

# Study on the development of cold ironing at the Port of Mallorca

## Deliverable 6.4

Month 36



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## Preface

The aim of **GREEN HYSLAND** is to **deploy a Hydrogen ecosystem on the island of Mallorca**. The initiative is receiving **10 Million Euros of funding** from the European Commission through the **Clean Hydrogen Partnership**. It is a 5-year-project that started on the 1<sup>st</sup> January 2021, and will end on 31<sup>st</sup> December 2025. The consortium is formed by **30 partners from 11 countries**, 9 from the European Union, as well as Chile and Morocco. The project will deliver the **first hydrogen valley of the Mediterranean**, developing a fully functioning hydrogen (H<sub>2</sub>) ecosystem covering all the value chain, from the production to the distribution and consumption of, at least, 330 tonnes per year of green H<sub>2</sub>, traced through a Guarantee of Origin System. This hydrogen will be used in six different applications, as follows:

- The **H<sub>2</sub> pipeline and the injection point** of part of the H<sub>2</sub> produced at the Lloseta plant into the island's natural gas network operated by Redexis.
- The **100 kWe fuel cell** that will supply electricity to the maritime station of the **Balearic Port**.
- The **50 kWe CHP** system to be located in the **Iberostar Bahía de Palma hotel (4\*)**, which will cover part of the hotel's energy demand.
- The **25 kWe CHP** system to be located at the **Municipal Sports Centre in Lloseta**, which will cover part of the site's energy demand.
- The integration of **5 hydrogen buses to the EMT** city bus fleet of Palma de Mallorca.
- The integration of **H<sub>2</sub> vans** in the Alfill Logistics vehicle fleet as well as the search for rental car companies to incorporate H<sub>2</sub> vehicles in their **rental car fleets**.

The infrastructures which will be developed within the project are:

- The **green H<sub>2</sub> production plant** located on CEMEX land in Lloseta.
- The deployment of a **Hydrogen Refuelling Station (HRS)** at the EMT facilities.
- The development of tube trailers which will transport the H<sub>2</sub> produced in Lloseta's plant to the different applications.

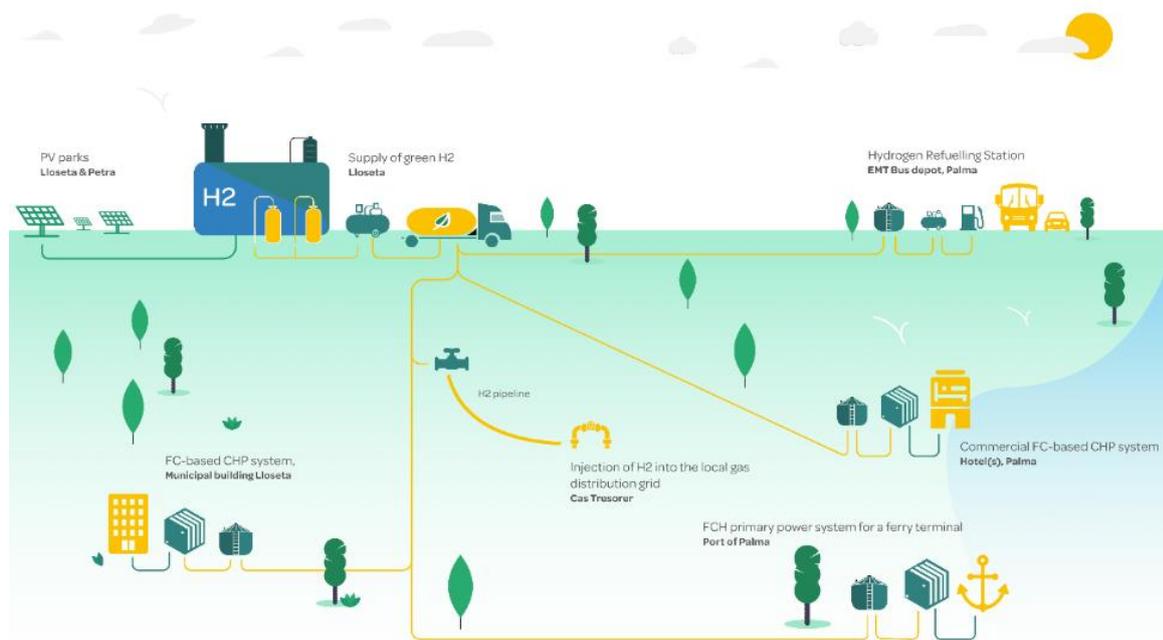
This initiative aims to reduce the CO<sub>2</sub> emissions of Mallorca up to 20,700 tonnes per year by the end of the project.

The project will also deliver a **roadmap towards 2050** that compiles a long-term vision for the **development of a widespread H<sub>2</sub> economy in Mallorca and the Balearic Region**, in line with the **environmental objectives set for 2050**. This long-term roadmap will be an evolution of the current regional roadmap for the deployment of renewable energies and the energy transition, and will involve local and regional stakeholders through public consultations.

In addition, GREEN HYSLAND contemplates the **development of replication experiences** in five other EU islands: Madeira (PT), Tenerife (ES), Aran (IE), Greek Islands and Ameland (NL) as well as Chile and Morocco. Within the project, the impact of deployment of H<sub>2</sub> technologies at regional level (Mallorca and Balearic islands) at technical, economic, energy, environmental, regulatory and socioeconomic levels will be analyzed. Additionally, detailed techno-economic studies for scaling-up renewable H<sub>2</sub>

production, interconnecting infrastructure and local H<sub>2</sub> end-uses, both within the island of Mallorca and beyond, will be developed to facilitate and de-risk future sector investment.

The infrastructures for the hydrogen production and distribution, together with the end-users' pilot sites and the logistics required for the green hydrogen distribution will be developed as follows:



No	Participant Name	Short Name	Country Code	Logo
1	ENAGÁS RENOVABLE S.L.	EGR	ES	
2	ACCIONA ENERGIA S.A.	ACCIONA ENER	ES	
3	REDEXIS GAS S.A.	REDEXIS GAS SA	ES	
4	Empresa Municipal de Transportes Urbans de Palma de Mallorca S.A.	EMT-PALMA	ES	
5	CALVERA HYDROGEN S.A.	CALVERA	ES	
6	AJUNTAMENT DE LLOSETA	Lloseta Council	ES	
7	AUTORIDAD PORTUARIA DE BALEARES	PORTS BALEARS	ES	
8	CONSULTORIA TECNICA NAVAL VALENCIANA S.L.	COTENAVAL	ES	

9	BALEARIA EUROLINEAS MARITIMAS S.A.	BALEARIA	ES	
10	INSTITUTO BALEAR DE LA ENERGIA	IBE	ES	
11	UNIVERSITAT DE LES ILLES BALEARS	UIB	ES	
12	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON	FHa	ES	
13	CENTRO NACIONAL DE EXPERIMENTACION DE TECNOLOGIAS DE HIDROGENO Y PILAS DE COMBUSTIBLE CONSORCIO	CNH2	ES	
14	ASOCIACION ESPANOLA DEL HIDROGENO	AeH2	ES	
15	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	CEA	FR	
16	ENERCY BV	ENER	NL	
17	HYENERGY TRANSSTORE BV	HTS	NL	
18	STICHTING NEW ENERGY COALITION	NEW ENER.COALIT	NL	
19	HYCOLOGNE GMBH	HyCologne	DE	
20	FEDERATION EUROPEENNE DES AGENCES ET DES REGIONS POUR L'ENERGIE ET L'ENVIRONNEMENT	FEDARENE	BE	
21	NATIONAL UNIVERSITY OF IRELAND GALWAY	UGalway	IE	
22	THE EUROPEAN MARINE ENERGY CENTRE LIMITED	EMEC	UK	
23	GASNAM - ASOCIACION IBERICA DE GAS NATURAL Y RENOVABLE PARA LA MOVILIDAD	GASNAM	ES	

24	UNIVERSIDAD DE LA LAGUNA	ULL	ES	
25	ENERGY CO-OPERATIVES IRELAND LIMITED	En.Coop.Ireland	IE	
26	AGENCIA REGIONAL DA ENERGIA E AMBIENTE DA REGIAO AUTONOMA DA MADEIRA	AREAM	PT	
27	GEMEENTE AMELAND	Gem.Ameland	NL	
28	DIKTYO AEIFORIKON NISON TOY AIGAIYOU AE	DAFNI	EL	
29	ASOCIACION CHILENA DE HIDROGENO	H2 CHILE	CL	
30	Association Marocaine pour l'Hydrogène et le Développement Durable	AHMYD	MA	
31	HYENERGY CONSULTANCY LTD	HYE	NL	
32	ENAGÁS S.A.	ENAGAS	ES	
33	Power to Green Hydrogen Mallorca S.L.	P2GH2M	ES	

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## Acronyms list

<b>AC:</b> Alternating Current	<b>MDO:</b> Marine Diesel Oil
<b>ACB:</b> Air Circuit Breaker	<b>MFC:</b> Mass Flow Controller
<b>AFC:</b> Alkaline Fuel Cell	<b>MGO:</b> Marine Gas Oil
<b>ALARP:</b> As Low As Reasonably Practicable	<b>OPEX:</b> Operational expenditures
<b>CAPEX:</b> Capital expenditure	<b>OPS:</b> Onshore Power Supply
<b>CII:</b> Carbon Intensity Index	<b>PAFC:</b> Phosphoric Acid Fuel Cell
<b>DC:</b> Direct Current	<b>PEMFC :</b> Proton Exchange Membrane Fuel Cell
<b>EU:</b> European Union	<b>PMES:</b> Powe and Energy Management System
<b>ESD:</b> Emergency shutdown device	<b>PVC:</b> Polyvinyl chloride
<b>FC:</b> Fuel Cell	<b>RCD:</b> Residual Current Device
<b>GHG:</b> Greenhouse gases	<b>RLAT:</b> High Voltage Lines Regulation
<b>HAZIP:</b> Hazard Identification	<b>RMS:</b> Remote Monitoring System
<b>HAZOP:</b> Hazard and Operability Study	<b>SEEMP:</b> Ship Energy Efficiency Management Plan
<b>HVAC:</b> Heating, ventilation and air conditioned	<b>SF6:</b> Sulphur hexafluoride insulator
<b>HVSC:</b> High voltage shore connection	<b>SFOC:</b> Specific Fuel Oil Consumption
<b>IMO:</b> International Maritime Organization	<b>SOFC:</b> Solid Oxide Fuel Cell
<b>IT:</b> Isolate neutral system	<b>TtW:</b> tank-to-wake
<b>LEL:</b> lower explosive limit	<b>UEL:</b> Upper explosive limit
<b>LCV:</b> Lower calorific value	<b>UNESA:</b> Spanish Association of Electric Power Companies
<b>LVSC:</b> Low voltage shore connection	<b>XLPE:</b> cross-linked polyethylene
<b>MARPOL:</b> International Convention for the Prevention of Pollution from Ships	<b>WtT:</b> well-to-tank
<b>MCCB:</b> Moulded Case Circuit Breaker	
<b>MCFC:</b> Molten Carbonate Fuel Cell	

## Executive Summary

This document “Study on the development of cold ironing at the Port of Mallorca. Techno-economic assessment on the use of fuel cells for cold ironing applications in Mallorca” is a part of the subtask 6.1.2, Technical Scale-up studies: end-user applications, managed by IBE in order to investigate the potential of the market and establish the basis techno-economics parameters for end-user applications in the Balearic Islands.

The aim of this part, managed by PORTS BALEARS, is to expose the systems and equipment to be installed for the development of cold ironing at the Port of Mallorca, including the use of fuel cells of H<sub>2</sub> gas, in order to supply of electric energy to the vessels. It will comprise the analysis of the port network requirements as well as the vessel requirements, in order to establish a correct connection between both.

Most vessels and ports are currently unprepared for OPS, necessitating considerable investments from shipping companies to **retrofit their fleets**. Ports must also **develop the infrastructure** to offer effective electrical connection services. This transition is driven by the **European Commission's mandate requiring ships at quayside in port states to connect to on-shore power supply for all electrical demands by January 2030**.

The focus of this study is the first alignment of the West Dock at the Port of Palma, as one of the most versatile docks of the port. However, the findings are relevant for broader applications, as PORT BALEARS is actively working to implement cold ironing connections in other docks, considering the **integration of renewable energies**.

From a vessel's perspective, adapting to OPS initially appears as a non-profit investment. However, in light of impending regulations targeting GHG emissions reduction from maritime operations, such investments are recontextualized as proactive measures **to avoid penalties**, thus becoming financially advantageous in the long term.

**Implementing OPS, even without the integration of fuel cells, substantially lowers GHG emissions. The addition of hydrogen fuel cells further enhances this reduction**, aligning with global efforts to mitigate environmental impacts. In the context of increasing penalties for GHG emissions, any reduction is not only environmentally beneficial but also economically favourable.

- Current CO<sub>2</sub> Emissions with Onboard Gensets: 3,105 tons/year.
- Reduction with Pure Cold Ironing: Decrease to 1,545 tons/year.
- Further Reduction with Fuel Cell Integration: Down to 1,302 tons/year.
- Overall GHG Emissions Reduction: An expected yearly reduction of about 1,804 tons of CO<sub>2</sub>, totalling over 48,000 tons of CO<sub>2</sub> not emitted up to 2050.
- Percentage Reduction in CO<sub>2</sub> Emissions: Over 58%, with the fuel cell contributing to nearly 8% of this reduction in a 2,374 kW total power supply scenario.

The report underscores the necessity for both vessels and ports to adapt to innovative technologies like hydrogen fuel cells in cold-ironing. This adaptation is crucial not only to comply with upcoming environmental regulations but also to capitalize on the financial benefits of reduced GHG emissions. The study indicates a clear path forward for reducing the environmental footprint of maritime operations, presenting hydrogen as a key player in the evolution of greener port practices.

# 1. Objectives

GREEN HYSLAND is an international European cooperation project as part of the general initiative to decarbonization through innovative solutions based on green hydrogen technology.

The project goal is to deploy an H<sub>2</sub> ecosystem on the Island of Mallorca, considering the end-users applications aside from the replication of such H<sub>2</sub> ecosystem to other islands or territories.

In this sense, this part contemplates the techno-economic study to use green H<sub>2</sub> as fuel for fuel cells to be used for cold ironing applications at the Port of Palma, and its contribution to the decarbonization of the vessel's energy consumption at port.

The works that are going to be carried out in this analysis include:

- Data collect and analysis for several vessels in order to define the power and energy demand.
- Available space at port for the fuel cells and shore connection installation.
- Hazard identification study and analysis.
- Safety requirements identification at port and onboard vessels.
- Economical assessment of the technical solutions defined.
- Pollutant emissions reduction assessment of the technical solutions defined.

## 1.1. Project description

Considering the end-users applications regarding mobility, and due to the characteristics of the territory considered, the vessels are important consumers into the whole scenario. Every day different vessels arrive and leave the island to connect with other islands in Balears as much as with the mainland, which represents an important focus of emissions.

The emissions during their stay at port can be reduced if the vessels do not have their auxiliary engines running and burning carbon fuels, to feed their own electrical network onboard. One of the alternatives is to connect the vessel with a shore power connection, called cold ironing, to the ashore network, and feed all the consumers in the vessel with this. Even if a part of this connection could be feed with a fuel cell using green H<sub>2</sub>, the total amount of emissions will be reduced.

## 1.2. Project scope and system boundaries

This part will consist in a techno-economic analysis based on a dock of the Port of Palma and the expected vessels to be moored at it, in order to determine the emissions reductions that could be achieved with the above considerations.

Regarding to the complete GREEN HYSLAND project and for a better understood of this study, refer to the figure below:

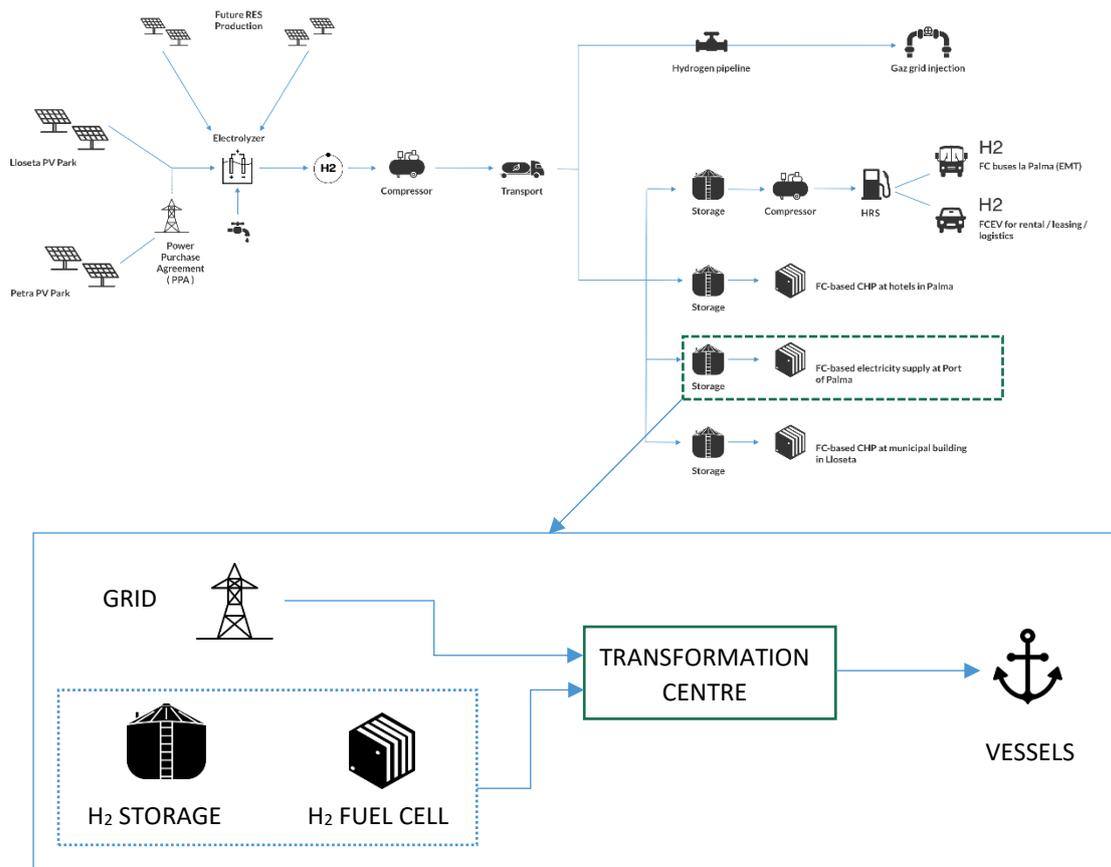


Figure 1: Schemes of GREEN HYSLAND project concept and focus on cold ironing development study

The works carried out in this analysis include:

- Data collect and analysis of the vessels moored at the selected dock in previous years in order to define the connection requirements.
- Fuel cells analysis and selection, in order to maximize the power supply by the fuel cell, reducing the power from the grid.
- Generation plant location and distribution.
- Hydrogen storage supply system and procedures.
- Hazard identification study and analysis and safety systems definition to prevent potential hazardous situations.
- Economical assessment of the technical solutions defined and operational cost analysis for subsequent years.
- Estimated reduction of pollutants and GHG emissions, from the current operational modes, pure cold ironing connection and the use of a hydrogen fuel cell as part of the power supplied. Considerations to be made regarding new regulations to be applied on vessels.

## 2. Current situation description

### 2.1. Introduction: hydrogen-based development of a cold ironing connection

Cold ironing is the term used to describe the condition of a vessel with all their engines stopped and connected with a shore power connection to the ashore grid.

The aim of this study is to consider part of the electric supply from a fuel cell hydrogen-based, removing the noise pollution at port, because of the cold ironing connection that allows the vessels to stop their auxiliary engines, but also with a significant reduction of the pollutant emissions thanks to the use of green hydrogen to power the fuel cell, that would supply a part of the energy required from the vessels at port.

Even though a battery-based Cold Ironing system could in principle also be considered for this application (as an alternative to FC-based or incumbent grid-based Cold Ironing systems), there is very limited information in the literature assessing the feasibility of Cold Ironing with the integration of battery-based systems (BESS). Furthermore, the economic and environmental benefits and ultimately the feasibility of BESS-based on-grid Cold Ironing systems remains unclear, mainly due to the high capacity of batteries required to meet the Cold Ironing operational requirements (see Section 2.3) and the necessity to enable a grid connection for battery charging over significant lengthy periods. In island territories it is also important to take into account the limited access to the power needed to cover the current and expected growing demand, around four years for a 250 MW substation. On this basis, within the context of the GREEN HYSLAND project, a FC-based system is considered as the most attractive alternative to existing grid-based Cold Ironing systems. A comparison between FC-based and a BESS-based Cold Ironing systems was therefore not deemed justified and was not included within the scope of the analysis presented in the deliverable.



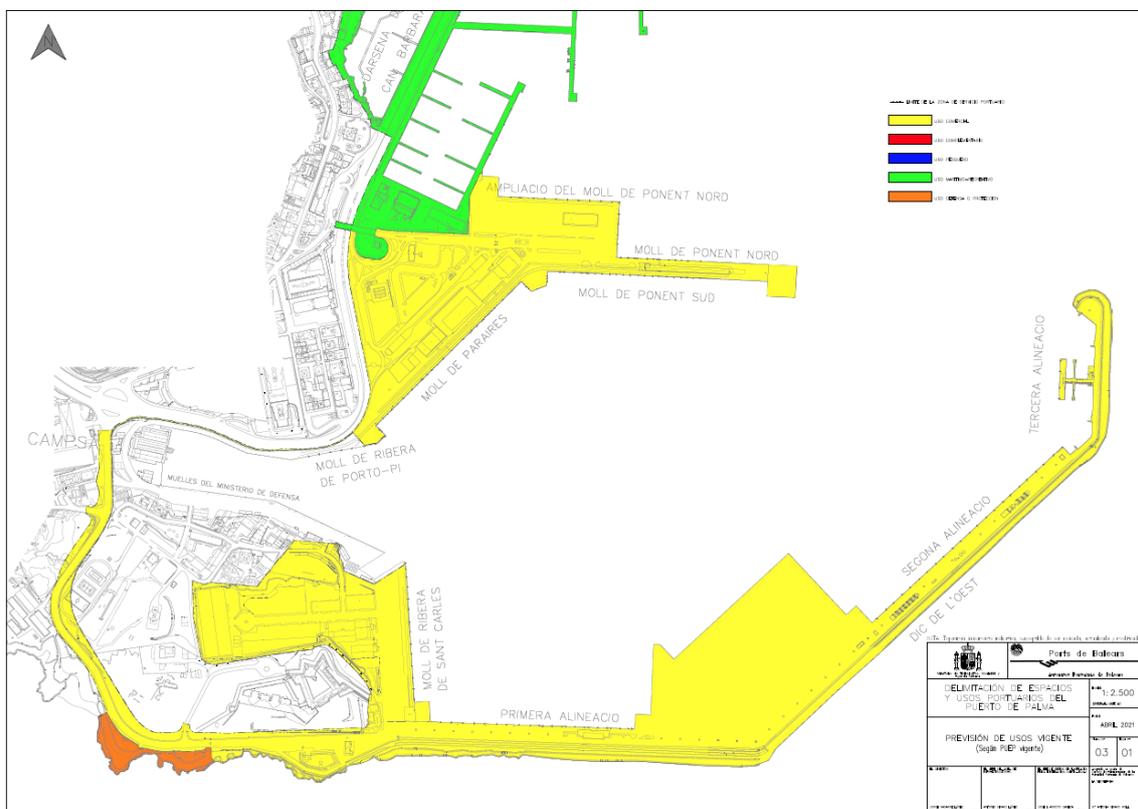
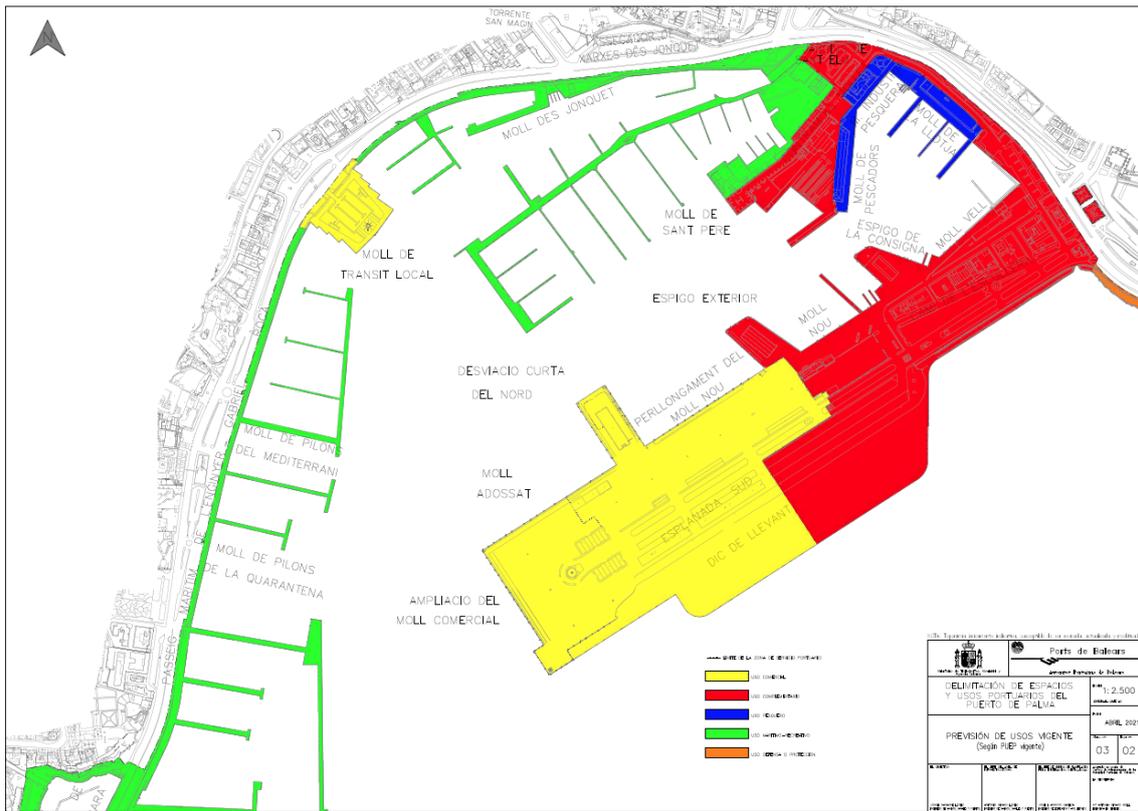


Figure 3: Docks with commercial uses (PORTS BALEARIS)

In the next table there are identified the different docks into these areas with their main characteristics, separated in three different areas.

The named commercial docks (*Molls Comercials*) are located in the north area of the Port of Palma, with almost 1250 meters of berthing lines.

Table 1: Commercial docks features (PORTS BALEARS)

COMMERCIAL DOCKS				
Dock	Length (m)	Depth (m)	Width (m)	Main use
1 <sup>st</sup> ext. section commercial docks	220	11	87	Ro-Ro
Commercial docks front	200	10-9	103	Ro-Ro
Attached dock prolongation	176	9-8	103	Ro-Ro
Attached dock	107	8	103	Ro-Ro
North Short Division (ext.)	130	8	30	Ro-Ro
North Short Division (front)	60	7	30	Miscellaneous
North Short Division (int.)	130	7	30	Ro-Ro
New dock prolongation	151	7	103	Tugs and miscellaneous
Consigna Breakwater (ext.)	66	7	45	Boats repair
Consigna Breakwater (front)	35	5	10	Boats repair
Consigna Breakwater (int.)	95	5	10	Boats repair
Lonja Dock (1 <sup>st</sup> section)	111	3	0	Local traffic and service

The Poniente Quays can be considered as the most important areas destined to cruise vessels and ferries, with almost 2280 meters of berthing lines.

