on the current electricity mix.
- Greater dependency on grid operators to manage peak demand.
- Limited contribution to the development of renewable energy generation capacity within the port.

3.2.5.3 Case 3: Mix project: photovoltaic, batteries and hydrogen engine

In this configuration, the OPS system is based on a **photovoltaic (PV) plant** covering most of the port's electricity demand, supported by a **hydrogen engine** providing backup power during **consumption peaks** or **extended low-generation periods**.

Key benefits are:

- Higher penetration of renewable energy while ensuring continuous supply reliability.
- Significant reduction in GHG emissions and improved energy autonomy.
- Modular and scalable architecture adaptable to evolving port energy needs.

Main challenges are:

- Higher system complexity, both in investment and in energy management.
- Need for a robust Energy Management System (EMS) to optimize generation and consumption.

Comparing the three case studies will enable a **comprehensive technical and economic assessment** of the different OPS supply alternatives for the Port of Seville, based on criteria such as:

- Degree of **decarbonization** achieved.
- Levelized Cost of Energy (LCOE).
- **Supply reliability** and system redundancy.
- Operational and regulatory feasibility.
- **Replicability potential** in other port facilities.Identify Challenges

3.2.6 Implementation Phases

The implementation of the OPS system at the Port of Seville is conceived in **two sequential phases**, aimed at ensuring a **progressive, safe, and economically efficient deployment**, fully aligned with maritime traffic evolution and European regulatory requirements.

This phased approach will allow commissioning of an **initial operational facility** while continuing the technical development of hydrogen technologies and securing **additional financing** to reach full capacity.

The implementation strategy is structured around the following key principles:

Scalability: Design a modular infrastructure enabling incremental capacity expansion without duplicating investments.

Technological flexibility: Allow future integration of new energy sources (green hydrogen, storage systems, photovoltaics) without altering ongoing port operations.

Regulatory alignment: Ensure full compliance with IEC/ISO/IEEE 80005 standards and European decarbonization mandates for maritime ports.

Resource optimization: Distribute investment and technical complexity across both phases to minimize risks and facilitate access to public or private funding.

3.2.6.1 Phase I – Initial Installation (4 MVA)

The **first phase** consists of commissioning an OPS system with a **1 MVA capacity**, sufficient to supply the first designated berths and to **validate the system's operational performance**.

Main objectives:

Deploy the primary electrical infrastructure, including transformers, medium-voltage switchboards, frequency converters, and shore connection systems.

Develop the base control and energy management platform (EMS) to enable autonomous or hybrid operation with different energy sources.

Depending on the selected case study, incorporate an initial generation system — whether grid-connected, photovoltaic, or hydrogen-powered — dimensioned for the 1 MVA demand.

Execute all required civil works and basic infrastructure, such as trenches, foundations, cabling, power connections, and safety zones.

Obtain the necessary technical and environmental permits for OPS operation and, where applicable, for hydrogen handling and storage.

Upon completion, **Phase I** will deliver a **fully operational OPS facility**, compliant with international standards, allowing real-world validation of the equipment and energy model. The collected data on **consumption, efficiency, and performance** will serve as a foundation to optimize design and scaling during the second phase.

3.2.6.2 Phase II – Expansion to Full Capacity (2 MVA)

The **second phase** will scale up the total OPS capacity to **2 MVA**, meeting the electricity supply needs of the main berths and ensuring full compliance with the **European OPS mandate** for larger vessels and higher power requirements.
Main objectives:

- Double the installed capacity, adding a second modular 1 MVA block integrated with the existing system.
- Integrate additional energy sources based on the selected configuration:
  - Introduction of photovoltaic plant with higher installed capacity.
  - Installation of battery energy storage systems (BESS) to manage load peaks and enhance supply stability.
  - Extension of the hydrogen generation system, either through internal combustion engines or on-site electrolyzer production.
- Optimize energy management and predictive maintenance via advanced monitoring and digital control systems.
- Assess the feasibility of complementary applications, such as cogeneration-based HVAC or hydrogen refueling points for port logistics.

After completion of **Phase II**, the OPS infrastructure will cover the **entire expected electrical demand (2 MVA)**, achieving full regulatory compliance, further reducing emissions, and consolidating the Port of Seville as a **sustainable and low-carbon energy hub**.

3.2.7 Implementation timeline

A detailed timeline for the implementation of the case study is provided below, in line with the port's expectations and objectives.

This timeline includes each stage of the project, highlighting key milestones and the expected completion dates.

The following phases are anticipated:

- Initial case study definition.
- Preliminary study: Initial research and data collection.
- Preliminary design and planning: Technical design and definition of various alternatives. Final decision on the alternative to be implemented.

Construction-level design and planning: Detailed technical design of the required infrastructure and obtaining regulatory approvals.

Management system implementation: Development of the infrastructure management system according to applicable regulations.

Construction: Development of infrastructure and deployment of hydrogen technologies through construction contracting.

Evaluation and reporting: Monitoring performance and analyzing feedback to assess the operational effectiveness of the deployed technology.

ITEM Nº	PHASES	DURATION	START DATE	END DATE
1	Initial case study definition		15/10/205	15/11/2025
2	Preliminary study: Initial research and data collection	1 month	15/11/2025	15/12/2026
3	Preliminary design and planning	3 months	15/12/2026	15/03/2026
4	Construction-level design and planning	6 months	15/03/2026	15/09/2026
5	Management system implementation	9 months	15/09/2026	15/06/2027
6	Construction	18 months	15/06/2027	15/12/2028
7	Evaluation and monitoring reports	Ongoing	15/12/2028	

Table 8: Milestones and Implementation Schedule of the Case Study – OPS Muelle del Centenario

CONTACT DETAILS

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