Table 2: Poniente Quays features (PORTS BALEARS)

PONIENTE QUAYS				
Dock	Length (m)	Depth (m)	Width (m)	Main use
Poniente quay enlargement (angle)	35	6	30	Ferries
Poniente quay enlargement (North) with Dukes of Alba	275.8	10-6	65	Ferries, cruises
Poniente quay enlargement (East)	99	9	37.8	Ferries, miscellaneous
1 <sup>st</sup> lineup Poniente North dock	300	12-8.5	35-8.4	Ferries, cruises

PONIENTE QUAYS				
Dock	Length (m)	Depth (m)	Width (m)	Main use
2 <sup>nd</sup> lineup Poniente North dock	360	12-8.5	-	Cruises
1 <sup>st</sup> lineup Poniente South dock	440	12-8.01	35-8.41	Miscellaneous
2 <sup>nd</sup> lineup Poniente South dock	370	12-8.01	-	Ferries, cruises
Poniente dock (front)	30	12-8.02	35-8.42	Miscellaneous
Perares quay	363	12-10	50	Ferries, cruises

The West Dock is located in the southern area of the port, with almost 2270 meters of berthing lines. It shows the most versatile area of the Port of Palma, with different kind of vessel berthing at it.

Table 3: West dock features (PORTS BALEARIS)

WEST DOCK				
Dock	Length (m)	Depth (m)	Width (m)	Main use
Ribera of Saint Charles dock	250	12	60	Bulkcarrier, conventional, Ro-Ro
1 <sup>st</sup> lineup West dock	360	12	30	Cruises
West lineup. West dock attached platform	130	12	-	Ferries, conventional
West lineup. West dock attached with Dukes of Alba	198	12	-	Ferries, conventional
North lineup. West dock attached platform	285	12	-	Ro-Ro, cruises, ferries
North lineup. West dock attached with Dukes of Alba	445	12	-	Ro-Ro, cruises, ferries
East lineup. West dock attached platform	155	12	-	Conventional, ferries
2 <sup>nd</sup> lineup West dock	440	12	30	Bulkcarrier, Ro-Ro, tankers, cruises, conventional

### 2.2.1. Schedules

As mentioned before, the West Dock is a multipurpose area where all kind of vessels are moored each day. This feature brings a wide vision of the type and frequency of the different type of vessel calling the Port of Palma.

All the port calls for last four years at West Dock, first and second line up, excluding those for the year 2020 due to the pandemic scenario which could skew the analysis, have been considered in the following figures. Considering each kind of vessel, there is a significant difference between the vessels with a longer port call and those with more port calls per year.

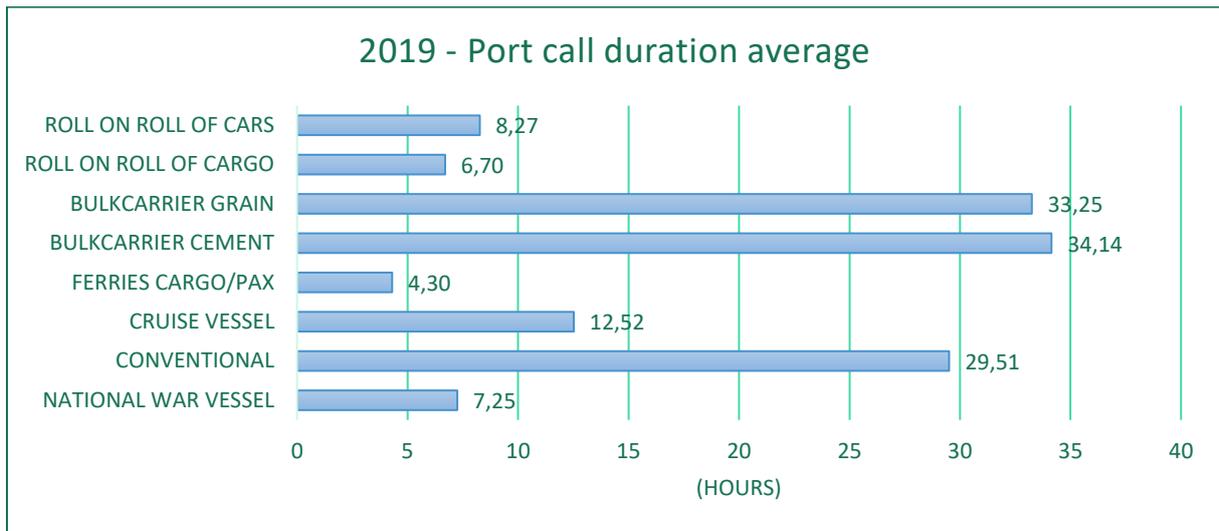


Figure 4: 2019 Port calls duration

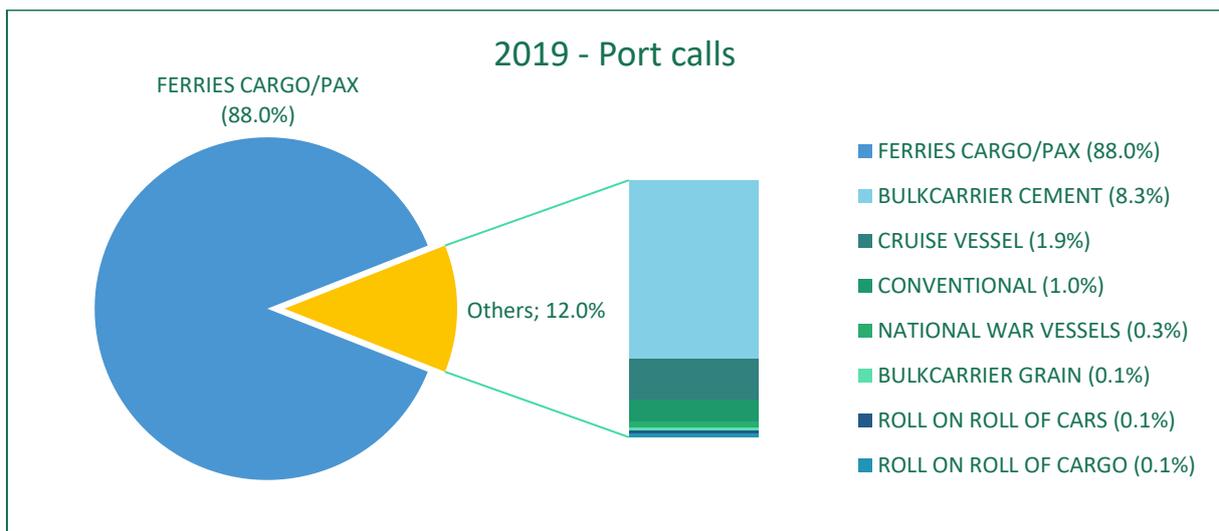


Figure 5: 2019 Port calls recount

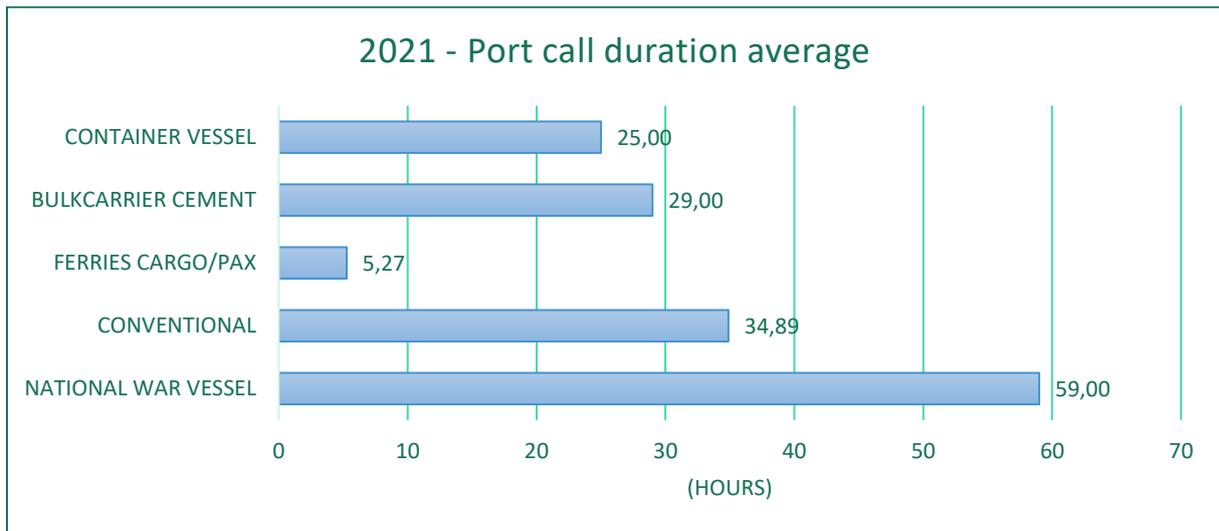


Figure 6: 2021 Port calls duration

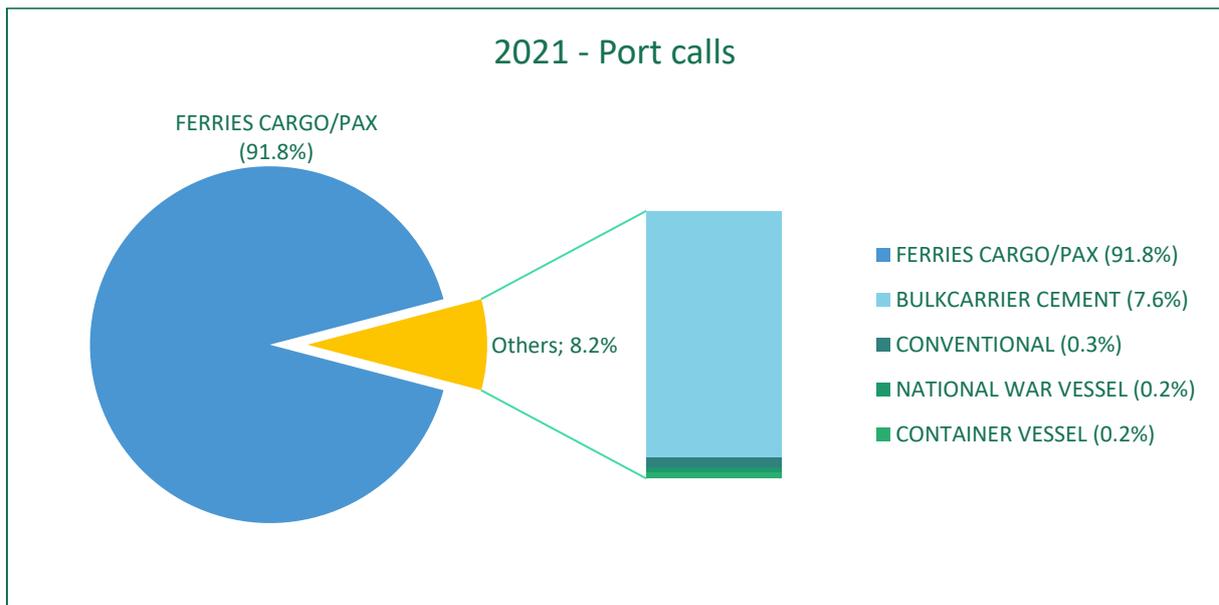


Figure 7: 2021 Port calls recount

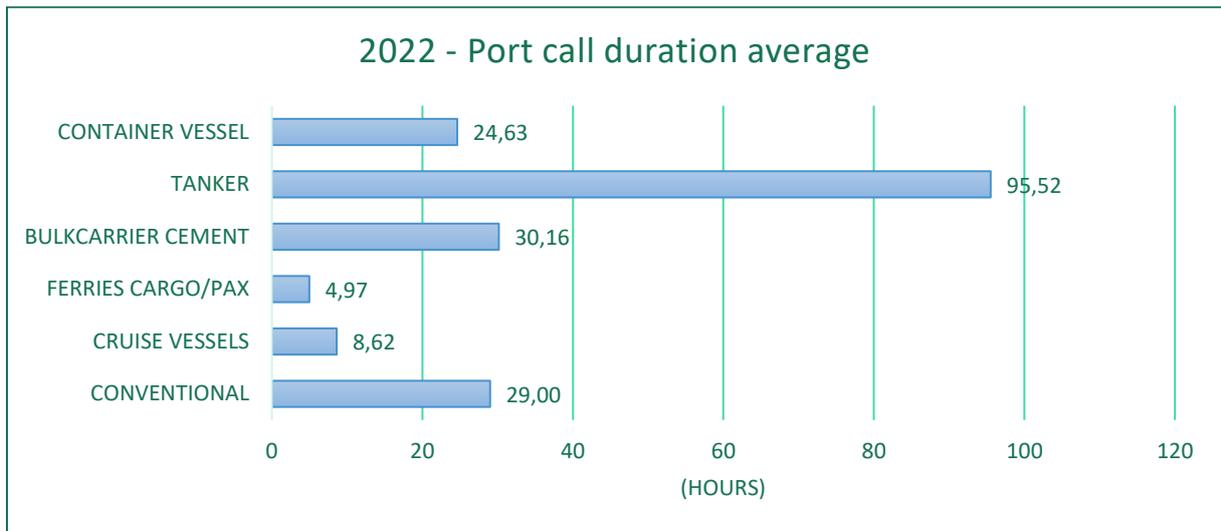


Figure 8: 2022 Port calls duration

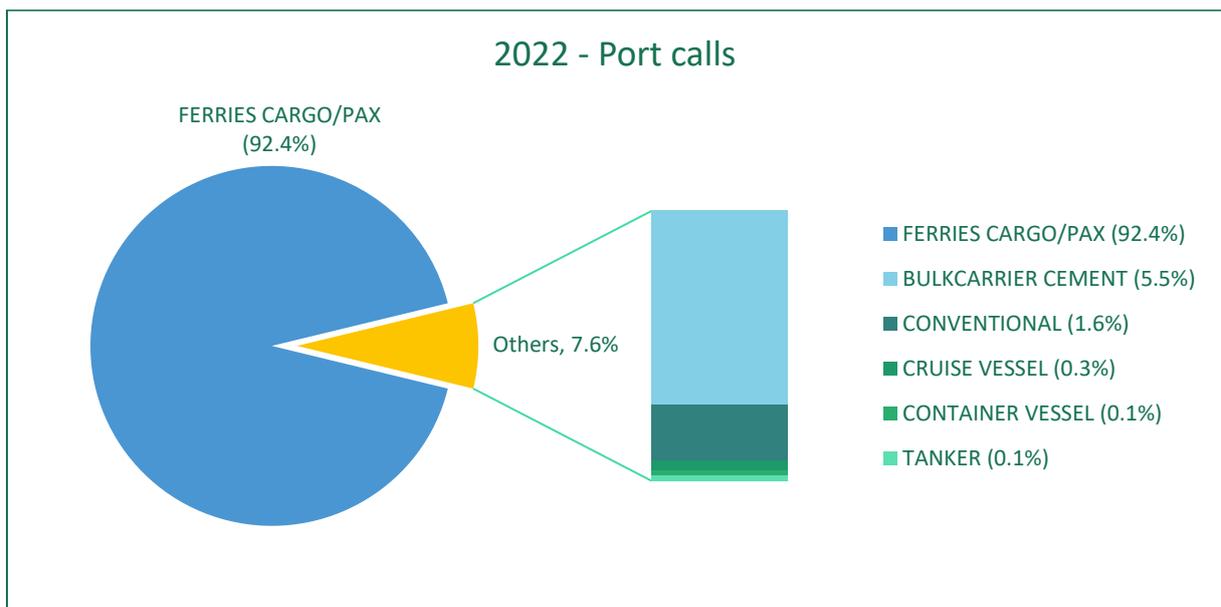


Figure 9: 2022 Port calls recount

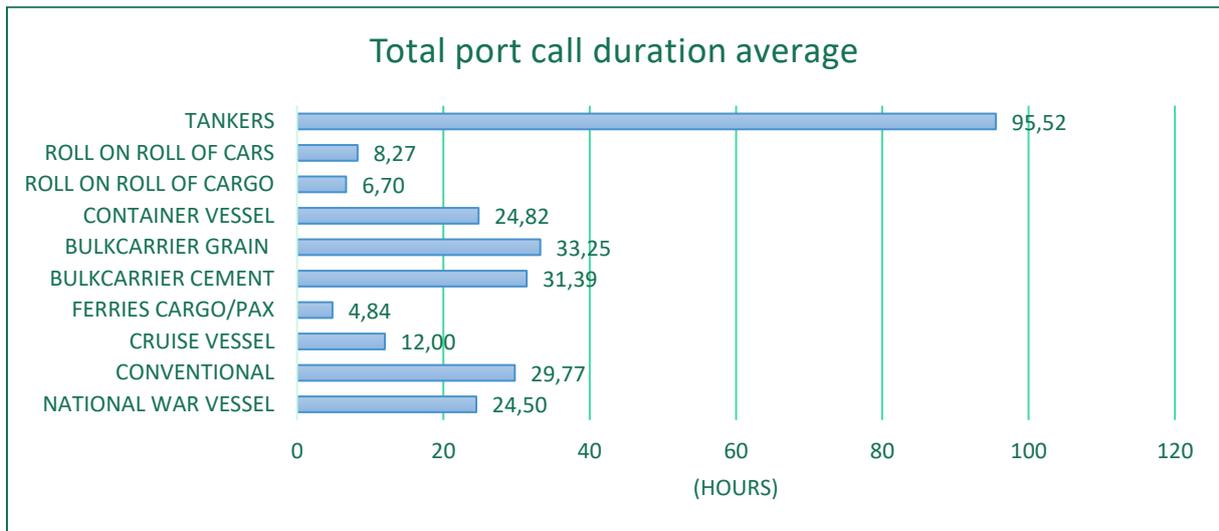


Figure 10: Total port calls duration

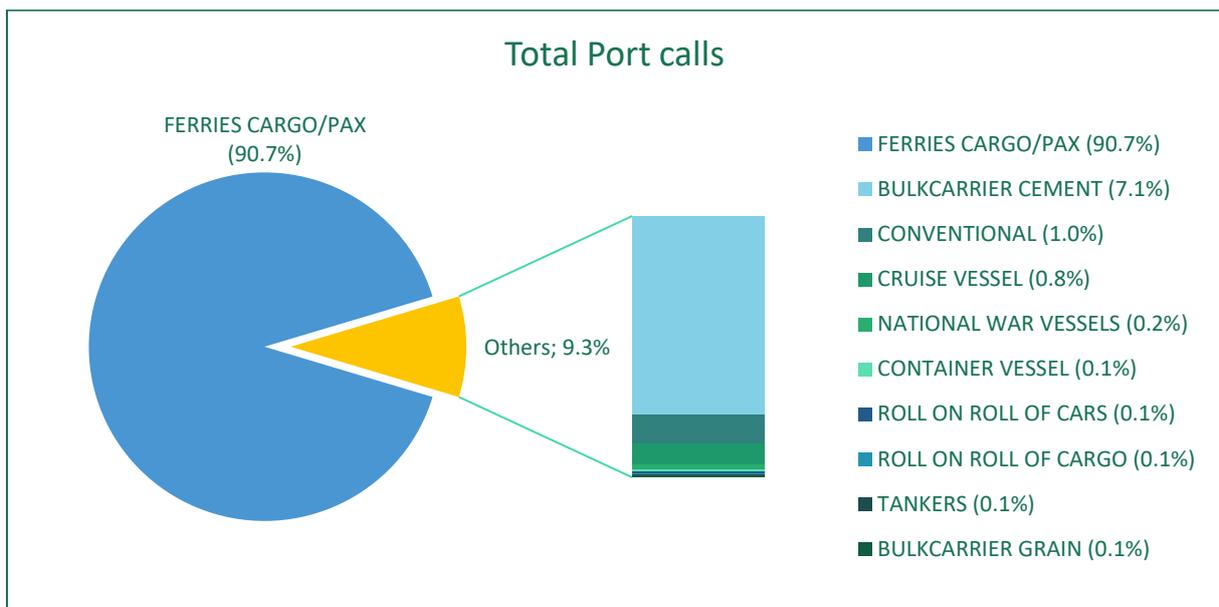


Figure 11: Total port calls recount

Looking at the figures above, tankers vessels have the longer port call, almost four complete days (95,52 hours), but with only one port call during the three years considered. It has no sense to have a complete installation of cold ironing at port to supply energy only to a vessel during three years. On the same way, there are other kind of vessels with less than five port calls in three years: ro-ro of cargo and cars, container vessels and bulkcarrier of grain.

Taking into account the total number of port calls, there is a clear winner: ferry vessels, with more than the 90% of the total port calls, each of them of 4.84 hours of average duration, which means approximately 2900 hours per year at port. The second place will be for bulkcarriers of cement, with approx. 1475 hours at port during a year, near to the half of the first one.

Looking at the results of the data analysis, as shown above, the present study will be focused on ferry vessels, as the kind of vessel with a more significant port call duration during a complete year, and also due to their importance to the port and the island. With this consideration, the cold ironing system could be defined into a defined range of consumption, that it could be also suitable for other kind of vessels with occasional port calls.

The complete list of port calls during the years 2019, 2021 and 2022, as well as all the vessels' main characteristics, is shown in the appendix.

### 2.2.2. Electrical consumption

Once the type of vessel being considered is selected, it is time to analyse their electrical consumption at port. The next table shows for each vessel the number and manufacturer of their gensets and the total electrical power available with them.

Table 4: Ferry vessels gensets and power

IMO	VESSEL	DWT (t)	GENSETS	ELECT. POWER (kW)	FREQ. (Hz)
9441130	ABEL MATUTES	5300	3 x MAK	3300	50
9441142	BAHAMA MAMA	3520	3 x MAK	3300	50
9019054	DENIA CIUTAT CREATIVA	5985	3 x YANMAR	2400	60
9498743	HEDY LAMARR	7000	3 x CATERPILLAR	1800	60
9498755	HYPATIA DE ALEJANDRÍA	7718	1 x WARTSILA + 2 x CATERPILLAR	5600	60
9243447	KERRY	7500	3 x CATERPILLAR	4020	60
9498767	MARIE CURIE	7718	1 x WARTSILA + 2 x CATERPILLAR	5600	60
9390367	MARTIN I SOLER	4370	3 x MAK	3300	50
9243423	NAPOLES	7500	3 x CATERPILLAR	3855	60
8208763	POETA LOPEZ ANGLADA	2430	3 x CREPELLE	3000	50
9137997	ROSALIND FRANKLIN	7823	3 x SULZER	3480	60
9261542	SICILIA	7500	3 x CATERPILLAR	3855	60

The main consumers in this kind of vessels at their port calls are the fans and ventilation systems in cargo decks and machinery spaces and the HVAC (heating, ventilation and air conditioned) system in the accommodation areas. The most common condition for this scenario is having all the gensets except one, running at about 65-85% of their total power.

Table 5: Ferry vessels harbour consumption estimation

IMO	VESSEL	TOTAL ELECT. POWER (kW)	HARBOUR CONDITION POWER CONSUMPTION (kW)	
			65%	85%
9441130	ABEL MATUTES	3300	1430	1870
9441142	BAHAMA MAMA	3300	1430	1870
9019054	DENIA CIUTAT CREATIVA	2400	1040	1360
9498743	HEDY LAMARR	1800	780	1020
9498755	HYPATIA DE ALEJANDRÍA	5600	2427	3173
9243447	KERRY	4020	1742	2278
9498767	MARIE CURIE	5600	2427	3173
9390367	MARTIN I SOLER	3300	1430	1870
9243423	NAPOLES	3855	1671	2185
8208763	POETA LOPEZ ANGLADA	3000	1300	1700
9137997	ROSALIND FRANKLIN	3480	1508	1972
9261542	SICILIA	3855	1671	2185

From all the values above, an average value of 2000 kW can be considered as the requested power by most of the ferry vessels calling port at the considered docks. Both frequency ranges should be considered, to guarantee the shore connection for all vessels.

Note that the consumption related above, had been considered in the worst scenario, that means, that with a higher consumption according to the operations at port since the vessel arrives until she leaves. Such value used to have the same considerations as required for the Administration or Classification Society for their approval of the electric load balance, with the considerations established in the rules and codes, which establish a running factor and a simultaneously factor for each of the consumers.

But looking at the real power consumption in port for this type of vessels, it is usually not so high. Some of the systems are not running at their maximum power and not all the systems are running at the same time, which brings lower values. But it will depend on the vessel and her operational profile.

It is assumed that vessel calling port will, prior to their arrival, request to the port for a shore connection and power demand estimated, so the port could arrange the connection, sockets, etc.

For the aim of this project and looking for a simultaneous connection to shore of several vessels, **the cold ironing connection will be defined for 2000 kW of electric power plus the power that could be provided by a fuel cell**. In most of the scenarios, such power would be enough **to feed at least two vessels at the same time**, looking at the real electric power consumption of this type of vessels.

In the case of any issue with the hydrogen supply or even with the fuel cell operation, the shore connection capacity will be enough to supply power to the connected vessels, only from the shore grid.

## 2.3. Docking facilities

There are actually several transformer centres in the West Dock. These will be used as reference for the new transformer centre designed for the cold ironing connection.

### 2.3.1. Dock selection. Dock characteristics description

As already mentioned in the chapters above, the West Dock has been selected for the installation of a cold ironing connection fed with a fuel cell using green H<sub>2</sub> as fuel. It is a dock with an important number of port calls of ferries and other vessels, being the most versatile area of the Port of Palma. This feature brings it a good flexibility to the new facilities.

The complete West Dock has almost 2770 meters of berthing lines, but the location of the transformation centre and the electric supply lines required a limitation in the berths designed for this use. The docks selected for the purpose of this project are the ones in the west side of the West Dock: the first lineup and those close to it.

Table 6: Selected dock main characteristics

DOCK	LENGTH (m)	DEPTH (m)	WIDTH (m)
Ribera of Saint Charles dock	250	12	60
1 <sup>st</sup> lineup West dock	360	12	30
West lineup. West dock attached platform	130	12	-

### 2.3.2. Dock selected. Consumption analysis

The vessels considered to define the electrical consumption requirements, those are ferry vessels, are all vessels dedicated to a regular traffic, which is based on the same timetable day by day. Such timetables define the power requirements along the day and then, the hydrogen supply to the fuel cell.

Looking at the port calls of this vessels on the last years, there was a significant increase on the duration of their average stay at port on 2021, and it was reduced again on 2022.

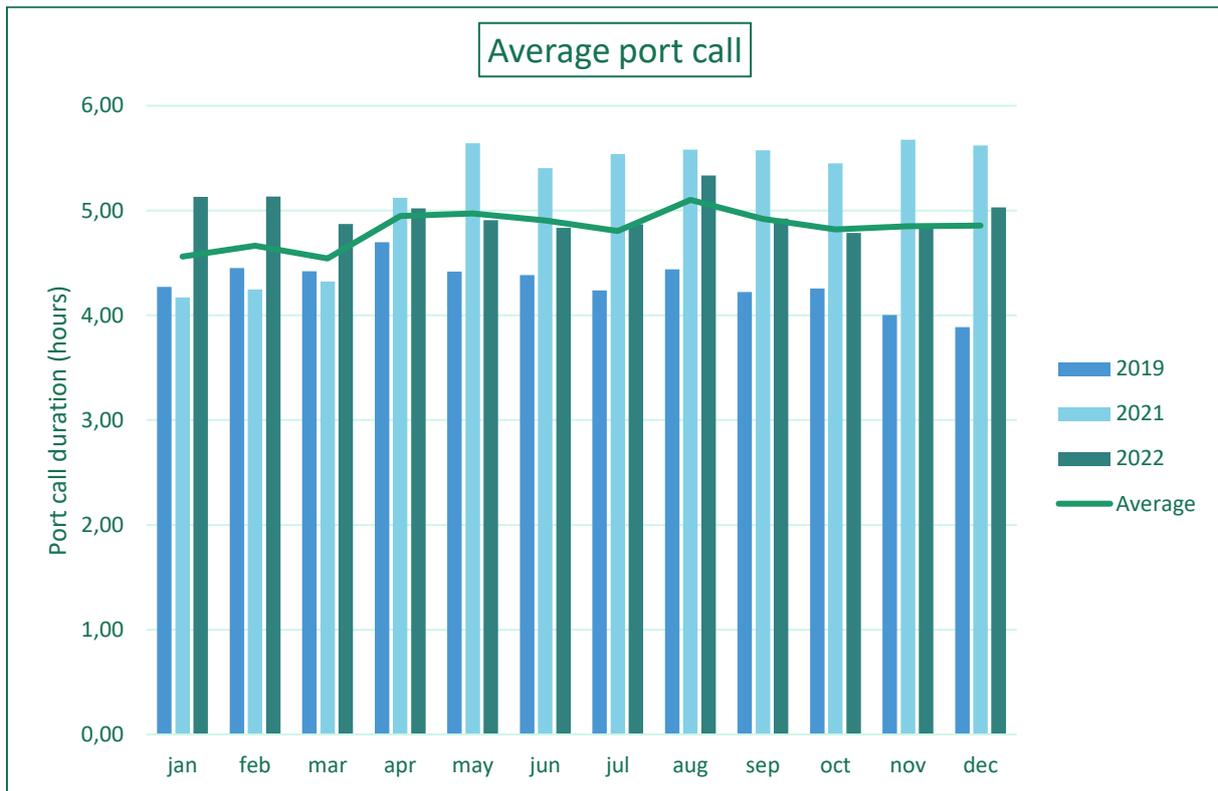


Figure 12: Port calls per month

Table 7: Port calls per month and average

Month	2019	2021	2022	Average
January	4.27	4.17	5.13	4.56
February	4.45	4.25	5.13	4.66
March	4.42	4.32	4.87	4.54
April	4.70	5.12	5.02	4.95
May	4.42	5.64	4.91	4.97
June	4.38	5.40	4.84	4.90
July	4.24	5.54	4.87	4.81
August	4.44	5.58	5.34	5.10
September	4.22	5.57	4.92	4.92
October	4.26	5.45	4.79	4.82
November	4.00	5.68	4.86	4.85
December	3.89	5.62	5.03	4.86
TOTAL	4.30	5.27	4.97	4.84

But a smooth growing trend can be observed in the average port call duration. That can be answered due to the operation of more efficient vessels, with improved hull forms and new generation propulsions systems, that could be summarize in an increase in the vessels speed. From the shipping companies' point of view, there should be an equilibrium between higher fuel consumption for higher speed and the fact that they could offer shorter trips to their clients.

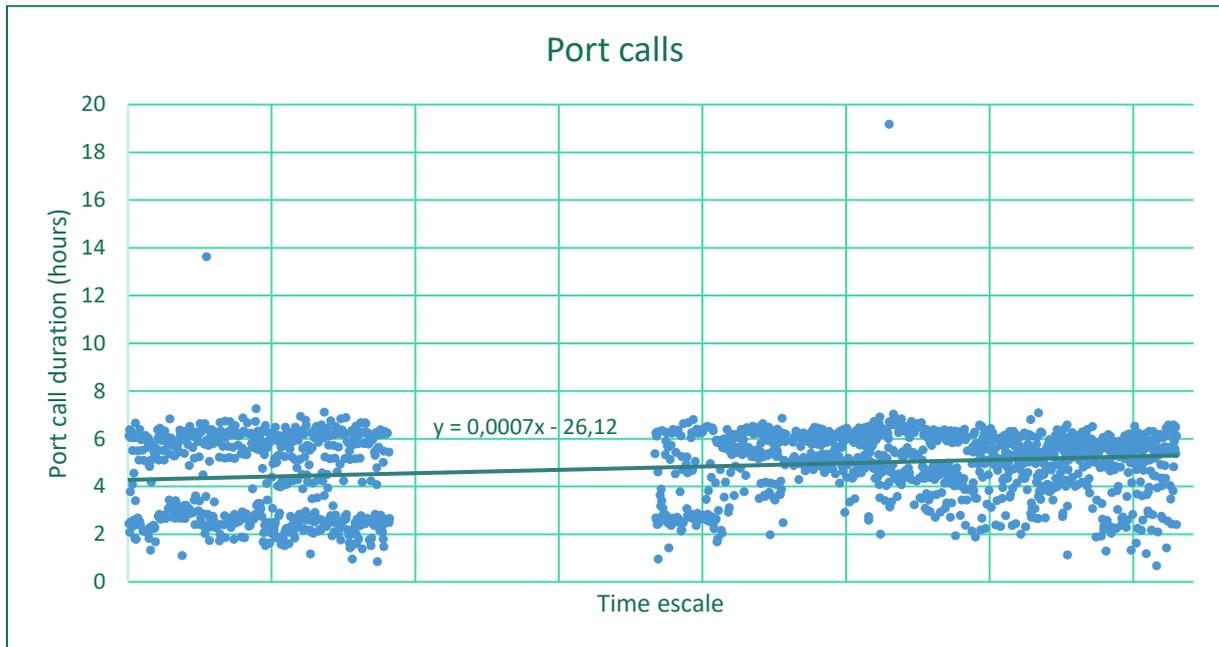


Figure 13: Growing trend for port calls along the last years.

Note that year 2020 data had not been included in this analysis, so a gap is represented in the graphic above concerning that year.

But neither the improvements in the propulsion technologies nor in the hull forms design are expected to grow up indefinitely due to the features of this kind of transport.

Looking at the data analysed, the number of vessels has been increased in the last years, and that is a more realistic scenario for the upcoming years.

For last years, the average port call is around 5 hours, but a small increase of this value can be supposed. In order to define the system characteristics with a margin for future scenarios. For the OPS (Onshore Power Supply) operation, 6 hours will be considered.

For the shore connection design, the most relevant data are to know the number of vessels to be connected at the same time, the time for each connection and the power required. In the following figure the number of vessels calling at the West Dock per day has been represented for each of the years analysed. More than the 80% of the days there were two vessels at port, which means a significant difference with other considerations, 1 or 3 vessels at port. This will be assumed as a design requirement. However, the number of available shore connections will finally be defined by the power requirement of each vessel.

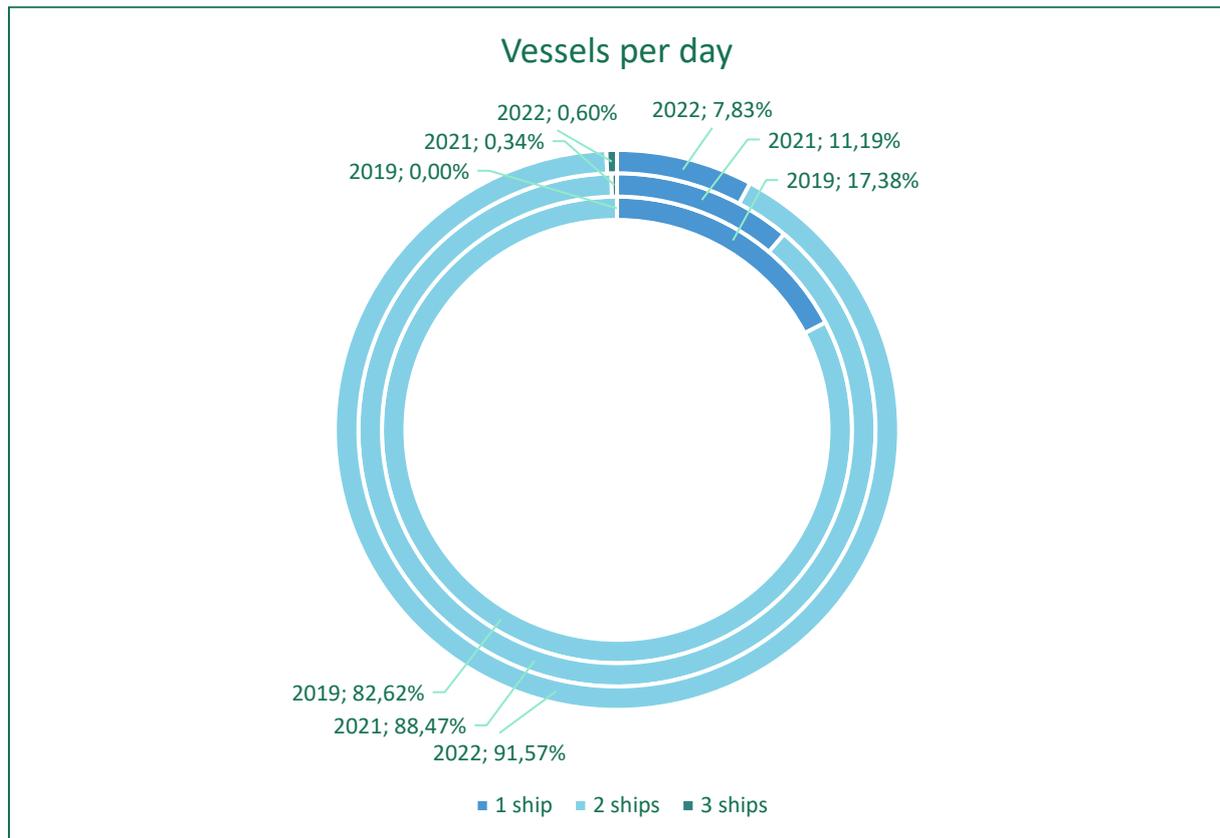


Figure 14: Number of vessels at the West Dock on the same day

### 2.3.3. Requirements specification of the generation plant

From the report made by INSTEIMED (included in Appendix), the design of the generation plant follows the prescriptions of the rule IEC PAS 80005-3 “*Utility connections in port -Part 3: Low Voltage Shore Connection (LVSC) Systems – General requirements*”, and IEC PAS 80005-3 “*Utility connections in port –Part 1: High Voltage Shore Connection (HVSC) Systems – General requirements*”.

The objective is to design an installation with the following characteristics:

- Integration into the existing electrical infrastructure of the port. Furthermore, the installation must guarantee the security in the electrical power supply.
- Installation prepared to be increased.
- Minimise the electric risk.
- Resistance and durability of all equipment.
- The installation must achieve: the required power supply for the vessel, facility in the connection and disconnection manoeuvres, quality in the power supply, integration with the electric vessel system.

Due to the current characteristics of the vessels calling port at the West Dock, the options considered have been:

- Vessels powered by 11 kV, 50-60 Hz.
- Vessels powered by 440 V, 60 Hz.
- Vessels powered by 400 V, 50 Hz.

In order to achieve the objectives of the project, a new transformation centre will be required to supply from the connection point in high voltage up to 2,5 MVA. Additionally, a hydrogen fuel cell will supply about 400 kW of electric power.

## 2.4. Current GHG emissions estimation

Currently most of the vessels are not connecting to a shore connection when they are at port, they use their own generators onboard, burning diesel oil or even natural gas, in order to supply energy to their own equipment and systems. For this study, diesel generators on ships will be considered, as it is the current most usual arrangement. Only vessels with dual-fuelled main engines used to have auxiliary engines able to run with natural gas.

Just the fact to be connected to a shore connection means a reduction on the GHG emissions at port. The GHG emissions does not depend neither on the port nor on the dock, it only depends on the vessel.

IMO (International Maritime Organization) is the United Nations specialized agency with developing and adopting global regulations on the safety, security and efficiency of ships and on the protection of the environment, both marine and atmospheric, from shipping operations. It has been working for the last years for the reduction of all the pollutants from vessels. The regulatory measures adopted by IMO, most of them included in MARPOL (IMO International Convention for the Prevention of Pollution from Ships) have proven effective reducing pollutant emissions from vessels.

Under MARPOL Annex VI, emissions reduction of SO<sub>x</sub>, NO<sub>x</sub> and particulate matter have been progressively implemented. But IMO now recognizes the increasing importance and urgency of controlling GHG emissions worldwide.

Estimated in the *Fourth IMO GHG Study 2020* from several long-term scenarios, the GHG emissions of total shipping were 1056 million tonnes of CO<sub>2</sub> in 2018, 9.6% increase from the values in 2012. The study outlines also that overall carbon intensity was approximately 20 to 30% better in 2018 than in 2008, as an average across international shipping. For the upcoming years, it is expected to have an increase from about 90% of 2008 emissions in 2018 to 90-130% of 2008 emissions by 2050.

IMO had developed several regulations and codes in order to continue with the control and reduction of emissions from ships, all to be included under MARPOL Annex VI. The energy efficiency of the vessel is determined by her design features, and the comparison between a required index and an attained index. But both indexes do not depend on the real emissions of the vessel.

Focused on the GHG emissions and related to the real emissions by the vessel, IMO has defined the CII, Carbon Intensity Index, an annual operational index to be measured according to the Ship Energy Efficiency Management Plan (SEEMP). The attained annual operational CII shall be verified against the required annual operational CII to determine the operational carbon intensity rating. For their calculation, a conversion factor is defined between the fuel consumption and CO<sub>2</sub> emissions, based on the carbon content of each type of fuel. For diesel oil, 3.206 tCO<sub>2</sub>/t fuel are considered.<sup>1</sup>

On the other hand, the Committee on Transport and Tourism from the European Parliament has been developed a proposal for regulation on the use of renewable and low-carbon fuels in maritime

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<sup>1</sup> Resolution MEPC.308(73) adopted on 26 October 2018 "2018 Guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships."

transport, called Fuel EU. Thinking on the distance and the amount of cargo transported, and compared to other modes of transport, maritime transport remains the most carbon efficient mode of transport. But all modes of transport must contribute with a reduction of GHG emissions.

Regarding vessels, both sailing and at port, GHG emissions shall be reduced. Fuel EU defines reference values for the yearly average GHG intensity of the energy used onboard by a ship.

Greenhouse gas (GHG) emissions means the releases of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). Fuel EU regulation defines the unit CO<sub>2</sub> equivalent, which considers, defined by a specific formula, the emissions caused by those most relevant greenhouse gases.

Fuel EU defines default emissions factor values depending on the type of fuel and even its origin, to be used for the determination of the greenhouse gas intensity index defined in such Regulation. For the purpose of this analysis, the same values will be considered.

For each type of fuel consumed at berth and at sea, Fuel EU distinguishes between well-to-tank (WtT) and tank-to-wake (TtW) emissions, bringing different emission factors.

Table 8: Default emission factors defined by Fuel EU Regulation

Fuel Class	Pathway name	LCV [MJ/g]	WtT	TtW		
			CO <sub>2eq</sub> WtT [gCO <sub>2</sub> eq/MJ]	C <sub>f</sub> CO <sub>2</sub> [gCO <sub>2</sub> /gFuel]	C <sub>f</sub> CH <sub>4</sub> [gCH <sub>4</sub> /gFuel]	C <sub>f</sub> N <sub>2</sub> O [gN <sub>2</sub> O/gFuel]
Fossil	MDO MGO ISO8217 Grades DMX to DMB	0.0427	14.4	3.206	0.00005	0.00018

Fuel EU analyses the complete operation of the vessel both at sea and at berth, in order to determine a GHG intensity value to be compared with the reference values given for the regulation for different periods of years. For the aim of this project, the complete operation of a vessels cannot be analysed, as it is focused on the OPS connection, but the same emission factors as defined for TtW, can be used in order to obtain comparable values.

Special mention is need to be done to Fuel EU Article 5 where additional zero-emissions requirements establishes that *“From 1 January 2030, a ship moored at a quayside in a port of call State which is covered by Article 9 of the Alternative Fuels Infrastructure Regulation shall connect to on-shore power supply and use it for all its electrical power demand at berth”*. The obligation for ports to provide on-shore power supply should be matched by a corresponding obligation for ships to connect to shore connections while moored.

A first scenario will be a vessel or several vessels at port with a total electric power consumption of 2000 kW, the same as defined for the OPS object of this study. That power will come from diesel generators onboard the vessel or vessels running with marine diesel oil (MDO) or marine gas oil (MGO). Such value cannot be converted directly on an energy value, as the engines have their own efficiency, and need to burn more energy that they can support to the grid onboard. This feature is already considered into the emission factors given by Fuel EU, as it defines the tonnes of CO<sub>2</sub> emitted from the tonnes of fuel burned.

Considering an average value of 200 g/kWh for the Specific Fuel Oil Consumption (SFOC) for a diesel engine running as a genset onboard a vessel, the consumption to obtain 2374 kW<sup>2</sup> of electric power during 6 hours per day results 2.4 ton/day, and 816 ton/year considering 340 days per year. Then the estimated emissions can be calculated with the previous values multiplied by the emission factor for different greenhouse gases.

Table 9: Estimated emissions due to electricity generated by gensets on vessels

	CO <sub>2</sub> emissions [tonCO <sub>2</sub> ]	CH <sub>4</sub> emissions [tonCH <sub>4</sub> ]	N <sub>2</sub> O emissions [tonN <sub>2</sub> O]
Per day (6 hours)	9.13	0.0001	0.0005
Per year (340 days)	3,105.31	0.0484	0.1743

For a whole year, 340 days have been considered in order to obtain comparable values with the ones to be obtained when the OPS connection includes a fuel cell, considering maintenance periods.

Unless CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O are all greenhouse gases, the total amount of CO<sub>2</sub> emissions expected is much bigger than the emissions of the other types of GHG. Any action or development in order to reduce the total CO<sub>2</sub> emissions will result much more beneficial to the environment than the same effort to reduce CH<sub>4</sub> or N<sub>2</sub>O emissions, in terms of their participation in the total amount of GHG emissions. From this point forward, CO<sub>2</sub> emissions will be considered as the total GHG emissions.

In the current situation, although neither all of the ports nor all the vessels have the ability to connect to an OPS connection, which is a scenario that need to be also considered: a vessel connected to a cold ironing connection directly from the grid.

On a similar way as considered on D6.3 from ENERCY, the carbon dioxide emissions associated to the consumption of the grid for cold ironing connections, depends on the emission factor of the electric system.

The national emission factor in Spain was 0.19 tonCO<sub>2</sub>/MWh in 2019, according to the values shown by *Red Eléctrica de España (REE)*. But from the information provided by *Autoridad Portuaria de Baleares' electricity supplier* at the Port of Palma for 2019, the resulting value is higher<sup>3</sup>:

Table 10: Total emission factor at Port of Palma (ENERCY BV, 2023)

	Electricity Consumption [kWh/year]	CO <sub>2</sub> emissions [tonCO <sub>2</sub> /year]	Emission factor [tonCO <sub>2</sub> /MWh]
Port of Mallorca	23,302,150	7,424.025	0.319

The amount of energy coming from the electric grid for a shore connection of 2374 kW during 6 hours per day for 340 days per year, considered maintenance periods, multiplied by the emission factor, results the estimated CO<sub>2</sub> emissions.

<sup>2</sup> According to chapter 2.2.2, considered for OPS, 2000 kW from grid plus the fuel cell electric power supply, 374 kW (fuel cell 85%).

<sup>3</sup> D6.3 from ENERCY

Table 11: Estimated CO<sub>2</sub> emissions due to electricity consumption per year

	Demand [kWh/year]	Emission factor [tonCO <sub>2</sub> /MWh]	CO <sub>2</sub> emissions [tonCO <sub>2</sub> /year]
Port of Mallorca (OPS)	4,842,960	0.319	1,545

Just on this point, **there is a relevant reduction of CO<sub>2</sub> emissions, near 50%, considering the electric power coming from diesel engines on the vessels or from the electric grid.**

This is one of the main objectives of the Fuel EU Regulations and other regulations from IMO with their entry in force in the upcoming years, to promote the OPS connection when mooring and the use of alternatives fuels when sailing.

### 3. Fuel cells selection

As already mentioned in other deliverables of the project (special reference to D6.3 from ENERCY), fuel cells using green hydrogen are an emerging technology with a bright future ahead due to their numerous advantages in terms of energy efficiency, emissions reduction and autonomy. Nowadays, the rise of this technology is due to the need to find new ways to provide clean and reliable energy. Using hydrogen produced from renewable sources, focused on solar energy for this project, green hydrogen fuel cells are a real, clean and sustainable option for energy generation.

Summarizing the main advantages of fuel cells, already mentioned by ENERCY on their deliverable, and included at INSTEIMED report:

- **High efficiency and versatile use:** Hydrogen fuel cells have electrical efficiencies that can reach around 60%, which means that a significant amount of the generated energy is usable. Additionally, during the electricity generation process in the fuel cell, heat is produced as a subproduct, increasing the total efficiency. But to the aim of this study, this heat power is not useful and would be discarded.
- **Low emissions:** Emissions of pollutants at fuel cells are lower than from other energy sources, and even can be zero in they are feed with green hydrogen, as this project's objective. In addition, the manufacturing process of the fuel cell can be controlled to minimized the environmental impact, with a significant reduction on the carbon footprint and negative impacts on air quality.
- **Simple maintenance:** Fuel cells generally require simple maintenance, without regular oil changes or filter replacement. Also, as they have no moving or mechanical parts, the possible failures are less compared with other energy sources.
- **Silent:** Fuel cells operate silently, thanks to the lack of mechanical parts, and generated minimal vibrations, making them suitable for applications where noise and vibrations should be avoided.
- **Energy storage:** The energy can be stored for a later use, supplying energy during high demand periods, which contributes to a greater stability and flexibility in energy management.

- **Modularity:** Several fuel cells can be connected in series, which means a greater flexibility and the possibility of grow the installation in the future if the demand or needs require it.
- **Durability and lifespan:** Unlike conventional batteries which degrade and lose their capacity over the time, hydrogen cells can retain their efficiency and performance even after long periods of use.
- **Flexibility and adaptability:** Fuel cells can be adapted to different environments and different applications, from stationary to portable applications, making them suitable for a wide range of applications.

There are different methods to supply hydrogen to the fuel cell, directly (pure hydrogen) or through reforming a fuel such as methanol, ethanol, etc. Since the use green hydrogen implies zero emissions in the process, due to the objective of avoiding emission of GHG into the atmosphere, the latter option is ruled out.

### 3.1. Market developments

There are different types of fuel cells on the market, basically differentiated by the electrolyte used, the fuel used, the operating temperature and the power range:

Table 12: Types of fuel cell main features (INSTEIMED, 2023)

Type	Electrolyte	Ion Transportation	Fuel	Temperature (°C)	Efficiency	Power per unit	Star-up time
PEM	Solid polymer	H <sup>+</sup>	H <sub>2</sub>	60 – 120	40/50% or 85%	1 W - 200 kW	>1 min
AFC	Aqueous solution KOH	OH <sup>-</sup>	H <sub>2</sub>	90 – 250	55% up to 70%	500 W - 10 kW	5-10 min
PAFC	H <sub>3</sub> PO <sub>4</sub> liquid	H <sup>+</sup>	H <sub>2</sub> hydrocarbon	175-200	40% or 80%	10 kW - 1 MW	1-4 hour
MFCF	Aqueous solution LIKCO <sub>3</sub>	CO <sub>3</sub> <sup>2-</sup>	H <sub>2</sub> hydrocarbon	650	60%	50 kW - 10 MW	5-10 hour
SOFC	Y-ZrO <sub>2</sub>	O <sup>2-</sup>	H <sub>2</sub> hydrocarbon	600-1000	60% or 75%	1 KW - 10 MW	30-50 hour

### 3.2. Needs to be met

It is important to analyse the operation conditions for this study in order to make the best decision and to select the most suitable fuel cell according to this application. (Reference made to INSTEIMED report).

- **High energy density.** Large amounts of energy will be required to meet the power demand. Therefore, it is necessary to search for a high energy density fuel cell.
- **Use hydrogen as the main fuel.** The purpose of this project, in order to contribute to the reduction of greenhouse gas emissions, starts at the generation of green hydrogen with photovoltaic panels, to be used for different applications.

- **Reduced start up times:** Since the flow of ships at port is not a constant, the energy demand will vary throughout the day. Hence, the selected fuel cell must be capable of delivering the maximum amount of energy in the shortest possible time to quickly meet these fluctuations.
- **High performance:** A higher fuel cell performance will enable better utilization of hydrogen, resulting in higher power output and greater energy efficiency.
- **Scalability:** It is important to this project the modularity of the fuel cell in order to upgrade the system in the future with other fuel cell units.

Looking at the previous chapter, a PEMFC (Proton Exchange Membrane Fuel Cell) is the most suitable for this study. This type of fuel cell **offers adequate efficiency, low start-up times, high power and they are also easily scalable**, which are the most suitable features for the application on this study.

### 3.3. Options comparative

Once the market has been analysed and the most suitable type of fuel cell selected for this application, it is necessary to look for several models in the market. The main features of different models, considered as the most convenient for this analysis, are shown below. (INSTEIMED)

Table 13: Fuel cell models main characteristics (INSTEIMED)

#### PMEFC models

EH81 – Fuel Cell Stack (100 kW)<sup>4</sup>

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Size (mm)	Weight (kg)	Temp. (°C)
100	110	450	230 - 500	400x120x610	78	65-80

FCwave<sup>5</sup>

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Size (mm)	Weight (kg)
100	200	2x300 1x550	350 720	122x738x2200	875

<sup>4</sup> Source: <https://hyfindr.com/marketplace/components/fuel-cell-stacks/pem-stacks/fuel-cell-stack-eh-81-100-kw/>

<sup>5</sup> Source: [www.ballard.com/fuel-cell-solutions/fuel-cell-power-products/marine-modules](http://www.ballard.com/fuel-cell-solutions/fuel-cell-power-products/marine-modules)

**Marine System 200<sup>6</sup>**

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Size (mm)	Weight (kg)	Efficiency
100	200	60 – 450	500 – 1000	700x900x2000	700	60%

**HyPM HD 180**

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Size (mm)	Weight (kg)
100	180	1000	2x180 - 360 or 360 - 420	1582x1085x700	720

**HyPM HD 100**

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Size (mm)	Weight (kg)
100	100	380	240 – 480	1150x1500x850	750

**GenSure HP<sup>7</sup>**

Minimum Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Weight container (kg)	Efficiency
60	1000	>80	480	<50.000	>50%

### 3.4. Fuel cell selection

Additionally, to the models shown above, there is another one that fits better to the requirements of this study, the model M400 Hydrogen fuel cell from DOOSAN.

M400 main characteristics<sup>8</sup>:

- Electric Power Output: 440 kW
- Electrical Connection: 480VAC, 50/60Hz
- Heat Grade @ up to 100°C: 0.295 Gcal/h
- Peak Overall Efficiency: 85%
- Electrical / Heat Efficiency: 48 / 37 %
- Length / Width / Height: 8.33 / 2.54 / 3.03 m (Power module)

<sup>6</sup> Source: <https://powercellgroup.com/product/marine-system-200/>

<sup>7</sup> Source: [www.plugpower.com/fuel-cell-power/gensure-backup-power/](http://www.plugpower.com/fuel-cell-power/gensure-backup-power/)

<sup>8</sup> Source: Doosan Fuel Cell Co., Ltd.

- Length / Width / Height: 4.85 / 2.31 / 1.85 m (Cooling module)
- Fuel: Hydrogen
- Fuel pressure: 5 bar
- Fuel Consumption: 297 Nm<sup>3</sup>/h
- Water discharge: 1.36 l/min
- Noise: 60 dB @ 10m
- Code & Standard: ANSI/CSA FC1-2012 (System), UL1741 (Inverter)
- Ambient Operation Temp. -29 to 45°C



Figure 15: Selected fuel cell

For its selection, the electrical efficiency, the electric power output, the operation conditions and the possibility of being synchronised with the grid, have been the key.

One of the main features considered is the maximum power output. For the aim of this project, only one fuel cell is being considered. Then, as much higher is the power supplied by the fuel cell, much lower is the electric power required from the grid, and finally, much higher is the GHG emissions reduction that could be achieved. The market is in a continuous development of new systems, and manufactures are immersed in a deep analysis of their products and designs, looking for better solutions and a wider range of operational profiles.

This fuel cell can be operated by a Remote Monitoring System (RMS), a remote access which allows any control of the fuel cell such as start-up, power output or shut-down commands. The communication between the operator and the fuel cell can be done through an internet connection. A wireless cellular modem is built-in this model. The RMS allows ramps up/down up to 20 kW/sec during regulation requirements of the grid.

Due to the location of the fuel cell, and even of the West Dock into the Port of Palma, this feature brings the opportunity to control and monitored the fuel cell operation from a remoted control centre, without the need of personnel on site.

Additionally, the fuel cell requires auxiliary services for its operation:

- Hydrogen supply line
- Nitrogen purge gas
- Water drain line
- Demi water supply
- Cooling module, using glycol as the coolant liquid

With the fuel cell under constant operation, its lifetime is around 20 years with replacement of the fuel stacks. As well, for a suitable condition during its lifetime, a maintenance of all the systems involved is required.

Synchronization and parallel connection of several power sources is done through specialized controllers and dedicated software implemented in such controllers. When adapting the voltage and frequency to be synchronized, the basis is the same: to rectify to DC (direct current) and then, using inverters, generate AC (alternating current) to be synchronized with the reference. Each equipment to adapt its voltage to the grid, includes its own controllers.

The fuel cell is able to connect and synchronize with 400 V/480 V networks, both 50 Hz and 60 Hz.

## 4. Generation plant for cold ironing

This study is based in the deployment of a shore connection at port and, as mentioned in previous chapters, it will be defined for ferry vessels calling port at the West Dock at the Port of Palma. That means a restriction on the design, not only at the port location but for the type of vessels.

Regarding the location, the system connections should be deployed from a transformation centre to the connection point, so not all the mooring berths will be available for the cold ironing connection.

And regarding the vessels, depending on the type of vessel and the voltage of their own grid, different vessels will have different plugs. Due to the occupation rate of the dock considered, ferry vessels have been selected for this analysis, so the new transformation centre and socket boxes will be prepared for ferry vessels. However, in a future development, the installation design could be adapted to allow a shore connection to other type of vessels by the use of a plug adaptation system.

Furthermore, also in the purpose of this study, is to include a fuel cell in the shore connection so that the power supply to the vessels comes both from a hydrogen fuel cell and the electrical network at port, including the connections to combine both energy sources in order to create a unique supply.

When handling hydrogen, the main concern is mitigating the risk of explosion. For such reason, several precautions have been considering in this study regarding the location and installation of the equipment, but additional ones need to be considered when operating the fuel cell

### 4.1. Location study

As defined in previous chapters, the analysis has been done for the development of a shore connection at the West Dock for the use of ferries. A suitable area needs to be selected at the West Dock considering the following precautions to minimize the risk related to explosion and any non-authorized access:

- The fuel cell and storage modules must be placed **separately from other ignition sources** or inflammable substances.
- The storage modules should be located in **open air**, ensuring adequate ventilation.
- All the equipment must be **protected against non-authorized access**.
- A **hazardous area** will be defined and marked on site, around the storage modules.

Ferry vessels need to be moored with their aft body at a specific part of the dock, allowing their ro-ro cargo to be loaded and unloaded. This issue limits the usable part of the docks for this type of vessels, but at the same time, brings a restriction to the shore connection location ashore.

In the figure below the possible mooring docks for ferry vessels are identified into a red circle.



Figure 16: Schematic view of the Port of Palma and West Dock Ro-Ro docks

After a general analysis of the dock arrangement, and due to its length and location of the mooring docks, the analysis will be focused on the 1<sup>st</sup> alignment, including Ribera de San Carlos dock, allowing four ro-ro ferries mooring location, shown in the figure below. In a future expansion of the cold ironing connections, the dock close to *Estación Marítima 6* is quite near to the others so the same location for the transformation centre could be useful. However, this mooring dock used to be used for cruise vessels, that have bigger power requirements, and it will probably require an extension of the shore connection.

Considering the 2<sup>nd</sup> alignment will require more than a transformations centre, in order to avoid the drop voltage due to the long distances.



Figure 17: Schematic view of the 1st alignment of the West Dock at the Port of Palma

In a first analysis, due to the network requirements and the dock arrangement, several limitations need to be kept in mind (INSTEIMED):

- **Socket boxes**

Due to the drop voltage produced from the new transformation centre to the mooring docks, the distance between both will lead to a limitation on the socket boxes for high voltage connections.

**Number of socket boxes in the West Dock**

- 2 socket boxes for low voltage
- 4 socket boxes for high voltage

- **Vessels**

As mentioned before, only ferry vessels could be supplied from the new transformation centre for high voltage. It is due to each type of high voltage vessel needs a different plug for their connection. In the future, the installation could be adapted to allow other types of vessels with a plug adaptation system.

#### 4.1.1. Required area and zones identification

Thinking on future development and extension of the shore connection and because of the current uses of the exiting areas, the most suitable zone to install the transformation centre seems to be between both alignments, 1<sup>st</sup> and 2<sup>nd</sup>. There is a quite extensive zone between the road and the *Estación Marítima 6* that brings enough area to the shore connection equipment installations keeping a safe area around it in order to avoid future pedestrian corridors or areas.

The new system installations will require, additionally to the socket boxes close to the vessels mooring areas, enough area to arrange:

- Transformation centre
- Fuel cell
- Hydrogen storage area

For coherence with other deliverables in the GREEN HYSLAND project, regarding the hydrogen supply and storage, the same type of modules will be selected for this analysis.

As the zone on the West Dock is quite extensive, the system installation could be considered in an enclosed area, in order to avoid non-authorized access, but enough to demarcate the operational areas and even the hazardous areas.

#### 4.1.2. Limitations and design configuration

Different vessels, with different power requirements and different electric networks will require different output values from the shore connection.

Thinking on the fact that several vessels could require a shore connection simultaneously as mentioned on chapter 2.3.2, the system would be designed in order to full fill with those situations. In the table below different scenarios to be taken into account are shown.

Table 14: Scenarios analysis for vessel's power requirements (INSTEIMED)

Number of ships	Ship #1			Ship #2			Ship #3			Total power (MVA)	Notes
	Power (MVA)	Voltage (kV)	Frequency (Hz)	Power (MVA)	Voltage (kV)	Frequency (Hz)	Power (MVA)	Voltage (kV)	Frequency (Hz)		
1	2.5	11	50 o 60							2.5	
1	1	0.4	50							1	
1	1	0.44	60							1	
2	1.25	11	50	1.25	11	50				2.5	
2	1.25	11	60	1.25	11	60				2.5	
2	0.5	0.4	50	0.5	0.4	50				1	N1
2	0.5	0.44	60	0.5	0.44	60				1	N1
2	1	0.4	50	1	0.44	60				2	
2	2.5	11	50 or 60	0.5	0.4	50				3	N1
2	2	11	50 or 60	1	0.4	50				3	
2	2	11	60	0.5	0.44	60				2.5	N1
2	1.5	11	60	1	0.44	60				2.5	
3	2	11	60	0.5	0.4	50	0.5	0.44	60	3	N1
3	1.5	11	60	1	0.4	50	0.5	0.44	60	3	N1
3	1.5	11	60	0.5	0.4	50	1	0.44	60	3	N1
3	1.25	11	60	0.75	0.4	50	1	0.44	60	3	
3	1.25	11	50	1.25	11	50	0.5	0.4	50	3	N1
3	1.25	11	60	1.25	11	60	0.5	0.4	50	3	N1

*Remarks:*

N1. Unhelpful combination. Available power will be insufficient in most cases.

N2. Combinations involving a maximum available power of less than 1.25 MVA at 11 kV or 0.5 MVA at 400 V or 440 V have not been considered.

*Limitations:*

- All 11 kV powered vessels shall operate at the same frequency.
- If a vessel is powered at 440V @ 60Hz, 11 kV vessels may only be powered at 60 Hz.
- If the 400 or 440V shore connections (LVSC1 and LVSC2) are used, the corresponding 11 kV shore connection (HVSC1 or HVSC2) will not be available.
- Maximum available power at 60 Hz: 2.5 MVA
- Maximum power at 11 kV: 2.5 MVA. It would be lower if used simultaneously with 440V.
- Maximum available power combining 50 and 60 Hz vessels: 3MVA
- In order to allow the supply of two low voltage vessels of the same voltage, the maximum power would be less than 1 MVA.
- If two vessels are powered in HV (High voltage), the connections shall be made in opposite corners of the dock (Ship A-HVSC1 or HVSC2 and ship B-HVSC3 or HVSC4)

### 4.1.3. Attachment point

In relation to the power supply of the project installations, the system would have an independent attachment point for high voltage to the existing electrical grid.

Table 15: High voltage attachment point (INSTEIMED)

Attachment point	REF	U	Location
High voltage	CT 12	15 kV	1 <sup>st</sup> alignment of West Dock

In this high voltage attachment point to the power supply at the West Dock, the existing conductor between both transformation centres is RH5Z1 12/20 kV 1x150 mm<sup>2</sup> Al.

The main characteristics of this high voltage attachment point are:

- Nominal voltage: 15kV
- Short-circuit power: 350 MVA

(Reference made to INSTEIMED report in Appendix).

## 4.2. Distribution system

### 4.2.1. Location and connection points

To manage, control, supply and distribute of the electrical power from the electric grid of the port to the socket boxes close to the vessels, a new transformation centre (CT13) is required to be installed. The proposal is shown in the drawing n.03973-E03\_00 *Scope of action* (INSTEIMED) in Appendix. This new transformation centre will be supplied from existing transformation centres CT12 and CT14.

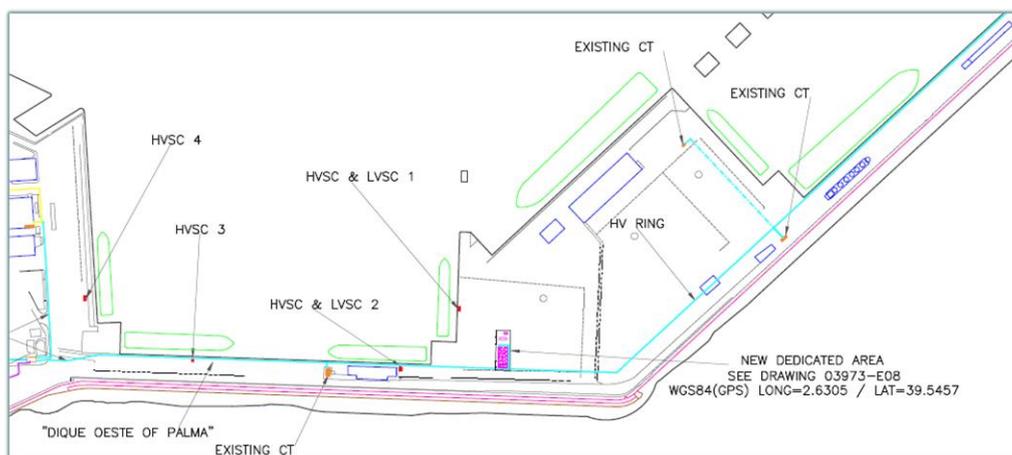


Figure 18: Transformation centre location (INSTEIMED)

From this CT the electrical power would be supplied to the vessels at four different mooring locations as described on previous chapter (4.1).

Then, there will be two types of socket boxes:

- High voltage socket boxes prepared for 11 kV, 50/60 Hz and 2.5 MVA.
- Low voltage socket boxes prepared for 400 V, 50 Hz, 1 MVA or 440 V, 60 Hz, 1MVA.

Solutions for the different tension grids are detailed at INSTEIMED report in Appendix.

#### 4.2.2. Control and automation

The system for the control, monitoring and automation of all the equipment and systems will be a PEMS (Power Energy Management System), composed of (INSTEIMED):

- **Energy management**  
Its function is to organize the energy supply, i.e. to organize the number of the vessels that can be supplied with the cold ironing installation depending on the power consumption and the time required of connection. It will also control de energy consumption.
- **Power management**  
Its function is to determine the status of the power plant, monitoring electrical parameters of the system, connections and transformers in use and their load. Furthermore, it is responsible of the control and synchronization of the two power supplies (network and fuel cell) in order to optimize the use of the fuel cell.
- **Control and safety**  
It monitors all parameters which can produce an alarm or a shutdown of the shore connection. This system includes communication with the ship's control and safety system for the shore connection. In addition, this system will be connected with the fuel cell control system in order to centralize all the alarms and safety connections to the OPS (Onshore Power Supply).

The energy source control strategy is based on ensuring the previously planned service and regulating the contribution of energy from the grid or from the fuel cell, as described in the following table:

Table 16: Energy source control (INSTEIMED)

	Demanded power (MVA)	H2 not available				H2 sufficient for the planned service				H2 not sufficient for the intended service			
		Grid (MVA)	Network (%)	Fuel cell (MVA)	Fuel cell (%)	Network (MVA)	Network (%)	Fuel cell (MVA)	Fuel cell (%)	Network (MVA)	Network (%)	Fuel cell (MVA)	Fuel cell (%)
<b>1</b>	2.5 up to 3	Operation NOT POSSIBLE				2 – 2.5	80 – 85	0.5	15 – 20	Operation NOT POSSIBLE			
<b>2</b>	0.5 up to 2.5	0.5 – 2.5	100	0	0	0 – 2	0 – 80	0.5	0 – 20	Necessary less provided by fuel cell		Reduced contribution See note 1	
<b>3</b>	0 up to 0.5	0 – 0.5	100	0	0	0	0	0.5	100	Necessary less provided by fuel cell		Reduced contribution See note 1	

Notes:

1 – If there is not enough H2 for the planned duration of the service, the energy input of the fuel cell shall be reduced to a rate that allows the planned service to be completed.

2 – The control system shall reduce the fuel cell input in case a subsequent operation with a requirement > 2.5 MVA is scheduled.

3 – This energy control system has been defined considering first the use of the fuel cell, when available. According to the data considered, the resulting electricity from the grid will be more cost competitive than fuel cell electricity. Note that a pure grid connection for cold ironing is already considered and in use at different port facilities (see chapter 8). Such conventional arrangements are not considered within the scope of this study, which is focused on the use of an hydrogen fuel cell in an onshore power supply.

The following figure shows a schematic view of the control system for the fuel cell:

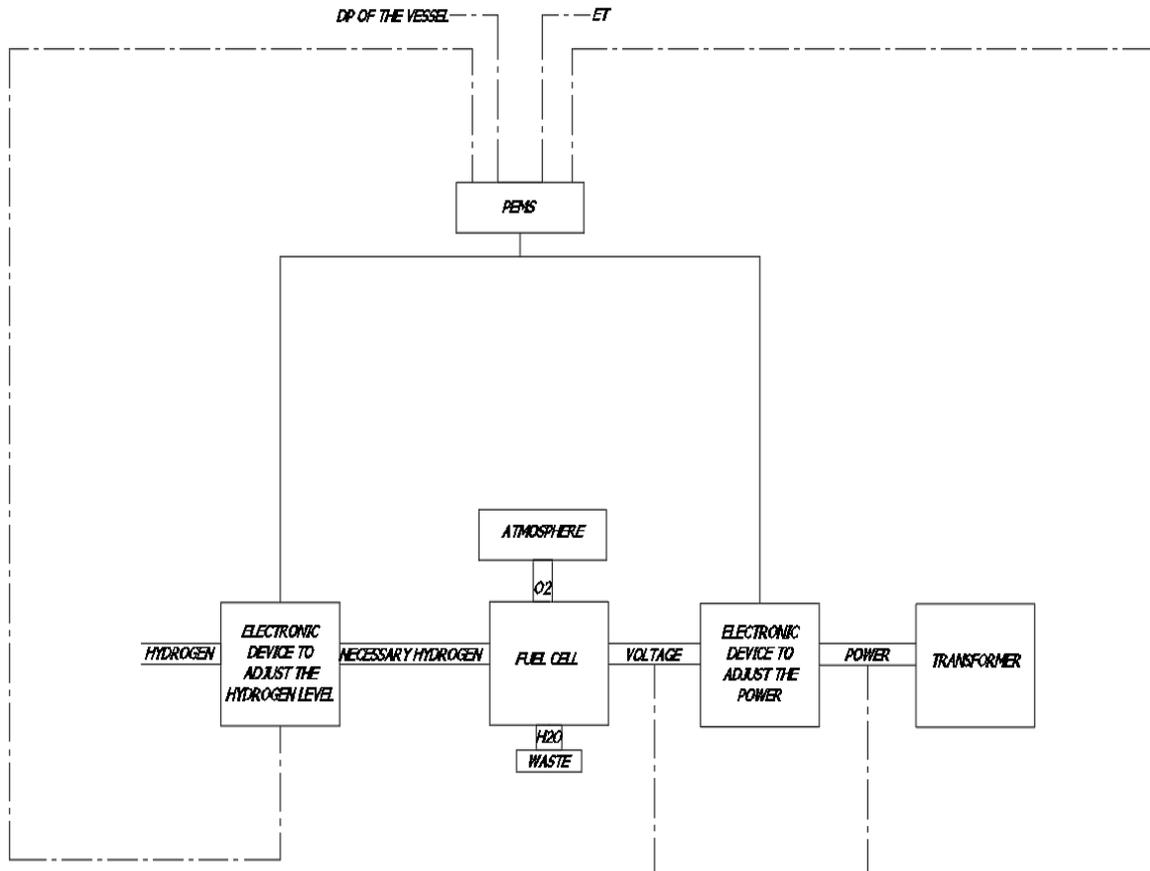


Figure 19: Fuel cell control system schematic view (NSTEIMED)

The electronic device responsible for the control of the hydrogen supply is the Mass Flow Controller (MFC), which regulates the precise flow rates to the flow cell. For this purpose, a sensor is used to control a valve in the supply pipeline in order to adjust the necessary flow according to the demand and the system requirements.

### 4.2.3. Fuel cell auxiliary systems

#### 4.2.3.1. Nitrogen purge gas

Before starting or stopping the fuel cell, a complete checking procedure is carried out in order to ensure that the complete system is on a safe state. As a part of this procedure, the system lines and the fuel cell stacks, need to be filled with an inactive gas, normally nitrogen is used.

In case of fuel disconnection or a failure when running, the nitrogen purge system will operate to secure the fuel stacks, and a re-start will be required.

A deeper analysis of the fuel cell requirements, data from vendor required, and the complete hydrogen installation would be required to define the total amount of nitrogen required for the purge gas system. As good practice, considering equivalent nitrogen to at least 3 or 5 times the total volume required is recommended.

#### 4.2.3.2. Emergency shutdown device (ESD)

In case of dangerous situation, the shutdown of part or the complete installation will be controlled by an Emergency Shutdown Device (ESD).

#### 4.2.3.3. Water from the fuel cell

From the normal operation of the fuel cell, it generates water on a rate of 1.36 l/min. For a daily operational profile of 6 hours per day, a total amount of 490 litres per day will be generated. Considering 340 days of operation per year, that means 166464 litres in a year of pure water. It could be led to the water waste line at the port, but considering collecting it at the fuel cell output to be reused at other installations of the port will be the most environmentally friendly solution.

#### 4.2.3.4. Glycol cooling system

A glycol cooling system is required for the fuel cell cooling itself. Glycol cooling systems use a mixture of glycol and fresh water in the proportion set by the vendor of the equipment to be cooled.

## 5. Hydrogen storage and supply system

The fuel cell container from the supplier, contains several bottles inside for hydrogen storage already prepared for its supply to the fuel cell. These bottles need to be feed from an additional hydrogen storage system outside the container.

In accordance with other deliverables in the GH project, specially D6.3 from ENERCY, the same hydrogen storage system has been selected. In D2.5 from CALVERA "*Connecting Infrastructure Transportable storage module specification issued*", different storage modules are defined to supply hydrogen from the H2 generation plant to end-users. There are mainly defined tube trailers for the hydrogen transport and mobile storage to be located at the end-users location. As described in D2.5, these mobile storage modules were finally considered to be fixed, in order to be filled locally at the Maritime Station (D6.3) from a tube trailer.

To the aim of this study, for a better coherence with the whole project, the same modules have been considered.

### 5.1. Storage requirements

The modules defined by CALVERA at D2.5 for H2 mobile storage have the following features:

- 6 bottles per rack (vertical)
- Operating pressure: 300 bar
- Capacity per cylinder:  $0.153 \text{ m}^3 \pm 2.5\%$
- Storage capacity:  $0.918 \text{ m}^3$
- Hydrogen capacity: 19.38 kg at 15°C
- Size of module (mm): 2525 x 1157.5 x 815.5

Considering the fuel cell running continuously during 6 hours each day, at 85% of its maximum power output, with the data from vendor, the following consumption data are obtained:

Table 17: H2 consumption

<b>CALCULATIONS</b>	
<b>H2 CONSUMPTION</b>	
Working time per day	6 hours
Working days per year	340 days
Daily energy	2244 kWh
Yearly energy	762,96 MWh
Daily fuel consumption	1782 Nm <sup>3</sup>
Daily fuel mass	149,86 kg
Yearly fuel mass	50,95 t/year

With these results, at least 8 modules as defined before would be required to storage enough H2 for a day of operations. Then, all the storage bottles should be re-filled every day, or the empty modules replaced with full modules.

Table 18: Fuel cell energy balance

<b>CALCULATIONS</b>	
<b>ENERGY BALANCE</b>	
Net power	374 kW
H2 mass flow	25,0 kg/h
H2 energy	120 MJ/kg
H2 power	832,53 kW
Efficiency	44,92%
Heat losses	458,53 kW
Heat losses	55,08%
Waste water	1,36 l/min
Daily water	489,6 l/day
Yearly water	166464 l/year

## 5.1. Supply systems

As mentioned before, the fuel cell container from the supplier, contains several bottles inside for hydrogen storage, and additional bottles will be installed outside the container. The inner bottles store the hydrogen in the required conditions to be supplied to the fuel cell.

The supply system to the fuel cell can be divided into two different stages:

- 1<sup>st</sup>: the supply for the outer storage bottles to the inner ones, and
- 2<sup>nd</sup>: the supply from the internal bottles to the fuel cell.

The second stage will be directly controlled by the control and monitoring system of the fuel cell, which will manage the supply features in order to ensure the hydrogen supply to be into the pressure range required for the correct running of the fuel cell.

The first stage needs an additional control system in order to control the hydrogen pressure, reducing it into the appropriate range.

The external bottles considered, modules designed by CALVERA at D2.5, could be re-filled or replaced. Considering a similar scenario as at D6.3 from ENERCY, these modules will be considered fixed, and they will be daily re-fill with the hydrogen tube trailers already designed by CALVERA at D2.5. Similar filling panel is being considered.

CALVERA tube trailer characteristics:

- 143 vertical cylinders
- Capacity per cylinder: 0.153 m<sup>3</sup> ± 3.5%
- Storage capacity: 21.87 m<sup>3</sup>
- Hydrogen capacity: 462 kg at 15°C
- Operating pressure: 300 bar
- Operating temperature: -20/+65°C
- Size (mm): 9125 x 2438 x 2215

## 5.2. Hazardous areas

Hazardous areas have been defined all around the H2 storage modules and H2 tube trailer, in the case while fuel transferring, as shown in the figure below and with the following considerations:

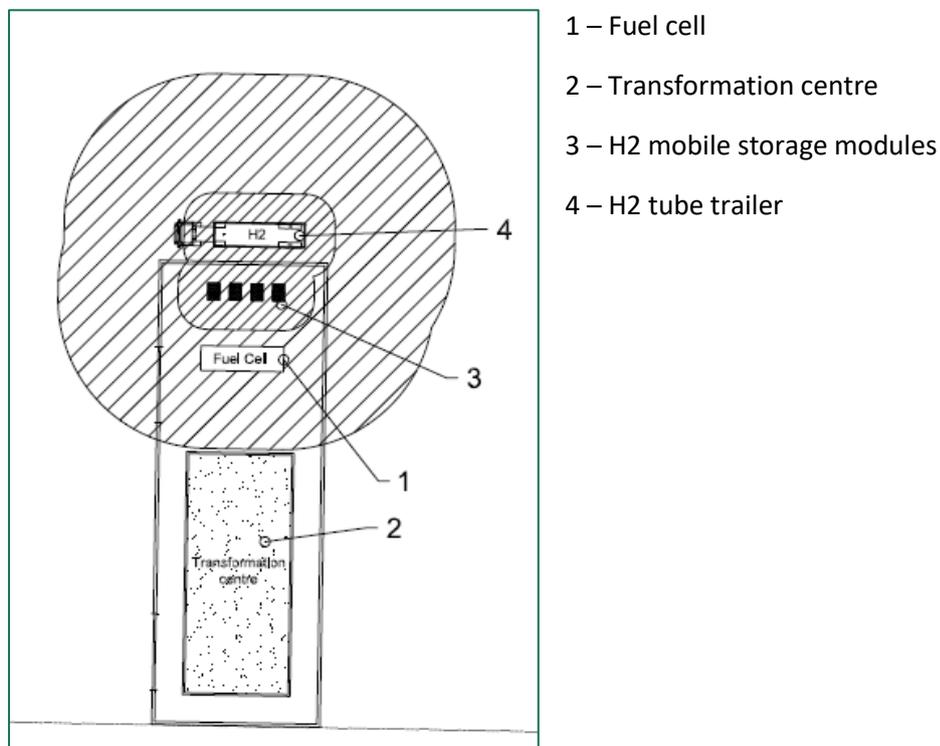


Figure 20: Hazardous areas

Considerations:

- The fuel cell is an enclosed space, so it does not generate a hazardous area outwards.
- The transformation centre has been located outside of the hazardous area, in order to avoid additional requirement for the electrical equipment associated to the cold ironing connection.
- A primary hazardous area of 3 meters distance has been considered both all around the H2 storage and tube trailer, as an exclusion area while operating.<sup>9</sup> A HAZOD (Hazardous and Operability Study) would define the exclusion areas, if required, relation to the operation in terms of the cold ironing connection, fuel cell operational features, H2 storage and transfer operations, but even operations at port in the areas next to the one considered.
- The whole hazardous area includes a major area that could be reduced with the location of a retaining wall:
  - Walls around the whole cold ironing station (including the transformation centre, the fuel cells and the H2 storage modules), could be designed as a retaining wall so the hazardous area outwards the station will be limited to the hazardous area generated from the H2 tube trailer truck.
  - The whole station could be re-arranged or re-designed in order to leave available space for a truck trailer inside, with the corresponding access doors. In such case, neither in operation of the fuel cell, nor while H2 transferring from the tube trailer to the storage modules, no hazardous area would exist outside the enclosed station.
  - Any other solution could be analysed at the corresponding HAZOD in order to avoid any conflict with any other operations at port.

### 5.3. Alternative solutions

As mentioned above, and for coherence with other deliverables in the project, the same storage modules have been considered for this study, and with the same considerations for the mobile storage modules as made at deliverable D2.5 from CALVERA.

However, alternatives solutions could lead into a more simple and safer solution. Options below could be considered:

- *One H2 storage tank*

It is a solution quite similar to the one considered but only with one storage tank, with means a significant reduction of the potential leakage points from the storage system. This solution would also require a regular tube trailer to be connected to the tank, so the hazardous area associated with the trailer would have the same considerations.
- *H2 mobile storage*

The truck would remove the empty modules and replace them with full modules. The truck would have no hydrogen supply connections, so it would not generate any hazardous area.

For both solutions, the hydrogen storage should be re-design according to the consumption requirements, considering also the possible future extensions of the fuel cell installations.

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<sup>9</sup> IEC 60079-10

## 6. Other aspects to be considered

### 6.1. Safety systems

Hydrogen is considered an excellent clean fuel, but there are serious safety concerns associated with the hydrogen process, as for other fuels and flammable substances. Hydrogen features and associated hazards can be summarized as follows:

- Low density (84 g/m<sup>3</sup> at 15°C and 1 bar), and hydrogen accumulation on the upper part of spaces. At the same time, reducing the risk of ignition at ground level in case of a leakage or an unintentional release.
- Wide range of flammability (LEL 4% vol – UEL 75.6% vol). Creation of an explosive atmosphere due to hydrogen concentration on air.
- Low minimum ignition energy (0.019 mJ)
- High burning velocity
- High leakage probability, due to the small size of the molecule and low viscosity
- Chemical reaction with oxidant agents
- Invisible and very hot flame during hydrogen burning

A risk assessment is to be conducted to ensure the analysis of all risks arising from the use of hydrogen as fuel that could affect people and the environment. In this analysis, hazards associated with installation, layout, operation and maintenance must be considered.

From the risk assessment the safeguards, operational procedures and additional safety systems are defined for each hazard analysed, so hazard could be eliminated or mitigated.

Concerning operation and maintenance, the manuals and procedures of the equipment will be used as the guide for the correct use of them, where the associated hazard for each operation is already considered.

As general advice for hydrogen handling, the following preventive measures, for installation, operation and maintenance, should be considered (*Abelló Linde, S.A.*):

- Hydrogen storage areas will be place in well-ventilated areas. Open air is considered in this study for the hydrogen storage modules. However, the selected fuel cell is enclosed in a container will additional hydrogen storage bottles inside. The safety issues regarding this container are considered out of the scope of this study, as they are inherent to the vendor fuel cell design. A deeper analysis should be developed with the final vendor, in case of installation, in order to obtain a general view of all the safety issues regarding the complete installation. For this study, the container is being considered safe itself.
- Hydrogen storage modules and pipes will be pressure tested according to rules requirements and to their operational pressure. Blind flanges and threaded joints will be avoided as far as possible.
- Leakage prevention measures to be considered, reducing as much as possible the non-welded connections in the hydrogen lines. Leakage detectors to be installed as necessary.
- Vent lines from the safety valves to be installed in open-air, in order to guarantee the correct dispersion of hydrogen to the atmosphere in case of a safety valve activation. These outlets will be placed separately from any ventilation inlet and clearly marked in their vicinity, so in

case of any hot works required, personnel were aware of the necessary safety measure to be taken.

- Hydrogen supply lines will have a close valve in the inlet to an enclosed space. This would be considered in the connection from the outdoors storage modules of hydrogen to the fuel cell container.
- An alarm system, including explosimeter where required, should be installed to control and monitored any eventual hydrogen concentration.
- In case of a hydrogen leakage, the installation becomes no safe. The procedure will ensure the correct way to make it safe again, being needed to depressurize, purge and repair.
- All the area including hydrogen storage and pipes, including surrounding area, will be considered as explosive atmosphere risk area<sup>10</sup>.
- All the electrical equipment installed and used during operation and maintenance should be classified for their use in explosive atmospheres.
- Hot working only allowed at working areas hydrogen free, to be checked with an explosimeter, and keeping in mind that sparks when working could fly up to 10 meters.
- Prior the start-up of the hydrogen system, all the oxygen shall be thrown out. The safer method is using an inert gas, nitrogen is considered in this study.
- In case of an uncontrolled hydrogen leakage, the gas supply should be immediately stopped, using all the necessary controls.

## 6.2. Regulatory aspects and social acceptance

There are currently different regulations concerning the operation of vessels at port that demand solutions that allow vessels to connect their own network to the port electrical grid.

From a local point of view, Ports of Balears regulates the noise levels from the decks of vessels and boats at their ports (*Ordenanza portuaria por la que se regulan las actividades generadoras de ruidos en la cubierta de buques y embarcaciones en los puertos de la APB*)<sup>11</sup>. The West Dock is not the closest dock to the city of Palma, but any noise reduction that could be achieved will contribute to the port general noise reduction. The fact of shutdown the diesel generators in the vessels and connecting them with a cold ironing connection, will have an important reduction of the noise from vessels.

An important outcome from this project is the social acceptance. Islands are territories highly dependent on maritime connections, for goods but also for passengers, as tourism plays a very important role in the island.

Noise in the cities coming from the industrial areas in their vicinity have a direct impact in the citizens, and measures to reduce noise have a positive outcome in the social acceptance of such industry.

The same fact means a reduction of the pollutant emissions from vessels at port, which will have an important impact on the public concerns, even greater if part of the electrical power supplied comes from a zero-emissions source of power.

This project main objective is using a hydrogen fuel cell to supply part of that electrical power. At a first stage, there is no doubt that using a zero-emissions source of power leads to a positive acceptance

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<sup>10</sup> UNE-EN IEC 60079-10-1, ISO-19880 and other relevant regulations

<sup>11</sup> According to Resolution of the 27<sup>th</sup> of February of 2020 of the *Ministerio de transportes, movilidad y agenda urbana*.

from the local population. But at the same time, it brings a new and unknown scenario of the use a new technology with a highly flammable fuel. It becomes a safety issue.

Hydrogen is certainly a highly flammable product, but it has been already used in other industries. Hydrogen presents itself as one of the most viable energy alternatives, being currently many studies under development for its use and implementation in different industries and applications. Handling procedures must be developed and implemented, and new regulations are still being developed. In this sense, a dissemination and training process is necessary for all the people involved in any part of the process, but it is even important for the local population.

And there, included in the Green Hysland project, all the partners are involved in different dissemination and communication activities. There is an important knowledge gained on the deployment of each of the studies, analysis and activities that should be shared with other sectors, including the public sector, as they would play a key role in the social acceptance.

There is a growing interest of citizens toward the adoption of green technologies, demanding more information about the advantages and benefits of the transition to this energy source. But citizens are concerned about the safety of hydrogen, mainly related to storage sites, transportations and use of pipelines. Knowledge and trust in the technology are essential for a correct implementation in society, where the dissemination work of this and other projects plays a fundamental role.

From a global point of view, new regulations are being developed to minimize GHG emissions. The European Green Deal aims to reduce net GHG emissions by at least 55% by 2030, aiming to become the first climate-neutral by 2050

The European Commission has adopted a set of proposals to achieve that objective, and particularly for vessel's operation, several indicators have been defined in order to evaluate the GHG emissions rate of vessels.

As already mentioned in chapter 2.4, Fuel EU Article 5 establishes that *"From 1 January 2030, a ship moored at a quayside in a port of call State which is covered by Article 9 of the Alternative Fuels Infrastructure Regulation shall connect to on-shore power supply and use it for all its electrical power demand at berth"*.

Then, the Ports will have a relevant role on this matter, as they will have the obligation to provide on-shore power supply (OPS) for vessels that will have such obligation. As public sector, they have the necessary tools for both implementation and dissemination of different solutions aimed to achieve the objectives of Europe.

That means that Europe is already considering the scenario object of this study, where an additional value is given considering also a fuel cell for the OPS.

## 7. Risk analysis

The objective of a risk analysis is to ensure that any risk arising from the installation and operation of the hydrogen fuel cell installation, including hydrogen storage and fuelling operations, is known and controlled, with adequate safety barriers to reduce the risk to As Low As Reasonably Practicable (ALARP).

The analysis aims are:

- Review the general layout of the hydrogen installation and the safety systems.
- Identify all major accidental events and other hazards with respect to the fuel cell installation.
- Ensure that the risks are eliminated or reduced to ALARP by mitigating and preventative safeguards.
- Identify action opportunities for risk reduction, such as any additional or alternative safeguards applicable to the design or the operation.

An overview of the risk analysis methodology<sup>12</sup> is given in the figure below:

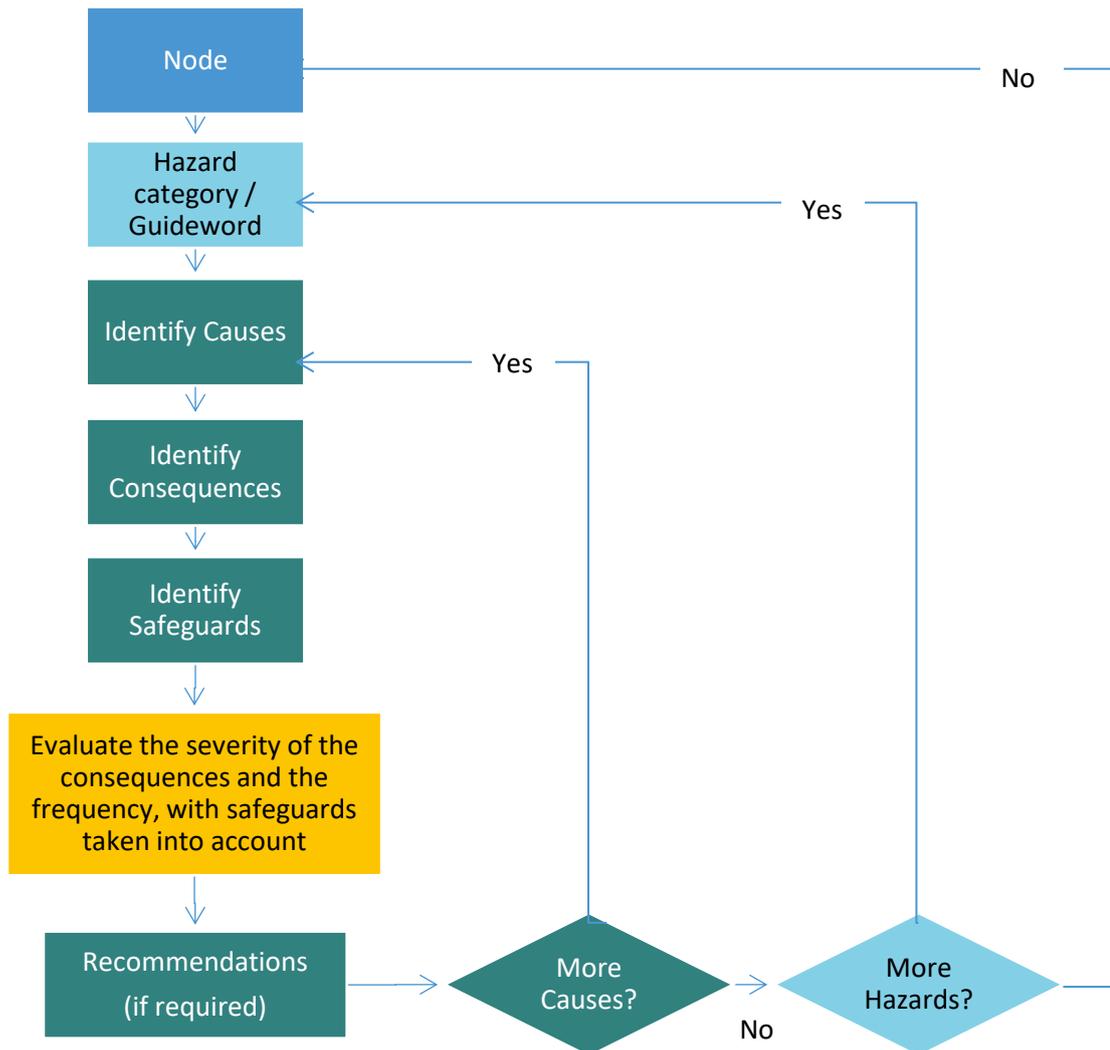


Figure 21: Risk analysis methodology (Bureau Veritas Solutions Marine & Offshore)

A safeguard is a prevention or mitigation method which can decrease either the frequency or the causes or the severity of the consequences of the hazardous event.

<sup>12</sup> Source: Bureau Veritas Solutions Marine & Offshore

The risk is defined as a combination of the likelihood and the severity of the consequences of each scenario.

Table 19: Likelihood index (IACS, 2016)

Cat.	Descriptor	Description
1	Remote	1 in a million per year or less
2	Extremely unlikely	between 1 in a million and 1 in 100,000 per year
3	Very Unlikely	between 1 in 100,000 and 1 in 10,000 per year
4	Unlikely	between 1 in 10,000 and 1 in 1,000 per year
5	Likely	between 1 in 1,000 and 1 in 100 per year
6	Very likely	1 in 100 per year or more

Table 20: Consequence severity index (IACS, 2016)

Cat.	Descriptor	Personnel Safety	Environment damage	Assest damage
A	Minor	Single or multiple minor injuries	Limited and reversible damage to sensitive areas/species in the immediate vicinity	Local equipment/structural damage Limited loss of operation (several hours)
B	Significant	Major injury - long-term disability / health effect	Significant but reversible damage to sensitive areas/species in the immediate vicinity	Non-severe damage Significant loss of operation (several days)
C	Severe	Single fatality or multiple major injuries	Extensive or persistent damage to sensitive areas/species	Severe damage Severe loss of operation (several months)
D	Catastrophic	Multiple fatalities	Irreversible or chronic damage to sensitive areas/species	Total loss

From the categorization of frequency and consequence severities from the tables above, a risk matrix is defined to identify the impact of the analysed risk.

Table 21: Risk Matrix (IACS, 2016)

		Frequency (chance per year)					
		Remote	Extremely unlikely	Very Unlikely	Unlikely	Likely	Very likely
		1	2	3	4	5	6
Consequence (severity)	Catastrophic D	M	M	M	H	H	H
	Severe C	L	M	M	M	H	H
	Significant B	L	L	L	M	M	H
	Minor A	L	L	L	L	M	M

Where:

- *High Risk*: The risk is not mitigated as necessary. Additional or alternative mitigation measures must be identified and implemented before operation, and these must reduce the risk to medium or low.
- *Medium Risk*: The risk is tolerable and considered mitigated as necessary. This assumes that all reasonably practicable mitigation measures have been implemented.
- *Low Risk*: Where practical and cost-effective, the implementation of mitigation measures would reduce the risk, considering it as an acceptable risk.

A continuous risk analysis is required through the whole GREEN HYSLAND project to ensure the proper management of all the design, installation, operational and maintenance risk, in order to implement the corresponding safeguard and measures to mitigate the risks ALARP.

Corresponding to the deployment phase of the GREEN HYSLAND project, and included in the deliverable D3.1 (Enagás S.A., 2022) its own risk assessment was already analysed, covering areas such as the safety and aspects of a regulatory nature. Also, in the deliverable D6.3 (Energy BV, 2023), a study on the decarbonisation of the sea-ferry stations at Balearic Ports, using a fuel cell at the Port of Palma, includes an extension of the risk analysis previously done by Enagás S.A. This study (D6.3) has a strong connection with the current one, being both focused on the use of a hydrogen fuel cell to the supply of electricity to the maritime terminals in case of D6.3, or as part of a cold ironing connection (OPS) to vessels moored at port, in the current case.

Then, using deliverable D6.3 from Energy BV as a reference, all risks and mitigation measures considered need to be kept in mind for this study. The following table shows a summary of the risks already considered in D6.3.

Table 22: Risk matrix of the system analysed on D6.3 (ENERCY BV, 2003)

Risk description	Frequency	Severity	Risk
Equipment defects; cannot be used	Extremely unlikely	Severe	Medium
Delivery delays	Unlikely	Severe	Medium
Changes in the expected H2 consumption	Extremely unlikely	Significant	Low
Failure during operation	Unlikely	Severe	Medium
Incidents associated to the operations	Unlikely	Severe	Medium
Delays in the execution	Extremely unlikely	Significant	Low
Safety concerns of the general public	Very unlikely	Severe	Medium

To extend such assessment, a risk analysis has been made for the risk concerning the operation and maintenance of hydrogen storage and equipment.

The following nodes have been considered for such assessment regarding the hydrogen installation, in order to obtain a complete review of the hazards associated to the whole system:

1. Hydrogen storage
2. Hydrogen piping between storage and fuel cell
3. Fuelling operations
4. Vent lines

As the fuel cell is enclosed in a container, from vendor supply, the whole container has been considered as an equipment itself, keeping in mind that a specific risk assessment should be carried out from vendor for the internal equipment. For the purpose of this study, very specific hazards that could be derived from the specific arrangement of the fuel cell system have been left out.

No additional hazards have been identified regarding the connection to vessels. Such connection does not depend on the energy source as there will be a transformation centre where both energy sources, electrical port grid and fuel cell, are mixed and delivered to the vessels. The hazards to be analysed are regarding the hydrogen storage, handling, operation and maintenance.

**Node 1: Hydrogen storage**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking			
					F	S	R	
1. Loss of containment	1. Hydrogen leaks	1. Loss of integrity of the hydrogen bottles	Potential hydrogen vent to the atmosphere. Explosive mixture. Potential fire and explosion.	Recognized standards design Maintenance plans Open space System monitoring	2	Extremely unlikely	B Significant	L
		2. Leaks from piping /valves	Potential hydrogen vent to the atmosphere. Explosive mixture. Potential fire and explosion.	Maintenance plans Open space System monitoring Welded pipes	3	Very Unlikely	B Significant	L
2. Operational hazards	1. Operational hazards when fuel cell operation	1. Hydrogen bottles empty	Loss of hydrogen supply to the fuel cell. Not a safety issue, economical and environmental issue.	System monitoring	6	Very likely	A Minor	M
		2. Under-pressure in the hydrogen bottles	Loss of hydrogen supply to the fuel cell. Not a safety issue, economical and environmental issue.	System monitoring	6	Very likely	A Minor	M
		3. Hydrogen trapped in the system	Not an issue					
		4. Insufficient hydrogen consumption	Not an issue					

**Node 1: Hydrogen storage**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking			
					F	S	R	
2. Operational hazards	1. Operational hazards when fuel cell operation	5. Fire on hydrogen racks space	Potential escalation to hydrogen racks	Not ignition sources Hydrogen bottles closing valves Port watching procedures Port fire-fighting systems and procedures	3	Very Unlikely	B Significant	L
	2. Operational hazards during hydrogen storage filling	1. Supply not correctly connected to fuel cell container after filling operations (operator error or valve failure)	Potential hydrogen vent to the atmosphere. Explosive mixture. Potential fire and explosion.	Hydrogen bottles closing valves Start-up procedures	3	Very Unlikely	C Severe	M
		2. Fire on hydrogen storage area	Potential escalation to hydrogen racks Potential escalation to hydrogen piping Potential escalation to hydrogen supply trailer	Not ignition sources Hydrogen bottles closing valves Hydrogen supply trailer closing valves Port watching procedures Port fire-fighting systems and procedures Personnel training	3	Very Unlikely	B Significant	L
	3. Operational hazards during hydrogen installation start-up	1. No causes identified						

**Node 1: Hydrogen storage**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking				
					F	S	R		
2. Operational hazards	4. Loss of related and auxiliary systems	1. Loss of glycol system	Not applicable						
		2. Loss of nitrogen system	Not applicable						
		3. Loss of control system of fuel cell	Not applicable						
	5. Maintenance of hydrogen installation	1. Inaccessibility to hydrogen racks to be inspected	Damage not detected. Potential hydrogen vent to the atmosphere. Explosive mixture. Potential fire and explosion.	Correct design maintenance area Maintenance procedures	1	Remote	C	Severe	L
		2. Inadequate isolation, depressurization, inerting for hydrogen bottles and valves repair or maintenance	Not an issue						
		3. Dropped object during material handling in hydrogen storage area	Damage to equipment. Potential hydrogen release	Personnel training Maintenance procedures	1	Remote	B	Significant	L
			Personnel injury	Personnel training Maintenance procedures PPE	1	Remote	B	Significant	L
	4. Non explosion proof and non-intrinsically safe portable equipment in hazardous area	Potential ignition source in hazardous area. Potential fire and explosion	Personnel training Maintenance procedures PPE	2	Extremely unlikely	B	Significant	L	

**Node 1: Hydrogen storage**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking		
					F	S	R
2. Operational hazards	6. Emergency operation	1. Emergency shut-down (ESD)	Not an issue				
		2. Gas leak from hydrogen racks	See above "Loss of containment" scenario				
		3. Fire in hydrogen storage area	Potential explosion	Not ignition sources Port watching procedures Port fire-fighting systems and procedures	1	Remote	C

**Node 2: Hydrogen piping between storage and fuel cell**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking					
					F	S	R			
1. Loss of containment	1. Hydrogen leaks	1. Leaks of hydrogen piping	Potential hydrogen vent to the atmosphere. Explosive mixture. Potential fire and explosion	Maintenance plans Open space System monitoring Welde pipes	2	Extremely unlikely	C	Severe	M	
2. Operational hazards	1. Operational hazards during fuel cell operation	1. Hydrogen bottles empty	Not an issue							
		2. Under-pressure in the hydrogen bottles	Not an issue							
		3. Hydrogen trapped in the system	Not an issue							
		4. Insufficient hydrogen consumption	Not an issue							
	2. Operational hazards during hydrogen storage filling	5. Fire on hydrogen storage area	1. Fire on hydrogen storage area	Potential escalation to hydrogen piping Potential escalation to hydrogen racks	Not ignition sources Hydrogen bottles closing valves Port watching procedures Port fire-fighting systems and procedures	3	Very Unlikely	B	Significant	L
				Potential escalation to hydrogen racks Potential escalation to hydrogen piping Potential escalation to hydrogen supply trailer	Not ignition sources Hydrogen bottles closing valves Hydrogen supply trailer closing valves Port watching procedures Port fire-fighting systems and procedures Personnel training	3	Very Unlikely	B	Significant	L

**Node 2: Hydrogen piping between storage and fuel cell**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking				
					F	S	R		
2. Operational hazards	3. Operational hazards during hydrogen installation start-up	1. Inappropriate welding of pipes / Leakage through the valves or measuring devices	Hydrogen leak in hydrogen piping, refer to above scenario "Loss of containment"	Commissioning procedures Approved design Tested lines Open space Monitoring of pressure	1	Remote	C	Severe	L
	4. Loss of related and auxiliary systems	1. Loss of glycol system	Not possible to operate with hydrogen. Not a safety issue, economical and environmental issue	Cooling system monitoring Maintenance plans	2	Extremely unlikely	A	Minor	L
		2. Loss of nitrogen system	Not possible to refill storage. Not possible to operate with hydrogen. Not a safety issue, economical and environmental issue. Not possible to do maintenance operations.	Nitrogen can be supplied from shore	2	Extremely unlikely	A	Minor	L
		3. Loss of control system of fuel cell	Close of all shutdown and control valves. Loss of hydrogen supply. Not a safety issue, economical and environmental issue.		2	Extremely unlikely	A	Minor	L
	5. Maintenance of hydrogen installation	1. Inaccessibility to parts to be inspected	Not an issue						

**Node 2: Hydrogen piping between storage and fuel cell**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking				
					F	S	R		
2. Operational hazards	5. Maintenance of hydrogen installation	2. Inadequate isolation, inerting for repair or maintenance	Not possible to operate with hydrogen. Not a safety issue, economical and environmental issue	Personnel training Maintenance procedures	2	Extremely unlikely	A	Minor	L
		3. Dropped object during material handling in hydrogen storage area	Damage to equipment. Potential hydrogen release	Personnel training Maintenance procedures	1	Remote	B	Significant	L
			Personnel injury	Personnel training Maintenance procedures PPE	1	Remote	B	Significant	L
		4. Non explosion proof and non-intrinsically safe portable equipment in hazardous area	Potential ignition source in hazardous area. Potential fire and explosion	Personnel training Maintenance procedures PPEs	2	Extremely unlikely	B	Significant	L
	6. Emergency operation	1. Emergency shut-down (ESD)	Not an issue						
		2. Gas leak from hydrogen piping	See above "Loss of containment" scenario						
		3. Fire in hydrogen storage area	See "Node 1. Operational hazards" scenario						

**Node 3: Fuelling operations**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking				
					F	S	R		
1. Loss of containment	1. Hydrogen leaks	1. Leaks at racks connection	Potential hydrogen vent to the atmosphere. Explosive mixture. Potential fire and explosion	Each bottle of the rack has a valve. Pressure control system Open space	3	Very Unlikely	C	Severe	M
2. Operational hazards	1. Operational hazards during fuel cell operation	1. Fire on hydrogen storage area	Potential escalation to hydrogen piping Potential escalation to hydrogen racks Potential escalation to hydrogen supply trailer	Not ignition sources Hydrogen closing valves Personnel training Port watching procedures Port fire-fighting systems and procedures	3	Very Unlikely	B	Significant	L
	2. Operational hazards during hydrogen storage filling	1. Fire on hydrogen storage area	Potential escalation to hydrogen racks Potential escalation to hydrogen piping Potential escalation to hydrogen supply trailer	Not ignition sources Hydrogen bottles closing valves Hydrogen supply trailer closing valves Port watching procedures Port fire-fighting systems and procedures Personnel training	3	Very Unlikely	C	Severe	M
	3. Operational hazards during hydrogen installation start-up	1. Inappropriate welding of pipes / Leakage through the valves or measuring devices	Not an issue						

**Node 3: Fuelling operations**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking				
					F	S	R		
2. Operational hazards	4. Loss of related and auxiliary systems	1. Loss of glycol system	Not an issue						
		2. Loss of nitrogen system	Not possible to refill storage. Not possible to operate with hydrogen. Not a safety issue, economic and environmental issue. Not possible to do maintenance operations.	Nitrogen can be supplied from shore	2	Extremely unlikely	A	Minor	L
		3. Loss of control system of fuel cell	Not an issue						
	5. Maintenance of hydrogen installation	1. Inaccessibility to parts to be inspected	Not an issue						
		2. Inadequate isolation, inerting for repair or maintenance	Not possible to refill storage. Not possible to operate with hydrogen. Not a safety issue, economic and environmental issue	Personnel training Maintenance procedures	2	Extremely unlikely	A	Minor	L

**Node 3: Fuelling operations**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking				
					F		S		R
2. Operational hazards	5. Maintenance of hydrogen installation	3. Dropped object during material handling in hydrogen storage and filling area	Damage to equipment. Potential hydrogen release	Personnel training Maintenance procedures Fuelling procedures	1	Remote	B	Significant	L
			Personnel injury	Personnel training Maintenance procedures PPE Fuelling procedures	1	Remote	B	Significant	L
		4. Non explosion proof and non-intrinsically safe portable equipment in hazardous area	Potential ignition source in hazardous area. Potential fire and explosion	Personnel training Fuelling procedures Maintenance procedures PPEs	2	Extremely unlikely	B	Significant	L
	6. Emergency operation	1. Emergency shut-down (ESD)	Not an issue						
		2. Gas leak from hydrogen piping	See above "Loss of containment" scenario						
		3. Fire in hydrogen storage area	See "Node 1. Operational hazards" scenario						

**Node 4: Vent lines**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking			
					F	S	R	
1. Loss of containment	1. Hydrogen leaks	1. Vent line leak	Potential hydrogen vent to the atmosphere. Presence of limited amount of hydrogen. Explosive mixture. Potential fire and explosion	Welded pipes. Welding procedures. Personnel training Maintenance procedures	2	Extremely unlikely	B Significant	L
2. Operational hazards	1. Operational hazards during fuel cell operations	1. Vent valves internal leakage	Continuous hydrogen release to atmosphere	Isolation valves Procedures Personnel training Monitored system	2	Extremely unlikely	B Significant	L
		2. Rain water accumulation in vent lines	Potential blockage of vent lines	Venting lines designed to prevent water accumulation Maintenance procedures	1	Remote	A Minor	L
		3. Fire on hydrogen storage area	Potential escalation to vent lines and hydrogen storage	Not ignition sources Hydrogen closing valves Personnel training Port watching procedures Port fire-fighting systems and procedures	3	Very Unlikely	B Significant	L

**Node 4: Vent lines**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking				
					F	S	R		
2. Operational hazards	2. Operational hazards during hydrogen storage filling	1. Fire on hydrogen storage area	See above "Operational hazards during fuel cell operations" scenario						
	3. Operational hazards during hydrogen installation start-up	1. Nothing specific							
	4. Loss of related and auxiliary systems	1. Loss of glycol system	Not an issue for vent lines						
		2. Loss of nitrogen system	Not an issue for vent lines						
		3. Loss of control system of fuel cell	Not an issue for vent lines						
	5. Maintenance of hydrogen installation	1. Inaccessibility to parts to be inspected	Not an issue						
		2. Inadequate isolation, inerting for repair or maintenance	Not possible to refill storage. Not possible to operate with hydrogen. Not a safety issue, economic and environmental issue.	Personnel training Maintenance procedures	2	Extremely unlikely	A	Minor	L
		3. Dropped object during material handling	Damage to equipment. Potential hydrogen release	Personnel training Maintenance procedures	1	Remote	B	Significant	L

**Node 4: Vent lines**

Hazard Category	Guidework	Causes	Consequence	Safeguard	Risk ranking				
					F		S		R
2. Operational hazards	5. Maintenance of hydrogen installation	3. Dropped object during material handling	Personnel injury	Personnel training Maintenance procedures PPE	1	Remote	B	Significant	L
		4. Non explosion proof and non-intrinsically safe portable equipment in hazardous area	Potential ignition source in hazardous area. Potential fire and explosion	Personnel training Fuelling procedures Maintenance procedures PPEs	2	Extremely unlikely	B	Significant	L
	6. Emergency operation	1. Unexpected activation of Emergency Shut-Down (ESD)	Not an issue						
		2. Hydrogen release at the vent mast	Not an issue.						
		3. Hydrogen release at the vent mast when lighting	Potential fire in case of hydrogen release. Potential back fire to vent lines. Major safety issue.	Port procedures Personnel training Isolating valves	1	Remote	C	Severe	L
		4. Fire in hydrogen storage area	See "Node 1. Operational hazards" scenario						

## 8. Techno-economic assessment

Cold Ironing has emerged as a transformative technology, offering the promise of reducing emissions and operational costs for vessels while they are berthed in ports. Implementing cold ironing technology requires complex systems and infrastructure, necessitating investments from both the port and ship sides. In this study, we will focus on the techno-economic assessment from the port's point of view.

The technical facility of cold ironing using grid connection as the main energy source of electricity has been proved in several EU port (A. Tariq, 2021). Port of Balears has already installed a Cold ironing system. The first cold ironing system, located at the Peraires quay in the port of Palma (See Fig. 22), is already prepared to connect to the electricity grid and serve vessels with varying power demands. This initiative has received unanimous support from local institutions, emphasizing the shared objective of environmental responsibility and climate neutrality. (Autoridad Portuaria de Baleares, 2023).



Figure 22: Cold ironing unit at Prairies quay at Port of Palma, Mallorca (Autoridad Portuaria de Baleares, 2023)

Onshore Power Supply (OPS) is a term commonly used to describe the infrastructure and systems that supply electrical power from the shore to a ship while it is in port. In earlier sections of this report, it has already been established that the energy system to supply electricity to the vessels at the berth in the West dock is comprised of a green hydrogen fuel cell system and a connection to the Port's electrical grid. The system also includes the electrical equipment, such as transformers, frequency regulators, and cables, required to supply electricity at the dock. In the context of this study and to differentiate it from "conventional" cold ironing systems, we will refer to the system under study as the GH-Cold Ironing system, to emphasize the innovation in incorporating green hydrogen Fuel Cell subsystem into the OPS.

Additionally, a Cable Management System (CMS) is required. This system encompasses the technology and software used to coordinate the transfer of electrical power from the shore to the ship, monitor power consumption, and ensure the safe and efficient integration of the vessel with the onshore power supply. While the technical description is not within the scope of the technical analysis of the energy supply system presented in the previous sections, it is a relevant component of the system from an

economic perspective. It requires both capital investment and operational expenditures from the port's point of view to offer a green cold ironing service to ships calling at the West dock.

The following figure depicts the system boundaries for the forthcoming techno-economic study are illustrated. The study is centred on the "Shore Side System" operated by the Port Authority. The system boundaries serve to delineate the specific components and processes that will be analysed in the study, providing a clear definition of what falls within the scope of the investigation.

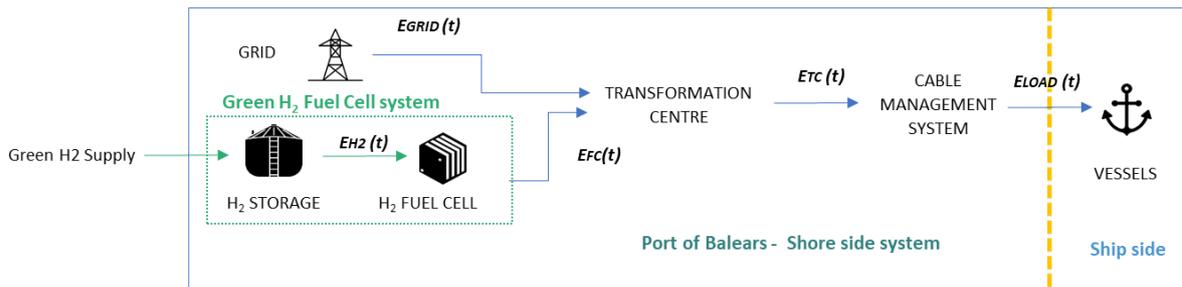


Figure 23: GH- Cold ironing System Boundaries for Techno-Economic Study

Within these boundaries, the study will examine various aspects of the Shore Side System, including but not limited to the Onshore Power Supply and the Cable Management system

#### Onshore Power Supply (OPS) components:

- **Power supply:** The sources of electrical power, such as the local electrical grid and the green hydrogen fuel cell system (**GHFCS**) that includes the fuel cell itself and the hydrogen storage system will be considered.
- **Electrical Infrastructure:** This encompasses the electrical infrastructure required to supply power to berthed vessels, including electrical connections, transformers, and distribution systems.
- **Power Energy Management Systems (PEMS):** The control and monitoring systems, which oversee the safe and efficient operation of the shore power supply to ships.

**Cable management system (CMS):** it can be defined as a set of mechanisms, procedures, and equipment used for the handling and organization of power cables during the process of connecting and disconnecting vessels from the dock. The CMS facilitates the deployment, positioning, and retrieval of power cables to enable the connection of ships to the onshore power supply, as well as their disconnection after use. It plays a crucial role in ensuring a safe and efficient power supply process for maritime operations.

The central aim of this section is to evaluate the sustainability of Cold Ironing with a hybrid energy supply system that incorporates green hydrogen within European ports, with a specific focus on the Port of Mallorca as an illustrative case. By clearly defining the system boundaries, this figure provides a visual representation of the study's focus and helps stakeholders and researchers understand the specific components and processes that will be evaluated within the shore side system of the Port Authority. This comprehensive approach will enable a thorough techno-economic assessment of the Cold Ironing technology and its potential impact on both the operational and environmental aspects of the port of Mallorca.

## 8.1. Methodology

According to literature the economic benefit of using cold ironing is strongly associated use of low-sulphur marine fuel, which is especially advantageous considering the increasing trend in fossil fuel cost (Radonja, 2011)2011) which is the argument for the application from the vessel's operator point of view.

As mentioned in the section's introduction, we will explore the sustainability of integrating green hydrogen as an electricity supply technology for cold ironing, with a focus on the shore-side perspective. The feasibility of the implementation of cold ironing can be enhanced by selling electricity to ships, offering a potential revenue stream (Glavinović R, 2023; Simon Bullock, 2023). This comprehensive analysis delves into the techno-economic feasibility of Cold Ironing, employing a cost-benefit analysis (CBA) and sensitivity analysis, focusing on two key economic indicators: the Levelized Cost of Electricity (LCOE) and Net Present Value of the investment (NPV). However, the true measure of the benefit derived from Cold Ironing extends beyond conventional economic indicators; it is fundamentally defined by its environmental impact, especially in terms of greenhouse gas (GHG) reductions and the mitigation of pollution, which is also included in the analysis.

A techno-economic model has been constructed in Microsoft Excel for the purpose of conducting the Cost-Benefit Analysis (CBA), with careful consideration given to the incorporation of the following parameters:

- **Technical considerations:** demand of electricity from vessels, selection of technology and required infrastructure to onshore power
- **Operational considerations:** frequency of hydrogen supply and berthing activity in a daily and yearly basis, electricity demand by vessels, number of hours of ships at berth per day , are the main variables to be considered
- **Economic Considerations:** Economic factors, including the cost of infrastructure development, operational expenses, revenue generation.

The techno-economic model serves as a tool for determining the financial aspects, including costs and economic benefits, of the investment. This model calculates the Levelized Cost of Energy (LCOE) at two distinct levels: one for the green Hydrogen system and another for the broader shore power aspect of the Cold Ironing system.

The primary source of revenue considered in this modelling is associated with the sale of electricity to the vessel operators. Additionally, the Net Present Value (NPV) and IRR (%) are presented as an output specifically at the Cold Ironing system level.

Furthermore, the model enables the execution of sensitivity analyses on four critical parameters: Total capital expenditures, operational expenditures, green Hydrogen costs, and electricity costs. In the sensitivity analysis pertaining to NPV, the variable of shore electricity prices is also incorporated, providing a comprehensive examination of the economic viability and resilience of the investment.

The data for this analysis has been meticulously gathered from a variety of sources, providing a comprehensive foundation for the techno-economic model. These sources include a collection of scholarly papers and research articles that have been consulted to acquire relevant information and insights on the feasibility of implementing Cold Ironing in Europe. Most of the literature refers to the Cold Ironing system using conventional and/or renewable electricity in ports. There is very limited

scientific publication assessing the feasibility of Cold Ironing with the integration of a green hydrogen fuel cell system (GHFCS), as presented in this study. Most of the data related to the deployment of the GHFCS is based on previous studies delivered by the Green Hysland project: (1) Deliverable 2.9 “ End User Applications Energy Port of Palma FC Layout and Preliminary Engineering Design “ (Enagas, 2022), and (2) Deliverable D.6.3 a “Study on the Decarbonization of the Sea-Ferry Stations at Balearic Ports” (Energy, 2023), offering practical insights and costs estimates into the implementation of GHFCS in the context of the Balearic ports.

Data has also been collected directly from the Port of Baleares, providing real-world information related to the implementation of the Cold Ironing system, port activity, and the integration of green hydrogen. The technical design, as proposed in preceding sections of this study, has been integrated into the data sources. This design includes the specific technological and engineering details related to the implementation of the Cold Ironing system and the incorporation of green hydrogen; a concept developed through this study.

The environmental impact assessment is discussed in more detail in Section 8.8.

## 8.2. Main technical and operational input parameters & assumptions

### 8.2.1. Electricity Demand

Estimating auxiliary power demand (APD) at berth can often be challenging, primarily because there is a lack of available data on engine specifications (Tocchi, et al., 2022). In Section 2.2.2, the electricity demand for the case study was examined, yet no hourly data on vessel electricity consumption was available. The analysis, nonetheless, indicates that, on average, most ferry vessels calling at the considered docks require approximately 2000 kW of power. This estimation is established assuming peak consumption throughout the vessel's entire stay at the port, in accordance with the stipulations of Administration and Classification Societies.

In practice, the actual power consumption by these vessels while at port tends to be lower. Not all onboard systems operate at maximum power concurrently, leading to more conservative power estimates. It is assumed that vessels will proactively request a shore connection and provide an estimated power demand before their arrival, allowing the port to make the necessary arrangements.

For the purposes of this study, the design of the cold ironing connection is intended to provide 2000 kW of electric power, with the option to supplement it with power from a fuel cell when required. In most scenarios, this power capacity is ample to concurrently supply power to at least two vessels, taking into account the typical power consumption patterns of such vessels. In cases where issues arise with hydrogen supply or fuel cell operation, the shore connection alone is capable of satisfactorily powering the connected vessels. For the economic evaluation, the following assumptions were made: Based on the analysis of shipping history data at the West dock, there are 340 days of shipping at the dock for 6 hours each day. Typically, two vessels are berthed simultaneously with a total demand of 2000 kW on 292 days per year. Only 4 days per year (1% of the time), the demand may increase up to 2374 kW. The rest of the time, approximately 44 days per year, the demand has been estimated at 1374 kW. Under these assumptions, the annual electricity requirement has been estimated to be 3,923,712 kWh per year for 2040 hours of operations, in the first year of operations.

Table 23: Annual load and demand from vessels a berth

Fuel cell E output (kW)	E grid (kW)	Total load (kW)	% operation (340 days/year)	Number of hours /year (hrs/y)	total demand/year (kWh/y)
374	2000	2374	1% (4 days)	24	56976
374	1626	2000	86% (292 days)	1752	3504000
374	1000	1374	13% (44 days)	264	362736
			Total	<b>2040</b>	<b>3923712</b>

### 8.2.2. Onshore Power Supply

The description fuel cell and storage system technologies considered for this analysis were previously detailed in Section 5. In the case of the fuel cell, it is assumed that the fuel cell will operate in a constant load mode, providing a consistent electrical output of 374 kW, which corresponds to 85% of its nominal capacity. According to the technical specifications of the provider, the expected conversion efficiency is 45 % at a constant operational mode.

The fuel cell stack undergoes a gradual loss of performance over time, which impacts its overall lifetime. This degradation effect results in a reduction in power output (percentage loss) every 1000 hours of operation (Hydrogen Europe, 2020).

For the fuel cell, operating in a constant load mode, a degradation rate of 0.4% per 1000 hours was chosen, in line with guidelines from Hydrogen Europe (Hydrogen Europe, 2020). For the case study, It implies a 1 % annual output loss when operating for 2040 hrs per year.

To determine the number of 1000-hour degradation cycles a fuel cell can endure before replacement, we considered a maximum allowable power loss of 20% compared to its nominal output (D.6.3). The count of these cycles determines the practical lifetime of the fuel cell stack, measured in hours. This is taking into account in the techno economic modelling

The difference in between the demand and the fuel cell energy output will be compensated by electricity from the grid (see table 24). It is assumed that a DC/AC inverter is included in the Fuel cell system. The Grid connection is described in section 4.1.3 (attachment point) and the electricity distribution system compound by the transformation centre and other connections are described in detailed in section 4.2.

While different storage options are mentioned in section 5, the economic assessment in this study is primarily based on the design of storage units by Calvera S.A (D.2.3 and D.6.3) as described in section 5.2. It is assumed that there is an adequate supply of hydrogen to meet the daily demand. Under the assumption that the hydrogen storage unit is fixed, a filling control panel is required for the supply of hydrogen in-situ.

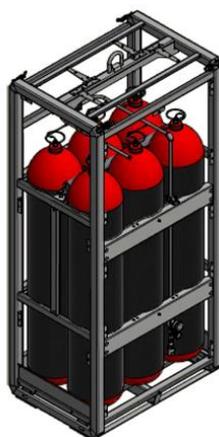


Figure 24: Mobile storage unit design by CALVERA (Enagas, 2022)

In section 5, a minimum of 8 storage units is considered to store approximately 129 kg per day, which is equivalent to 51 tons per year. The number of storage units may vary depending on factors such as pressure, temperature conditions, the number of stages in the refilling process, and the hydrogen buffer volume within the tanks. Furthermore, accounting for stack degradation and its impact on efficiency, hydrogen consumption will progressively increase over the stack's lifetime to ensure a consistent electrical output at the established rate until replacement. The model presented in D.6.3, account for these variables indicating that a number of 10 to 12 storage units might be required. Therefore, for this assessment, we will consider 10 units. The storage technology options and requirements will be reevaluated in a later phase of the project, as recommended in Section 5.4.

Overall, it is assumed that there always will be electricity supply available and it will be sufficient to satisfy the demand over 340 days for 6 hours per day.

### 8.2.3. Cable Management System

The design of this system component is not within the scope of the technical study. It will be considered in the future. As a reference, it is recommended to read the technical specifications for the public tender of the Cable Management System for the Paraires dock, available to the general public on the corresponding portal of the Balearic Ports. (Autoridad Portuaria de Baleares, 2021)

In the model it is assumed that the CMS will be operational 2040 hours per year to supply energy to the ships at berth.

## 8.3. Economic parameters and lifetime of the various components

Economic considerations pose a significant obstacle to the feasibility of cold ironing implementation. The financial commitments required for both ports and shipowners are substantial (Glavinović R, 2023). In the context of the Port of Balears, where the primary revenue source for cold ironing activities is the sale of electricity to vessels at berth, understanding the right electricity selling price and associated costs of energy supply is imperative for building a solid business case. Our economic model assesses the levelized cost of electricity (LCOE) for both the hydrogen and cold ironing systems, measuring the average net present cost of electricity generation over their lifetimes. Furthermore, the impact of critical parameters has also been explored, such as capital expenditures (CAPEX), operational expenditures (OPEX), and energy costs, to provide a comprehensive understanding of the project's economic feasibility determining the impact on the overall cold ironing system NPV and LCOE.

This section describes the key economic modelling inputs and assumptions for each element of the shore side system (see fig.22): the green hydrogen fuel cell system, the transformation centre (including grid connections and electricity distribution system and the Cable management system

The data collection for costs (CAPEX and OPEX) draws upon various sources, including Clean Hydrogen reports, information provided by the Port Authority, Calvera Hydrogen, and Cotenaval. They are also supported by the information published in other Green Hyland projects deliverables for the decarbonation of seaport activities (Energy, 2023) and literature research. Additionally, quotations obtained from various equipment providers are used to confirm the values for total CAPEX.

### 8.3.1. Green Hydrogen Fuel Cell System costs

For the fuel cell three major components have to be included in the initial investment of the system the stack and balance of plant (BOP) and inverters. The BOP has a useful lifetime of 20 years (Nedstack fuel cell technology B.V), and its specific CAPEX are considered to be 20% of those for the stack (IDOM, 2022).

The fuel cell stack has a useful lifetime that varies as function of the degradation factor and the annual working operations. The expenditure will occur at the year in which the stack replacement will be necessary. The cost of the stack replacement is included in an economic indicator used for estimating the Operational and maintenance (O&M) costs of the stationary fuel cell equipment (Bednarek, 2021)

The costs estimations for the hydrogen storage components (storage units and filling panel) are based on the research of Energy for the deliverable D.6.3. The CAPEX for each storage unit and the filling panel were given by CALVERA, the O&M cost assumptions are based on literature research (D.6.3, 2023).

### 8.3.2. Transformation Centre Cable management system costs

The capital expenditures estimations transformation centre (CT), as provided by COTENAVAL and INSTEMEID (2023) encompass not only the required electrical infrastructure for the Onshore Power Supply (OPS) but also civil works necessary for their installation.

The CMS capex is provided by Port of Balears based on their previous experience deploying cold ironing system in the Prairies dock. (Autoridad Portuaria de Baleares, 2021) and corrected for inflation in 2022.

The O&M for both components are modelled as a percentage (2%) of their initial investment costs.

### 8.3.3. Hydrogen costs

For the economic analysis, hydrogen costs are derived from the research conducted for the decarbonization of seaports report (D.6.3). This report presents a reference price scenario for Mallorca, establishing an average hydrogen price at approximately **7 EUR per kilogram over a 20-year period.**

### 8.3.4. Grid Electricity costs

The total electricity cost structure comprises a fixed component and a variable component. The fixed contribution is contingent upon the end user's connection to the grid and is expressed in €/kW, while the variable contribution is contingent upon the amount of electricity consumed during these various periods and is measured in €/kWh and listed in the following table:

Table 24: Electricity Fixed and variable costs.

Cost of Electricity	P1	P2	P3	P4	P5	P6
<b>Fixed (€/kWh)</b>	22.965215	19.841178	10.327582	8.560662	1.908583	1.148958
<b>Variable (€/kWh)</b>	0.05663473	0.04844873	0.03493273	0.03053673	0.02494473	0.01769973

As outlined in the deliverable D.6.3, have been provided by the port authority and pertain to 2023's tariff 6.1TD (3.1A). These electricity prices are categorized into six distinct periods (FIG. 25), contingent upon the month of the year and the time of day.

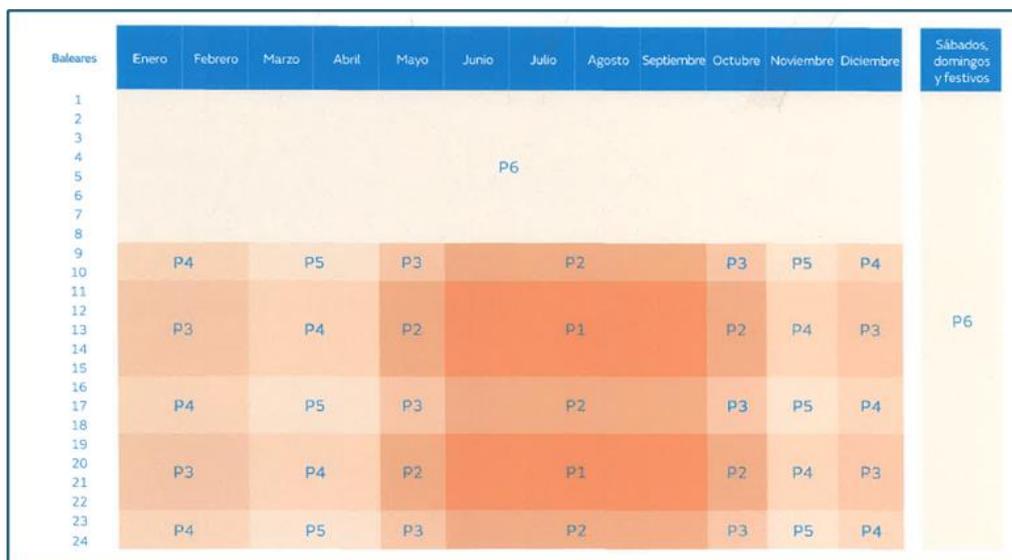


Figure 25: Tariff periods for Balearic Islands, provided by Autoridad Portuaria de Baleares (Naturgy, 2022)

Both price categories encompass the costs of the electricity resource, including grid operation, and guarantee of origin certificates<sup>13</sup>. In this study, it is assumed that electricity costs will remain constant throughout the economic horizon.

<sup>13</sup> Total grid electricity consumer purchase costs including all fees, taxes and capacity payments.

Table 25: Summary of Operational Expenditures input.

Parameter	Value	Unit	Source
O&M Fuel cell	5.00	(cents/Kwh)	Includes stack replacement (CHP, 2022)(Bednarek, 2021)
O&M Fuel cell Growth Rate	1	(%)	Assumption
Hydrogen price (EUR/Kg)	7	EUR/Kg	Assumption D6.3
O&M Filling panel	1000	Eur/y	Assumption D6.3
O&M storage per unit	100	Eur/y/unit	Assumption D63
O&M storage	1000	EUR /y	Assumption D63
Total O&M storage	2000	EUR /y	
O&M TC	2	(% capex)	Assumption
O&M TC	35440.5126	EUR /y	
O&M CMS	2	(% capex)	Assumption
O&M CMS	16000	EUR /y	
E fixed costs	171219.1057	EUR/y	(Naturgy, 2022)
E variable costs	0.028090945	EUR/kWh	(Naturgy, 2022)

## 8.4. Additional Financial parameters and assumptions

For the economic assessment, a discount rate of 8% was chosen. This same value is used in the IRENA report for Green Hydrogen cost reduction report in 2020 (IRENA, 2020)

Additionally, an inflation rate of 1.5% was selected, representing the average over a five-year period from 2017 to 2021 in Spain. However, in 2022, the country experienced a significant rise in the inflation rate, reaching up to 8.4%. This surge was attributed to the considerable instability resulting from the conclusion of the COVID-19 pandemic and the recent conflict in Ukraine. Nonetheless, it is anticipated that such a high inflation rate will not persist over an extended period. As of March 2023, the inflation rate in Spain had already receded to 3.3% (Trading economics, 2023). Thus, the 1.5% value was deemed more suitable for a longer 20-year horizon.

Table 26: Other financial parameters and assumptions.

Parameter	Value	Unit	Source
Project Lifespan	20	Years	BOP lifetime
Inflation rate	1.5	%	(Trading economics, 2023)
Discount Rate	8	%	(IRENA, 2020)
Annual H2 Fuel Consumption	50,939	Kg	CotenaVal- Energy
Shore power selling price (Palma)	0.3585	(€/kwh)	(Autoridad Portuaria de Baleares, 2023)
Annual Electricity Output FC	747,701	kWh	CotenaVal- Energy
Annual E grid consumption	3,335,268	kWh	CotenaVal- Energy
Annual E output Cold ironing	3,921,283	kWh	CotenaVal- Energy

The shore power selling price included in Table 26 is used as a reference of the selling price that is charged to vessels as Cold Ironing services. It is an official commercial service from the State Ports and it can be consulted here: <https://seu.portsdebalears.gob.es/seuapb/file/pdf/43453/Suministro%20de%20energ%C3%ADa%20el%C3%A9ctrica.pdf;jsessionid=eqr2kq-ORzb7Iz1ZPU7fxTns.undefined>. The figure includes the corresponding margin/mark-up and it is therefore significantly higher than the grid electricity costs provided in Table 24.

## 8.5. Sensitivities analysis: main parameters and assumptions

Table 27: Sensitivity Analysis key parameters and assumptions.

Variable	Reduction	Increment
TOTAL CAPEX	-25%	25%
Annual OPEX	-25%	25%
H2 price	- 4 EUR	+ 3 EUR
Variable Electricity costs	-25%	25%
Shore power selling price	-10%	10%

## 8.6. Economic assessment results

For the Mallorca-based study described previously, and based on the cost assumptions indicated above, the total initial investment of the FC-based cold ironing system is estimated at 4,334,026 EUR. The total yearly discounted costs (calculated applying the yearly discount factors indicated in Table 29) and energy output per year are shown below in Table 28.

Table 28 : yearly values of discounted system costs and energy output used to calculate npv and lcoe for the fc-based cold ironing system

Year	1	2	3	4	5	6	7	8	9	10
<b>Yearly discounted costs</b>	669,437	632,296	597,231	564,124	532,865	503,352	475,484	449,171	424,324	400,862
<b>Energy output</b>	3,685,28	3,463,48	3,255,03	3,059,12	2,875,01	2,701,98	2,539,36	2,386,53	2,242,89	2,107,90
Year	11	12	13	14	15	16	17	18	19	20
<b>Yearly discounted costs</b>	360,048	340,252	321,551	303,886	287,198	271,433	256,540	242,470	229,177	216,618
<b>Energy output</b>	1,981,04	1,861,81	1,749,76	1,644,45	1,545,48	1,452,46	1,365,04	1,282,89	1,205,68	1,133,11

Based on the values indicated in Table 28, the total discounted costs and the total energy output of the FC-based cold ironing system are estimated at 12,412,344 EUR and 43,538,322 kWh respectively. Based on these values, in the context of the Mallorca case study on Cold Ironing and based on our proposed design and assumptions, the economic assessment reveals crucial LCOE figures: 761.93 EUR/MWh at the hydrogen system level and 285.09 EUR/MWh at the cold ironing system level.

Based on the above mentioned costs assumptions, the yearly income, total costs and revenues used for the calculation of the overall NPV are shown in Table 29.

Table 29: Total yearly income, costs, revenues and discounted cashflows for the FC-based cold ironing system

<b>Year</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>
<b>Total Income</b>	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780
<b>Total Costs</b>	712,307	715,873	719,474	723,112	726,785	730,496	734,243	738,029	741,851	745,713
<b>Revenues</b>	693,472	689,907	686,305	682,668	678,994	675,284	671,536	667,751	663,928	660,067
<b>Discount Factor</b>	0.940	0.883	0.830	0.780	0.733	0.689	0.648	0.609	0.572	0.538
<b>Discounted cashflow</b>	651,736	609,362	569,698	532,573	497,826	465,308	434,876	406,400	379,754	354,823
<b>Year</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>
<b>Total Income</b>	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780	1,405,780
<b>Total Costs</b>	712,682	716,626	720,610	724,634	728,697	732,802	736,947	741,134	745,363	749,634
<b>Revenues</b>	693,098	689,153	685,170	681,146	677,082	672,978	668,832	664,645	660,417	656,146
<b>Discount Factor</b>	0.505	0.475	0.446	0.419	0.394	0.370	0.348	0.327	0.307	0.289
<b>Discounted cashflow</b>	350,155	327,208	305,737	285,649	266,855	249,274	232,829	217,446	203,059	189,603

Despite the positive overall NPV estimated in 3,196,145 EUR, based on the yearly values indicated above in Table 29, the business case remains marginal, as does the IRR (8 %) for the reference case under consideration.

These optimistic results were obtained under the assumption of an annual demand of 2000 kWh. However, introducing a 20% reduction in the total annual demand, while keeping the fuel cell contribution at the same 85% ratio of the nominal capacity, leads to a significant reduction in IRR down to 1%. It's important to note that while higher fuel cell contributions lead to greater GHG emissions reductions from an environmental perspective, the economic impact may be adverse when the contribution is equal to or lower than the grid supply. Therefore, optimization of the fuel cell and grid contributions is recommended to strike a balance between both benefits.

An alternative solution is to offer a shore power selling price that includes a green premium, encouraging consumers who are willing to pay extra to increase their contribution and reduce pollution in the port and emissions from their vessels.

The sensitivity analysis performed shows the impact of the selected parameters on the LCOE, NPV and IRR, note that the shore power selling price does not influence LCOE by definition. The results are depicted in the following figures.

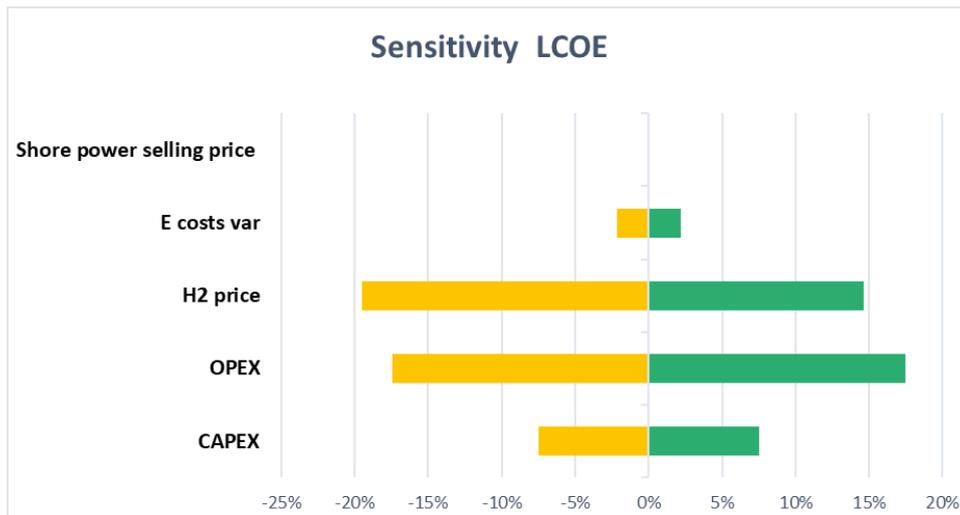


Figure 26: Relative impact of economic variables on LCOE at Cold Ironing system level

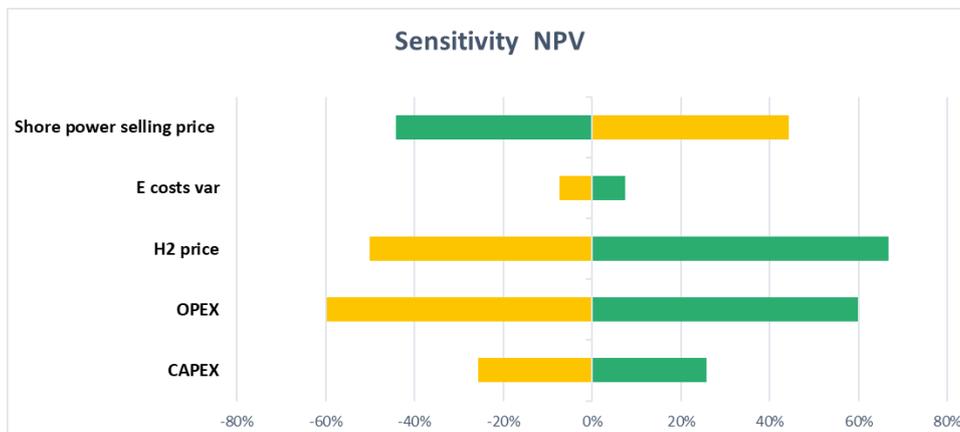


Figure 27: Relative impact of economic variables on NPV at Cold Ironing system level

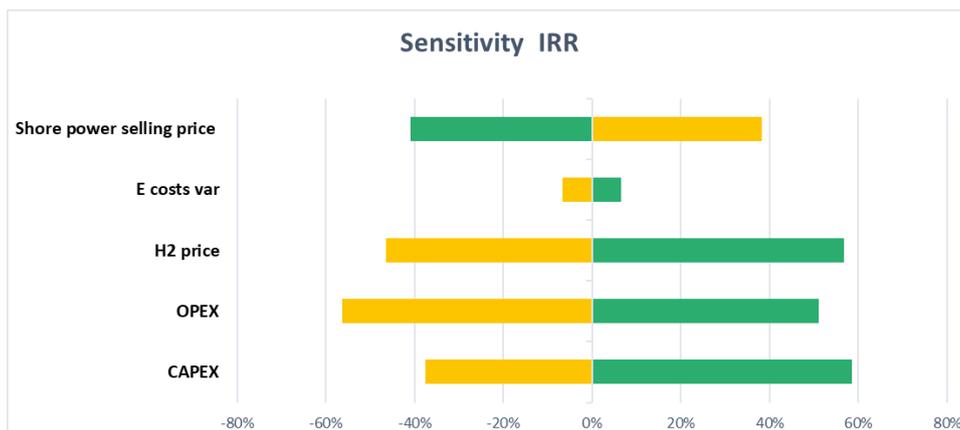


Figure 28: Relative impact of economic variables on IRR at Cold Ironing system level

The sensitivity analysis conducted on the techno-economic study highlights that OPEX and hydrogen prices have the most substantial impact on the economic indicators. Specifically, for the IRR, Capex is also a significant influencer, although in the case of other parameters such as NPV and LCOE, their

impact is relatively lower compared to IRR. It's important to note that the variables with the highest degree of uncertainty require actual data from the implementation of their results to reduce this uncertainty and assess viability accurately.

Of utmost significance is the sensitivity of the business case to the shore power price. A mere 10% variation concerning the reference price can be a decisive factor in the project's viability. Conversely, it has the potential to pave the way for a significant success in the deployment of this technology.

The techno-economic analysis carried out reveals important conclusions in terms of the economic feasibility of the FC-based cold ironing system. The analysis presented here establishes the basic techno-economic parameters for the implementation of FC into this specific market application, using key indicators like the Levelized Cost of Electricity (LCOE) and Net Present Value of the investment (NPV). However, the true measure of the benefit derived from Cold Ironing extends beyond conventional economic indicators; it is fundamentally defined by its environmental impact, especially in terms of greenhouse gas (GHG) reductions and the mitigation of pollution, which is also included below in Section 8.8. Therefore, as of today, due to the relatively high costs of commercially available fuel cells and green hydrogen supply, the benefits are fundamentally defined not by economic incentives, but by the positive environmental impacts of the FC-based Cold Ironing system vs. incumbent grid-based solutions, especially in terms of greenhouse gas (GHG) reductions and the mitigation of pollution.

## 8.7. Techno economic assessment limitations

It is important to acknowledge that this techno-economic study, while comprehensive, it does have its limitations. One notable exclusion is the socio-economic benefits associated with pollution reduction, specifically in terms of reducing health costs. The implications of these benefits, which could be significant, have not been factored into this analysis. Future research should address this aspect, particularly concerning its relevance to the island's specific context.

Additionally, exploring various storage alternatives and green hydrogen storage refilling options could provide valuable insights into optimizing the overall system. However, due to constraints and data availability, this analysis focuses on a specific set of assumptions. Future work may consider these alternatives for a more in-depth assessment.

Another limitation stems from the absence of hourly demand data from vessels in the modelling process. Once real demand data becomes available, there's potential for optimizing operations to enhance efficiency and cost-effectiveness.

The modelling also assumes constant electricity and hydrogen prices. Future trends and fluctuations in these prices may significantly impact the outcomes of this study. As such, revisiting and updating these assumptions in the future will be crucial to maintaining the accuracy and relevance of the economic assessment.

A more in-depth investigation into the availability and applicability of tax benefits and subsidies specific to the region and technology under consideration could shed light on additional economic advantages or challenges. Assessing the potential financial support offered by government policies is crucial for a comprehensive evaluation of the technology's sustainability and economic viability. This aspect should be considered in future research and techno-economic studies to provide a more complete picture of the financial landscape.

## 8.8. Estimated reduction of pollutants and GHG emissions

As mentioned before, the European Green Deal aims to reduce net GHG emissions by at least 55% by 2030, aiming to become the first climate-neutral by 2050. Then, new regulations are being developed in order to minimize GHG emissions, where those sectors and activities that produce the most harmful effects on the planet will be the main areas of intervention.

There, ships and shipping operations will require a major transformation to comply with the GHG emissions reduction required, changing some of the equipment and fuel types burned on board, but also with changes in their way of operation.

Depending on the type of vessel and her operational profile, port calls have more or less impact on the total operation of the vessel, but for sure it means a main part of it. And any beneficial effect achieved when moored, will have an important effect on the total GHG emissions.

Europe is already considering the scenario where vessels at port are connected to an onshore power supply (OPS). It is already considered in the new regulations related to the GHG emissions and included in their formulae to obtain the GHG intensity and the amount of CO<sub>2</sub>eq emissions. An that is the main object of this study, where an additional value is given considering also a fuel cell for the OPS.

The European Commission has adopted a set of proposals to achieve that objective, and particularly for vessel's operation. Several indicators have been defined in order to evaluate the GHG emissions rate of vessels, and those are finally related to penalties to be paid by shipping companies.

That would be an issue related directly with the vessels, and to be considered included in the complete operational profile of the vessels, considering both at sailing and at port. For the aim of this study, it was considered relevant to be mentioned, according to the significant impact that the OPS could have into the vessels' way of operation. But that would be part of an additional analysis, where information from the shipping companies could be used to obtain the reduction of penalties to be obtained using the OPS when at berth.

From the values obtained on chapter 2.4, a significant reduction of the GHG emissions is expected just due to the use of a pure cold ironing connection (OPS), and even greater if a part of the supplied power comes from a fuel cell using green hydrogen.

The table below shows the values of CO<sub>2</sub> emissions per year for the three scenarios considered:

Table 30: Estimated CO<sub>2</sub> emissions per year [tonCO<sub>2</sub>/year]

	Current situation – Onboard gensets	Pure cold ironing	Cold ironing with fuel cell using green hydrogen
Port of Mallorca	3,105	1,545	1,302

The expected reduction for the GHG emissions per year is about 1,804 tonnes of CO<sub>2</sub>, meaning more than 48,000 tonnes CO<sub>2</sub> not emitted to the atmosphere up to 2050. That means a reduction of more than the 58% of the CO<sub>2</sub> emissions for a OPS using a fuel cell with a total power supply of 2374 kW, 2000 kW from the grid and 374 from the fuel cell, where the fuel cell provides almost the 8% of such reduction.

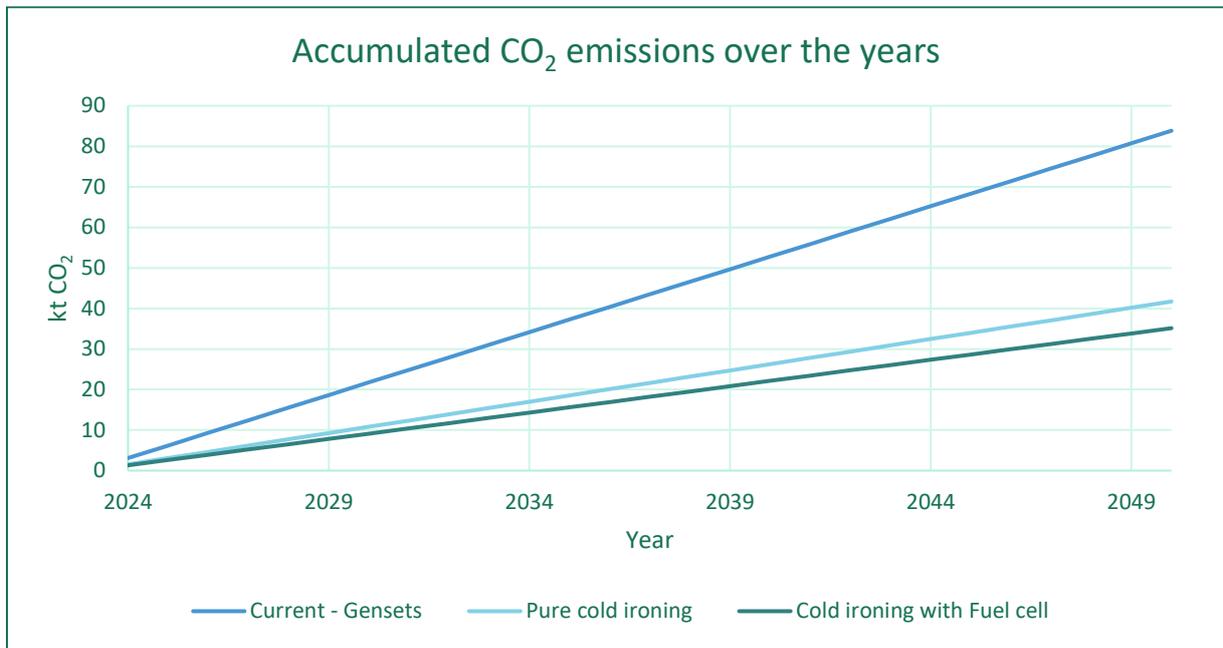


Figure 29: Accumulated CO<sub>2</sub> emissions over the years

Looking at the figures obtained, the European Commission positioning is totally understood, as the pure cold ironing connection brings a quite significant reduction of the greenhouse gases emitted. Considering a part of that power substituted with power from a H<sub>2</sub>-FC, the reduction of the GHG is even higher.

## 9. Extensions for future projects

With the current design of the project but with a **new fuel cell added** to the system, it will be possible to increase the amount of power apported by the hydrogen fuel cells and the ability to simultaneously supply different voltage/frequency connections, reducing the amount of GHG emissions.

Considering the same model of fuel cell as selected (0.5 MVA), the addition of the following equipment will be required (INSTEIMED):

- New transformer 600 KVA. The CT13 has enough free space to locate it.
- New cable from the new fuel cell to CT13, with minimum interference over public spaces.
- New breaker in LV01. The switchboard constructive project shall consider spare space for such a new breaker, and also the busbar shall be dimensioned accordingly.

The total available power will be then 3.5 MVA instead of the current 3 MVA, which increase the number of connection combinations as well as the power of the actual ones. Nevertheless, the limitations for one ship will be the same but for more simultaneous vessels.

- 2 vessels
  - Ship A: 11 kV, 50/60Hz; 2.5 MVA
  - Ship B: 400 V, 50 Hz, 1 MVA
- 3 ships
  - Option 1:
    - Ship A: 11 kV, 60Hz; 2 MVA
    - Ship B: 440 V, 60 Hz, 0.5 MVA
    - Ship C: 400 V, 50 Hz, 1 MVA
  - Option 2:
    - Ship A: 11 kV, 60Hz; 1.5 MVA
    - Ship B: 440 V, 60 Hz, 1 MVA
    - Ship C: 400 V, 50 Hz, 1 MVA
  - Option 3:
    - Ship A: 11 kV, 50/60Hz; 1.25 MVA (same frequency as ship B)
    - Ship B: 11 kV, 50/60Hz; 1.25 MVA (same frequency as ship A)
    - Ship C: 400 V, 50 Hz, 1 MVA

In such case, considering and additional fuel cell with the same characteristics, the GHG emissions could be reduced up to 66% of the current CO<sub>2</sub> emissions using the onboard gensets.

But from an economic point of view, considering the costs mentioned in previous chapters, adding a FC does not seem the most appropriate solution. Expanding the grid power (0.5 MVA), which would required also a new transformer, new cables, new breaker and so on, would increase in the same way the number of connection combinations.

In terms of GHG reduction, the most significant emission reduction comes from the fact that less kW are generated from the diesel generators in the vessels. And as mentioned before, even a lightly higher reduction is achieved when using H<sub>2</sub>-FC. Then, once the current design is decided to be increase, probably the cost impact becomes a significant feature to the system updating.

Similar projects can be developed for different docks and different vessel traffics requirements, even considering a bigger apport of the power consumption coming from a bigger fuel cell or from a multiple fuel cell system. The current demand of fuel cell is growing and manufactures and immersed in the development of bigger fuel cells and improvements into the existing types. For sure, in the future more efficient fuel cells will be developed ensuring higher reductions of GHG emissions.

With these growth expectations of the fuel cell manufactures and considering fluctuation of the energy markets, not a clear scenario is defined of the most adequate source to provide power to a cold ironing solution, considering all the parameters involved. The design of a combined system, like the one described in this study, brings many different power source combinations to be defined at each moment, and looking for the best solution for each scenario in terms of GHG emissions reduction and costs.

## 10. Conclusions

From the different assessment done in this study, several valuable insights have been obtained for the use of cold ironing at the Port of Palma with a fuel cell using green hydrogen:

- The capability of the vessels to be connected to an OPS is currently unreal due to most of the vessels are not still ready for it nor the ports. **Important investments** are required from the shipping companies in order **to adapt** their vessels to be connected at berth with a cold ironing connection. But also the ports, as the main responsible for offering a valid electrical connection service to the vessels moored at their docks, with the aim of complying with the requirements from the European Commission, as established in Fuel EU Article 5: *“From 1 January 2030, a ship moored at a quayside in a port of call State which is covered by Article 9 of the Alternative Fuels Infrastructure Regulation shall connect to on-shore power supply and use it for all its electrical power demand at berth”*.
- The current study has considered only the 1st alignment of the West Dock. It is known that PORT BALEARS is already working on the deployment of cold ironing connections in other docks in the Port. From the insights provided at this techno-economic assessment, **future extensions** of those OPS could be achieved, with the integration of **renewable energies**.
- From the vessel point of view, it could seem a non-profit investment, but there is nothing further from the reality. With the upcoming regulations, any investment direct to **reduce the penalties amount** could be considered as a **profit investment**. And that will be the matter, looking for equipment and solutions that could reduce the GHG emissions of the vessel, both sailing and mooring.
- Just an OPS, without using a fuel cell, brings a quite significant reduction of the GHG emissions. But the fuel cell gives an **extra reduction of the emissions**. And talking regarding penalties to be paid, any reduction on them would be welcome.

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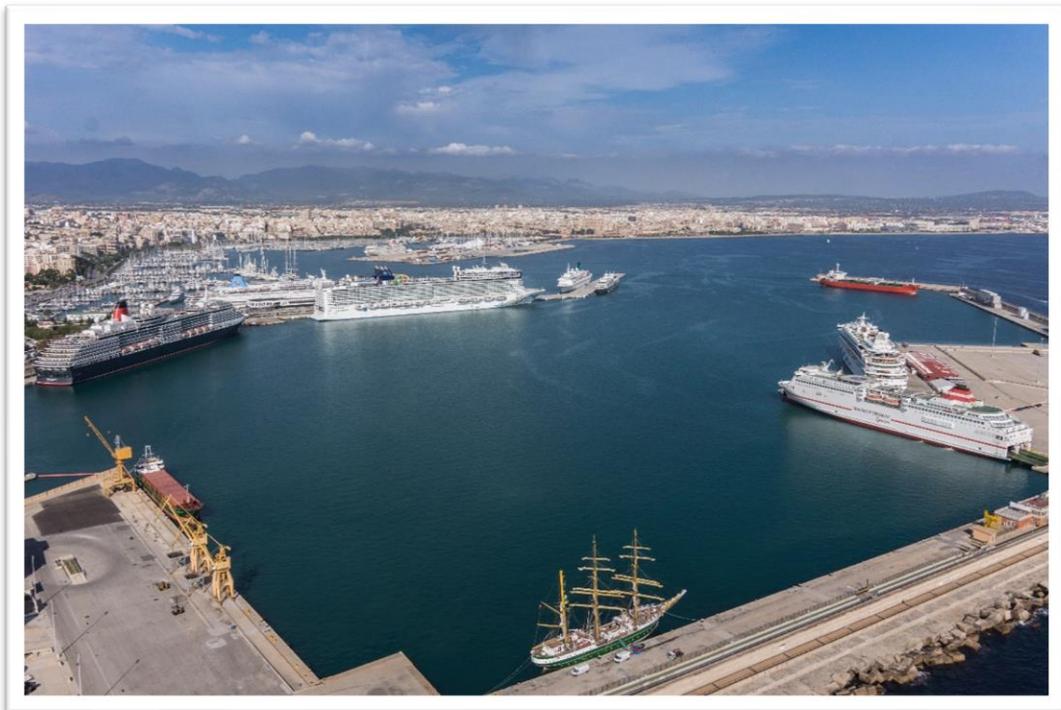
## Appendix

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2	03973-E02_00	Location and site (INSTEIMED)
3	03973-E03_00	Scope of action (INSTEIMED)
4	03973-E04_00	Block diagram (INSTEIMED)
5	03973-E05_00	Single-line diagram (INSTEIMED)
6	03973-E06_00	Trench arrangement (INSTEIMED)
7	03973-E07_00	Trench details (INSTEIMED)
8	03973-E08_00	Station arrangement (INSTEIMED)
9	03973-E09_00	Station earthing system (INSTEIMED)
10	03973-E11_00	Budget (INSTEIMED)
11	GH-FC.01	Hazardous areas

# COTENAVAL – GREEN HYSLAND

## REPORT



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# 1 REPORT

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## 1.1 NOMENCLATURE

### 1.1.1 ABBREVIATURES

ACB – Air Circuit Breaker

CT – Transformation Centre / Transformer Station

HV – High Voltage

HVSC – High Voltage Shore Connection

IT – Isolated neutral

LV – Low Voltage

LVSC – Low Voltage Shore Connection

MCCB – Moulded Case Circuit Breaker

MSB – Main Switchboard

OPS – Onshore Power Supply

PEMS – Power and Energy Management System

RCD – Residual Current Device

### 1.1.2 ITEM DESIGNATION

CLH\_xx – High Voltage Cable

CLV\_xx – Low Voltage Cable

HVxx – High Voltage Cell

HVS\_xx – High Voltage Shore Connection Box

LVxx – Low Voltage Switchboard

LVS\_xx – Low Voltage Shore Connection Box

Qxx – Breaker

TR-xx - Transformer

## 1.2 PREVIOUS INFORMATION ABOUT CONDITIONS, LIMITATIONS AND DIFFERENT CONFIGURATIONS

### ➤ Socket box

- **Number of socket box in the “Dique Oeste”**

- 2 socket boxes for low voltage
- 4 socket boxes for high voltage

- **Limitations about socket boxes**

- It is impossible to install 2 socket boxes in the west berths due to the drop voltage produced from the location of the new transformation centre.

### ➤ Vessels

- **Limitations about different vessel**

Only ferry vessels can be supplied from the new transformation centre for high voltage, it is due to each type of high voltage vessel needs a different plug. For that reason, in this project, the new transformation centre and socket box will be prepared for ferry vessel. However, in the future the installation can be adapted to allow other types of vessels to be supplied by the use off a plug adaptation system.

Number of ships	Ship 1			Ship 2			Ship 3			Total power (MVA)	Notes
	Power (MVA)	Voltage (kV)	Frequency(Hz)	Power (MVA)	Voltage (kV)	Frequency(Hz)	Power (MVA)	Voltage (kV)	Frequency (Hz)		
1	2,5	11	50 o 60							2,5	
1	1	0,4	50							1	
1	1	0,44	60							1	
2	1,25	11	50	1,25	11	50				2,5	
2	1,25	11	60	1,25	11	60				2,5	
2	0,5	0,4	50	0,5	0,4	50				1	N1
2	0,5	0,44	60	0,5	0,44	60				1	N1
2	1	0,4	50	1	0,44	60				2	
2	2,5	11	50 or 60	0,5	0,4	50				3	N1
2	2	11	50 or 60	1	0,4	50				3	
2	2	11	60	0,5	0,44	60				2,5	N1
2	1,5	11	60	1	0,44	60				2,5	
3	2	11	60	0,5	0,4	50	0,5	0,44	60	3	N1
3	1,5	11	60	1	0,4	50	0,5	0,44	60	3	N1
3	1,5	11	60	0,5	0,4	50	1	0,44	60	3	N1
3	1,25	11	60	0,75	0,4	50	1	0,44	60	3	
3	1,25	11	50	1,25	11	50	0,5	0,4	50	3	N1
3	1,25	11	60	1,25	11	60	0,5	0,4	50	3	N1

**Remarks:**

N1 Unhelpful combination; available power will be insufficient in most cases.

N2 Combinations involving a maximum available power of less than 1.25 MVA at 11 kV or 0.5 MVA at 400 V or 440 V have not been considered.

**Limitations:**

1 All 11 kV powered vessels shall operate at the same frequency.

2 If a vessel is powered at 440V 60 Hz, 11 kV vessels may only be powered at 60 Hz.

3 If the 400 or 440 V shore connections (LVSC1 or LVSC02) are used, the corresponding 11 kV shore connection (HVSC1 or HVSC2) are not available.

4 Maximum available power at 60 Hz: 2.5 MVA.

5 Maximum power at 11 kV: 2.5 MVA. It will be lower if used simultaneously with 440 V.

6 Maximum available power combining 50 and 60 Hz vessels: 3 MVA.

7 In order to allow the supply of two low voltage vessel of the same voltage, the maximum power will be less than 1 MVA.

8 If two vessels are powered in HV, the connections shall be made in opposite corners of the dike (Ship A HVSC1 or HVSC2 and ship B HVSC3 or HVSC4)

### 1.3 PURPOSE OF THE PROJECT

The purpose of this project is to introduce a study to define the connection between a hydrogen fuel cell and the electrical power in order to supply different vessels in Palma de Mallorca's Port.

Furthermore, this Project must define both power supplies, on the one hand, the power supply from the electric network and on the other hand, the power supply from the hydrogen fuel cell. Moreover, it will include the connections to combine both suppliers in order to create one unique source.

### 1.4 SITUATION AND LOCATION

The construction works, which are included in the project will be located in the area, which belong to the Palma de Mallorca Port.

The action's field is limited to the Dique Oeste Palma area, as showed in the drawing Scope of action.

## 1.5 ATTACHMENT POINT

In relation to the power supply of the project installations, the project will have an independent attachment point for high voltage.

Attachment point	REF	U	location
HIGH VOLTAGE	CT 12	15 kV	First alignment of the Dique Oeste

In this high voltage attachment point to the supply of the “Dique Oeste”, the existence conductor between the two CT’s is RH5Z1 12/20 kV 1x150 mm<sup>2</sup> Al.

The characteristics of this high voltage attachment point are:

- Nominal voltage: 15 kV
- Short-circuit power: 350 MVA

## 1.6 REGULATIONS

The specific mandatory regulations for the installations subject to this project are those listed below:

### General regulations

- Real Decreto 337/2014, de 9 de mayo, por el que se aprueban el Reglamento sobre condiciones técnicas y garantías de seguridad en instalaciones eléctricas de alta tensión y sus Instrucciones Técnicas Complementarias ITC-RAT 01 a 23.
- Real Decreto 223/2008, de 15 de febrero, por el que se aprueban el Reglamento sobre condiciones técnicas y garantías de seguridad en líneas eléctricas de alta tensión y sus Instrucciones Técnicas Complementarias ITC-LAT 01 a 09.
- Real Decreto 842/2002, de 2 de agosto, por el que se aprueba el Reglamento Electrotécnico para Baja Tensión.
- Real Decreto 1955/2000, de 1 de diciembre, por el que se regulan las actividades de transporte, distribución, comercialización, suministro y procedimientos de autorización de instalaciones de energía eléctrica.
- Real Decreto 314/2006, de 17 de marzo, por el que se aprueba el Código Técnico de la Edificación.
- Real Decreto 842/2013, de 31 de octubre, por el que se aprueba la clasificación de los productos de construcción y de los elementos constructivos en función de sus propiedades de reacción y de resistencia frente al fuego.
- Real Decreto 2267/2004, de 3 de diciembre, por el que se aprueba el Reglamento de seguridad contra incendios en los establecimientos industriales.
- Real Decreto 102/2011, de 28 de enero 2011, Mejora de la calidad del aire, establece objetivos de calidad respecto a las concentraciones de las sustancias siguientes: Dióxido de azufre, dióxido de nitrógeno, óxido de nitrógeno, partículas, plomo, benceno, monóxido de carbono, ozono, arsénico, cadmio, níquel, benzopireno, hidrocarburos aromáticos policíclicos, mercurio, y amoníaco.
- • Ordinances of the Palma de Mallorca City Council
- • Circulars from the Ministry of Industry and Energy that are applicable.
- • UNE standards and UNESA recommendations.

## Electrical equipment

- IEC PAS 80005-3. Utility connections in port - Part 3: Low Voltage Shore Connection (LVSC) Systems - General Requirements.
- IEC/ISO/IEEE 80005-1 Ed. 1: Utility connections in port - Part 1: High Voltage Shore Connection (HVSC) Systems - General requirements.
- IEC 60051-1:2016 specifies definitions and general requirements for direct acting indicating analogue electrical measuring instruments and their accessories.
- IEC 60076. CEI 726, UNE 20.178, UNE 21.538, UNE 20182 y CEI 76 to three-phase and single-phase power transformers
- IEC 60269. Low-voltage fuses general requirements
- IEC 60289. lightning impulse and switching impulse testing - Power transformers and reactors.
- IEC 60417. Graphical symbols for use on equipment.
- IEC 60947. Low-voltage switchgear and control gear.
- IEC 61439-2: Low voltage equipment - Part 2: Power equipment.
- IEC 60947-2: Low voltage equipment - Part 2: Circuit breakers.
- IEC 60947-3: Low voltage equipment - Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units.
- IEC 61271-1: HV equipment - Part 1: General rules.
- IEC 61271-200: HV equipment in metallic envelope.
- IEC 60146-1-1, 2009, General rules - Part 1-1: Basic specifications.
- IEC 60439-2, 2005, Low voltage equipment - Part 2: Specific rules for busbars.
- IEC 60092-351: Electrical installations in ships - Insulating materials for shipboard and offshore units, power, control, instrumentation, telecommunication, and data cables.
- IEC 60092-353: Electrical installations in ships - Power cables for rated voltages 1 kV and 3 kV.
- IEC 60092-354: Electrical installations in ships - Single and three core power cables with extruded solid insulation for rated volt ages 6 kV up to 30 kV.

- Normas UNE para cableado: UNE EN 50265-2-1, UNE EN 50266-2-4, UNE EN-50268, UNE EN-50267-2-1, UNE EN-50267-2-3, UNE NES 713, UNE 21089, UNE-EN 60228:2005.
- Norma UNE 53.112 para tubos de PVC.
- IEC 614-2-2, UL94, ASTM1929B and DIN 53460, Specification for Rigid Plain Conduits Of Insulating Materials.
- Normas DIN 49.020, UNE 20.324, DIN 1.629 para tubos de acero.
- Normas DIN 1624 y UNE 20324 para tubos metálicos en general.

### Security:

- Ley 31/1995, de 8 de noviembre, de prevención de Riesgos Laborales. BOE 10 de noviembre de 1995.
- R.D. 39/1997, de 17 de enero, por el que se aprueba el Reglamento de los Servicios de Prevención. BOE 31 de enero de 1997.
- R.D. 1627/1997, de 24 de octubre, por el que se establecen disposiciones mínimas de seguridad y salud en las obras de construcción. BOE de 25 de octubre de 1997.
- R.D. 486/1997, de 14 de abril, Disposiciones mínimas de seguridad y salud en los locales de trabajo.
- R.D. 485/1997, de 14 de abril, sobre disposiciones mínimas en materia de señalización de seguridad y salud en el trabajo. BOE 23 de abril de 1997.
- R.D. 486/1997 de 14 de abril de 1997 sobre disposiciones mínimas de seguridad y salud en los centros de trabajo. BOE 23 de abril de 1997.
- R.D. 487/1997, de 14 de abril, sobre disposiciones mínimas de seguridad y salud relativas a l manipulación manual de cargas que entrañe riesgos, en particular dorsolumbares, para los trabajadores. BOE 23 de abril de 1997.
- R.D. 664/1997, de 12 de mayo, sobre la protección de los trabajadores contra los riesgos relacionados con la exposición a agentes biológicos durante el trabajo. BOE de 24 de mayo de 1997.
- R.D. 665/1997, de 12 de mayo, sobre la protección de los trabajadores contra los riesgos relacionados con la exposición a agentes cancerígenos durante el trabajo. BOE de 24 de mayo de 1997.

- R.D. 773/1997, de 30 de mayo, sobre disposiciones mínimas de seguridad y salud relativas a la utilización por los trabajadores de equipos de protección individual. BOE de 12 de junio de 1997.
- R.D. 1215/1997, de 18 de julio, por el que se establecen las disposiciones mínimas de seguridad y salud para la utilización por los trabajadores de los equipos de trabajo. BOE de 7 de agosto de 1997.
- Ley 37/2003, de 17 de noviembre, del ruido. BOE de 18 de noviembre de 2003.
- Ley 54/2003, de 12 de diciembre, de reforma del marco normativo de la prevención de riesgos laborales. BOE de 13 de diciembre de 2003.
- R.D. 171/2004, de 30 de enero, por el que se desarrolla el artículo 24 de la Ley 31/1995, de prevención de riesgos laborales, en materia de coordinación de actividades empresariales. BOE 31 de enero de 2004.
- R.D. 2177/2004, de 12 de noviembre, por el que se modifica el R.D. 1215/1997, de 18 de julio, por el que se establecen las disposiciones mínimas de seguridad y salud para la utilización por los trabajadores de los equipos de trabajo, en materia de trabajos temporales en altura. BOE de 13 de noviembre de 2004.
- R.D. 286/2006, de 10 de marzo, sobre la protección de la salud y la seguridad de los trabajadores contra los riesgos relacionados con la exposición al ruido. BOE de 11 de marzo de 2006.
- R.D. 337/2010, de 19 de marzo, por el que se modifican el R.D. 39/1997, de 17 de enero, por el que se aprueba el Reglamento de los Servicios de Prevención; el R.D. 1109/2007, de 24 de agosto, por el que se desarrolla la Ley 32/2006, de 18 de octubre, reguladora de la subcontratación en el sector de la construcción y el R.D. 1627/1997, de 24 de octubre, por el que se establecen disposiciones mínimas de seguridad y salud en obras de construcción.

## 1.7 NEED TO BE MEET

### 1.7.1 DESIGN CONDITIONS

The proposal has been to design an installation which will be operational for the Autoridad Portuaria and for the vessels which dock in the Dique Oeste Palma.

The design follows the prescriptions of the rule IEC PAS 80005-3 “Utility connections in port -Part 3: Low Voltage Shore Connection (LVSC) Systems – General requirements”, and IEC PAS 80005-1 “Utility connections in port –Part 1: High Voltage Shore Connection (HVSC) Systems – General requirements”

The objective is to design an installation with the following characteristics:

- Integration into the existing electrical infrastructure of the port. Furthermore, the installation must guarantee the security in the electrical power supply.
- Installation prepared to be increased.
- Minimise the electric risk.
- Resistance and durability of all equipment.
- The installation must achieve: the required power supply for the vessel, facility in the connection and disconnection manoeuvres, quality in the power supply, integration with the electric vessel system.

### 1.7.2 REQUIREMENTS PROGRAMME

Due to the current characteristics of the vessels which dock in the “Dique Oeste”, the options which we have been considered for this project are:

- Vessels powered by 11 kV, 50-60 Hz
- Vessels powered by 440 V, 60 Hz
- Vessels powered by 400 V, 50 Hz

With the proposal to achieve the objectives of this project, it is necessary to install:

- A new transformation centre in order to supply from the connection point in high voltage up to 2,5 MVA.
- A new area for the installation of a hydrogen fuel cell with a power supply about 400 kW.

## 1.8 DESCRIPTION OF THE NEW INSTALLATIONS

It is required the installation of a new transformation centre (CT13), whose proposal is showed in the drawing Scope of action, this new transformation centre will be supply from the transformation centre (CT12) and the transformation centre (CT14).

### 1.8.1 HIGH VOLTAGE 11 KV AND 50/60 HZ SOLUTION

In order to power supply ships working at 50 Hz and also ships working at 60 Hz, a frequency converter will be used. The incoming frequency is 50 Hz, and the outgoing frequency will be selectable 50 or 60 Hz. Being 500 V the optimal input voltage and 475 V the optimal output voltage for a frequency converter of the size that is being considered, incoming power supply from the power grid (15 kV) and from fuel cell will be adapted by using power transformers. So, two 1,25 MVA, 15/0,5 kV transformers and another 600 kVA transformer for the fuel cell will be included in CT-13. Primary voltage for the fuel transformer will be defined according to the standard output voltage of the fuel cell.

The selectable 50/60 Hz will be adapted to 11 kV by a 475 V/ 11 kV, 2,5 MVA power transformer. This power transformer is located inside the CT13.

There are two outgoing HV circuits and four HVSC boxes. Each HV outgoing circuit can supply one of its two HSVC boxes. Selection of HVSC box working is made inside CT13. This limitation has been imposed due the requirements for the safety circuit, the size of the transformers and frequency converter and the power needed by the considered ferries.

The connection from the joint box to each vessel will be realized by a cable management system, with 1 plug according to the IEC PAS 80005-1, for a maximum intensity in each connector of 350 A and a maximum power supply of 2500 kVA.

### **1.8.2 LOW VOLTAGE 440 V AND 60 HZ SOLUTION**

The 440 V 60 Hz will be obtained by selecting 60 Hz in the frequency converter and by using a power transformer 475/440 V 1MVA. This transformer is located inside the CT13.

As the frequency converter is the same if final voltage is 11 kV or 440 V, the selected output frequency is a limitation in the possible combination of shore connexion boxes that can be used simultaneously.

### **1.8.3 LOW VOLTAGE 400 V AND 50 HZ SOLUTION**

As the frequency converter of the 500 V, 50 Hz matches the frequency of the power grid and fuel cell, the outgoing 400 V, 50 Hz is obtained through a 500/400 V, 1 MVA power transformer. Another 500/400 V, 50 KVA as been foreseen for the space services (ventilation, lighting, control communication, and so on). Both transformers are located inside CT13.

### **1.8.4 VOLTAGE SELECTION FOR THE LOW VOLTAGE SHORE CONNECTION BOXES.**

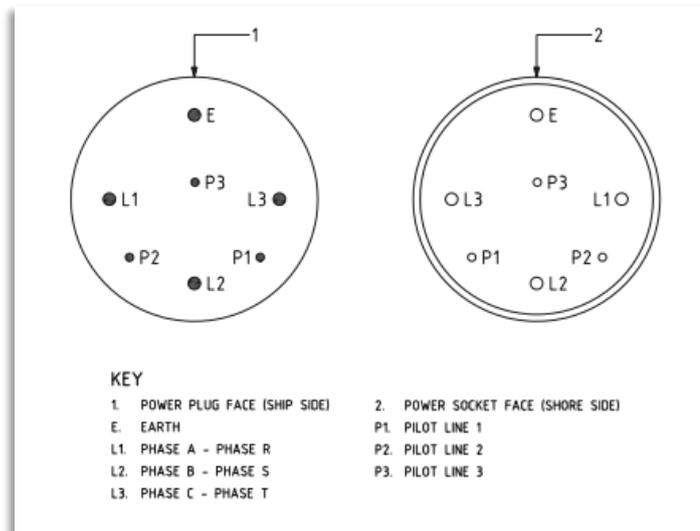
There are two shore connection boxes for low voltage. Each of them can be selected for 400 V, 50 Hz or 440 V, 60 Hz. Selection is made inside CT13. Both shore connection boxes can supply the same or distinct voltage, but the amount of power that can be supplied must be in count as the power of the frequency converter or the transformer is limited.

### 1.8.5 NUMBER OF FEEDERS SOLUTION

As the LVSC boxes are the same for 400 V and 440 V, five plugs are available, but only four can be working when 440 V, 60 Hz is selected. Also, the LV distribution switchboard has circuit breakers for each of the five plugs but only four of them can be working when 400 V, 60 Hz is selected. Despite the plugs available, and according to the rules, all the ship's socket-outlet will be used. The non-used plugs and its corresponding circuit breakers will remain out of service.

According to the IEC 80005-1, we will use one single cable to the high voltage supply due to the IEC PAS 80005-1 demands one cable for Ro-Ro ships up to 6,5 MVA.

The plug will have 3 phases (R, S, T), ground and minimum 3 pilot contacts according to the IEC 80005-1.



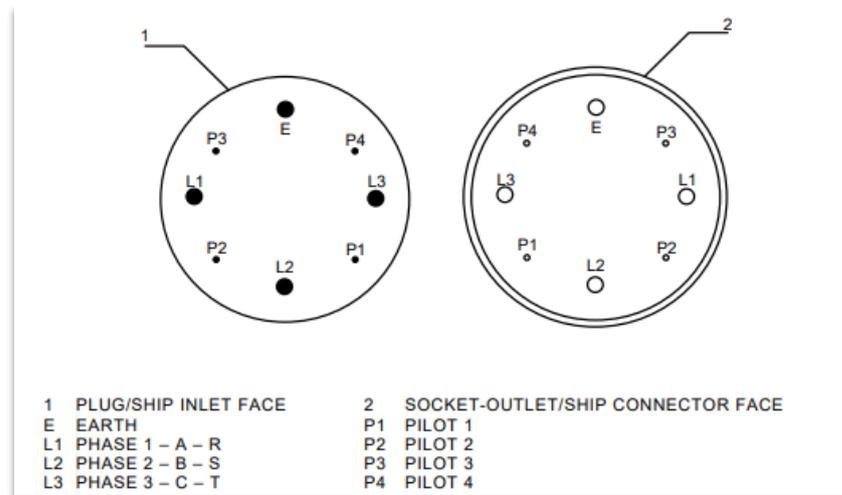
**Figure 1. Plug for HV (Ro-Ro ship).**

According to the IEC PAS 80005-3, a maximum of 4 cable for the distribution in 440 V and 5 cables for the distribution in 400 V can be used. The following table indicates the different number of cables according to the power and voltage.

Power demand kVA	Voltage V		
	400	440	690
250	2	1	1
500	3	2	2
750	4	3	2
1 000	5	4	3

**Figure 2. LV. Quantity of connectors.**

The plug will have 3 phases (R, S, T), ground and minimum 4 pilot contacts according to the IEC 80005-3.



**Figure 3. Plug for LV**

### 1.8.6 ELEMENT DESCRIPTIONS

- ET13: New transformation centre, which will be installed in the Dique Oeste
- HV01: High voltage cells (15 kV)
- HV02: High voltage cells (11 kV)
- LV01: Low voltage switchboard 500 V 50 Hz
- LV02: Converter Output switchboard 475 V (50/60 Hz)
- LV03: Low voltage distribution switchboard 440 V 60 Hz
- LV04: Low voltage distribution switchboard 400 V 50 Hz
- LV05: Low voltage distribution selector switchboard 440V 60 HZ / 400V 50 Hz
- LV06: Low voltage services switchboard 400/230 V 50Hz
- HVSC\_01: High voltage shore connection box 11 kV, 50/60 Hz, 2,5 MVA
- HVSC\_02: High voltage shore connection box 11 kV, 50/60 Hz, 2,5 MVA
- HVSC\_03: High voltage shore connection box 11 kV, 50/60 Hz, 2,5 MVA
- HVSC\_04: High voltage shore connection box 11 kV, 50/60 Hz, 2,5 MVA
- LVSC\_01: Low voltage shore connection box 400/440 V, 50/60 Hz, 1 MVA
- LVSC\_02: Low voltage shore connection box 400/440 V, 50/60 Hz, 1 MVA

## 1.9 DETAILED PROJECT DESCRIPTION.

### 1.9.1 CIVIL WORK

The transformation centre of this project will be a single enclosure where all electrical equipment, machines, and other equipment are located.

The design of this transformer station has considered all the regulations.

- Foundation

A foundation of 0.5m width of concrete with a mass of 250 Kg Portland cement per m<sup>3</sup> of concrete will be established, which will be required to have a characteristic strength of 150 Kg/cm<sup>2</sup> in a cylindrical sample after 28 days.

The depth of the foundation will be the necessary one until the ground can withstand an overload of 1 Kg/cm<sup>2</sup>.

The depth of the foundations will be at least 0.5m.

The foundation slab will support the vertical loads assigned for the fixed and mobile loads mentioned before for the floors.

When the slab is made of masonry, it shall be made with a layer of mortar of a suitable composition to prevent the formation of dust and to be resistant to abrasion. It shall be elevated at least 0.20 m above the exterior level and shall contain the equipotential mesh. It shall have a slight slope towards the outside or a suitable point for collecting liquid, within the CT itself.

- Walls

The walls of the transformer station will be made of German-type concrete block masonry with four walls, 20 cm thick, or of brick masonry of the same thickness.

- Bands

The necessary bands will be established at the top of the walls and other openings that are made.

The bands will be made of reinforced concrete with 350 Kg Portland cement per m<sup>3</sup> of concrete, which is required to have a characteristic strength of 180 Kg/cm<sup>2</sup> in a cylindrical sample after 28 days.

The reinforcements will be made of corrugated steel, consisting of four 12 mm round bars and 6 mm stirrups every 20 cm.

- Roof

The roof will be made up of a reinforced concrete slab with pre-stressed beams and concrete vaults. This slab will be directly supported by the perimeter band and should extend 10 cm beyond it on all sides. Only in places where there are built party walls, the slab will be completely facing the exterior wall of the transformer station.

Once the slab is built, the necessary partition walls and flat vault panels will be constructed for the placement of the tiles. The slope will be at least 25%.

- Trenches, Pipes, Manholes

The trenches through which the HV cables will run to the transformer station will have a width ranging from 40 to 60 cm, depending on requirements, and a depth of 80 cm.

The cables will enter the transformer station through PVC pipes with a diameter of 160 mm and a pressure rating of 4 atmospheres. The number of pipes will be at least equal to the number of cable compartments in the transformer station, and they will be arranged in a layer of 2, in a triangle for 3, or in pairs for 4. They will be properly fixed with concrete, and the ends will be cut in such a way that the cables cannot be damaged at the entry and exit points. Once the cables are in place, the pipe openings will be sealed to prevent rodents from entering.

Inside the transformer station, the cables will reach the corresponding cells or switchboards through a system of pits or channels. The pipes will be made of high-density polyethylene, with a diameter of PN 160, their inner surface will be smooth, and curves will not be allowed. Those that are not used will be sealed with impermeable and expandable foams.

When watertight cable glands are used for the passage of HV and LV cables outside of the CT, the metallic part of these glands shall be installed in such a way that it is not in contact with the equipotential system.

- Access

The CT room must have direct access both for personnel and for installation or replacement of equipment. It will have an exterior sidewalk, preferably at least 1.10 meters wide, for additional protection against contact voltages.

The roads for accessing to the CT must allow the transport, by truck, of the transformers and other elements that are part of it, to the place of its location.

Access to the interior of the CT will be exclusive to the Palma de Mallorca port personnel. This access will be located in an area that, with the CT open, permanently leaves free passage for firefighters, emergency services, emergency exits or relief.

The CT will be adequately protected against water entry in those areas where there is a possibility of flooding.

The location of the CT must allow the laying of all planned underground conduits.

The access doors of the transformer station will be metallic, galvanized, and opening outwards. They will be 2.50 meters high and 1.50 meters wide.

All doors will have a protection degree of IP 23, IK 10, and will be installed in such a way that they are not in contact with the equipotential system and separated by at least 10 cm from the wall reinforcements.

- Dimensions (10,75 x 23,3 x 3 m)

These dimensions must allow:

- The movement and installation of the necessary elements and machinery inside it for the proper implementation of the installation.
- Perform the manoeuvres necessary for its operation under optimal safety conditions for the personnel involved, according to ITC-RAT 14.
- Maintenance of the equipment, as well as the replacement of any of its components, can be carried out without the need to dismantle or move the rest of the equipment.
- The installation of prefabricated HV cells.
- The installation of seven transformer.
- The installation of low voltage switchboards.
- In cable ducts, channels with a minimum depth of 0.4 m will be considered.
- Acoustic insulation and anti-vibration measures

During the design and construction phase of the civil works, it will be foreseen that the transformer station has the corresponding acoustic insulation and anti-vibration measures, so that with the CT in service, no levels higher than those allowed by the Municipal Ordinances are transmitted.

- Fire prevention measures

During the project and construction phase of the civil works, fire protection measures will be taken in accordance with ITC-RAT 14.

- Oil collection

In order to allow the evacuation and prevent the spread of the flammable liquid, a tray equipped with gravel firebreaks will be provided, as indicated in MIE RAT-014, to contain or channel the oil to a tank with a tight lining capable of withstanding temperatures higher than 400°C. This applies even if dry-type transformers are used because in the future they can be replaced.

- Carpentry and locksmithing

The CT room will have the necessary devices to remain closed to ensure that unauthorized persons cannot access it. The carpentry and locksmithing will be made of metal with sufficient strength to guarantee inaccessibility. In environments with high pollution, anodized aluminium will be used for "Protection against environmental aggression.

- Ventilation grilles

The ventilation openings will have a system of grilles and metal mesh that prevent the entry of water and small animals.

They will have an IP 33 protection degree and an IK 09 and will not be in contact with the equipotential system or protective earth network.

When the ventilation inlet or outlet is located on the floor, a pit with a grate will be provided to accommodate it. The pit will have a drain to evacuate rainwater or irrigation through a pipe connected to the general drainage system.

## **1.9.2 ELECTRICAL INSTALLATIONS.**

### **1.9.2.1 INTERIOR DISTRIBUTION NETWORKS IN HIGH VOLTAGE.**

From the existing transformation centre CT12 to the new transformation centre, just as another existing transformation centre located in the proximity of "Dique Oeste" it has been considered for the high voltage distribution an underground line of high voltage 15 kV and 50 Hz. Their general characteristics are:

- Designation UNE: RHZ1 12/20 kV 1x150 Al
- Insulation voltage: 12/20 kV
- Nature of the conductor: Aluminium
- Section: 3x(1x150 mm<sup>2</sup>)
- Insulation: XLPE
- Cover: PVC

Details of the calculation are given in the annex 1 High Voltage Installation.

Regarding the installation conditions, everything specified in the High Voltage Lines Regulation (RLAT) and its Complementary Technical Instructions (R.D. 223/2008) will be considered, particularly the ITC-LAT-06 on Underground Lines with Insulated Cables.

From the High voltage cells (HV01) to the transformers TR-01 and TR-02 there is an air installation (installation in trays, supports, clamps or directly attached to the wall) of a high voltage line of 15 kV and 50 Hz. Their general characteristics are:

- Designation UNE: RHZ1 12/20 kV 1x120
- Insulation voltage: 12/20 kV
- Nature of the conductor: Cooper
- Section: 3x(1x120 mm<sup>2</sup>)
- Insulation: XLPE
- Cover: PVC

Details of the calculation are given in the annex 1 high Voltage Installation.

From the TR-07 (0,475 / 11 kV) to the high voltage cells (HV02), it has been considered for the high voltage distribution an air installation for 11 kV and 50/60 Hz. Their general characteristics are:

- Designation UNE: RHZ1 12/20 kV 1x185
- Insulation voltage: 12/20 kV
- Nature of the conductor: Copper
- Section: 3x(1x185 mm<sup>2</sup>)
- Insulation: XLPE
- Cover: PVC

Details of the calculation are given in the annex 1 high Voltage Installation.

From the high voltage line of the high voltage cells (HV02), it has been considered for the high voltage distribution an underground line of high voltage 11 kV and 50/60 Hz to the four socket box. Their general characteristics are:

- Designation UNE: RHZ1 12/20 kV 1x185
- Insulation voltage: 12/20 kV
- Nature of the conductor: Copper
- Section: 3x(1x185 mm<sup>2</sup>)
- Insulation: XLPE
- Cover: PVC

Details of the calculation are given in the annex 1 high Voltage Installation.

### 1.9.2.2 TRANSFORMER STATION

The new transformation centre will have a pair of transformers of 1,25 MVA each one of them. The location of it, will be in the “Dique Oeste”. It can see in the drawing 03973-E03.

The construction and design of this transformation centre will be in accordance with the Regulation on technical conditions and safety guarantees in high voltage electrical installations, approved by Real Decreto 337/2014 del 9 de Mayo 2014, and its Complementary Technical Instructions ITC-RAT 01 to 23.

Its principal characteristics will be:

- Voltage of the distribution network: 15 kV
- Insulation level of the switchgear: 24 kV
- Type of connection to the network: loop connection
- Short-circuit power: 350 MVA
- Type of switchgear of high voltage: modular
- Insulation type: insulation and SF6

In this project, the distribution system is based on IT rules, because it is the most appropriated system to supply the vessel.

- **MAIN COMPONENTS**

- **High voltage switchgear 15 kV (HV01)**
  - Nominal current: 400 A
  - Nominal voltage 15 kV
  - Short-circuit current: 16 kA-1s
  - General protection (transformer): circuit breaker equipped with relay
- **Transformer 1: 1250 kVA (TR-01)**
  - Insulation: resin-encapsulated dry
  - Frequency: 50 Hz
  - Transformer relation: 15/0,5 kV
  - Nominal power: 1.250 kVA
  - Short-circuit voltage (Ucc): 6%
  - Connection group: Dyn11
  - Thermal protection: PT 100
  - Construction: according to IEC 60076-11
  - Dimensions: maker dependent, about 16450 length, 850 width, 2070 high
- **Transformer 2: 1250 kVA (TR-02)**
  - Insulation: resin-encapsulated dry
  - Frequency: 50 Hz
  - Transformer relation: 15/0,5 kV
  - Nominal power: 1.250 kVA
  - Short-circuit voltage (Ucc): 6%
  - Connection group: Dyn11
  - Thermal protection: PT 100
  - Construction: according to IEC 60076-11
  - Dimensions: maker dependent, about 16450 length, 850 width, 2070 high

-

- **HIGH VOLTAGE EQUIPMENT.**

- **15 kV Power Grid Supply (HV01)**

For the high-voltage equipment, SF6 cells will be used. For the protection cells, it will be required the ability to interrupt loads in order to protect transformers or receivers from overloads and short circuits. These cells will be automatic SF6 circuit breakers. For internal sectioning control of the CT, cells with the ability to interrupt loads but without protective capability will be used. These cells will be SF6 or vacuum. All HV cells shall be as indicated by standard. For measuring equipment, both voltage and current measuring transformers will be used as indicated by standard.

- **11 kV Shore Connection (HV02)**

For the high-voltage equipment, SF6 cells will be used. For the protection cells, it will be required the ability to interrupt loads in order to protect transformers or receivers from overloads and short circuits. These cells will be automatic SF6 circuit breakers. All HV cells shall be as indicated by standard.

- **TRANSFORMERS.**

- **Transformer 3: 2500 kVA (TR-03)**

This transformer is a resin-encapsulated dry transformer of 2.5 MVA of power, with a transformation relation of 475 V to 11 kV and a frequency of 50/60 Hz. The function of this transformer is to supply the high voltage cells. This transformer is according to the IEC 60076-11.

Characteristics:

- Insulation: resin-encapsulated dry
- Frequency: 50/60 Hz
- Transformer relation: 0,475/11 kV
- Nominal power: 2.500 kVA
- Short-circuit voltage (U<sub>cc</sub>): 6%
- Connection group: Dyn11
- Thermal protection: PT 100
- Dimensions: 1890 x 1200 x 2390 mm

- **Transformer 4: 1000 kVA (TR-04)**

This transformer is a resin-encapsulated dry transformer of 1 MVA of power, with a transformation relation of 475 V to 440 V and a frequency of 60 Hz. The function of this transformer is to supply the selector switchboard. This transformer is according to the IEC 60076-11.

Characteristics:

- Insulation: resin-encapsulated dry
- Frequency: 60 Hz
- Transformer relation: 475/440 V
- Nominal power: 1.000 kVA
- Short-circuit voltage (U<sub>cc</sub>): 6%
- Connection group: Dyn11
- Thermal protection: PT 100
- Dimensions: 1470 x 950 x 1590 mm

- **Transformer 5: 1000 kVA (TR-05)**

This transformer is a resin-encapsulated dry transformer of 1000 kVA of power, with a transformation relation of 500 V to 400 V and a frequency of 50 Hz. The function of this transformer is to supply the selector switchboard. This transformer is according to the IEC 60076-11.

Characteristics

- Insulation: resin-encapsulated dry
- Frequency: 50 Hz
- Transformer relation: 500/400 V
- Nominal power: 1.000 kVA
- Short-circuit voltage (U<sub>cc</sub>): 6%
- Connection group: Dyn11
- Thermal protection: PT 100
- Dimensions: 1880 x 900 x 1530 mm

- **Transformer 6: 30 kVA (TR-06)**

This transformer is a resin-encapsulated dry transformer of 30 kVA of power, with a transformation relation of 500 V to 400 V and a frequency of 50 Hz. The function of this transformer is to supply the services switchboard. This transformer is according to the IEC 60076-11.

Characteristics

- Insulation: resin-encapsulated dry
- Frequency: 50 Hz
- Transformer relation: 500/400 V
- Nominal power: 30 kVA
- Short-circuit voltage (U<sub>cc</sub>): 4%
- Connection group: Dyn11
- Thermal protection: PT 100
- Dimensions: 710 x 415 x 597 mm
-

- **Transformer 7: 600 kVA (TR-07)**

This transformer is a resin-encapsulated dry transformer of 600 kVA of power, with a transformation relation of 480 V to 500 V and a frequency of 50 Hz. The function of this transformer is to supply the main switchboard. This transformer is according to the IEC 60076-11.

Characteristics

- Insulation: resin-encapsulated dry
- Frequency: 50 Hz
- Transformer relation: 480/500 V
- Nominal power: 600 kVA
- Short-circuit voltage (U<sub>cc</sub>): 6%
- Connection group: Dyn11
- Thermal protection: PT 100

- **FREQUENCY CONVERTER**

This frequency converter has the characteristics of 2,5 MVA of power, nominal voltage of 500 V and 50 Hz and an output voltage of 475 V and a frequency of 50/60 Hz. Modular construction based on accumulable power modules until reach the desired power, it has a unique inverter controller customized for the specific application.

The frequency converter will be prepared for IT networks and will include the necessary filters to obtain an output voltage with low harmonic.



**Figure 4. Sample image for frequency converter (obtained from commercial datasheet)**

- **LOW VOLTAGE EQUIPMENT**
  - **Main switchboard (LV01)**

The board located at the output of the input transformers (TR-01-TR-02) consists of 6 automatic circuit breakers whose function is to protect the entire installation from overloads and short circuits. This panel distributes power to 3 points:

- The frequency converter
- The service transformer TR-06
- The output transformer TR-05

The internal connections of this board will be made through busbars due to the high power with which it operates. When calculating the corresponding short circuit in this panel with the contribution of the three available energy sources, which are the transformers and the fuel cell. Therefore, the three-phase short circuit in this panel is 60 kA due to the short-circuit of the TR-01, TR-02 (24 kA from each transformer) and the fuel cell (12 kA), so the breaking capacity of these 6 circuit breakers must be greater than 60 kA.

Assuming an adjustment of the circuit breakers, the calibers would be as follows:

- Q1:  $I_n = 1600 \text{ A}$      $I_{sc} = 66 \text{ kA}$
- Q2:  $I_n = 1600 \text{ A}$      $I_{sc} = 66 \text{ kA}$
- Q3:  $I_n = 800 \text{ A}$      $I_{sc} = 66 \text{ kA}$
- Q4:  $I_n = 1250 \text{ A}$      $I_{sc} = 66 \text{ kA}$
- Q5:  $I_n = 100 \text{ A}$      $I_{sc} = 70 \text{ kA}$
- Q6:  $I_n = 3200 \text{ A}$      $I_{sc} = 66 \text{ kA}$

All adjustments will be made according to their nominal current.

- **Output frequency converter switchboard (LV-02)**

Board located downstream of the frequency converter consisting of 3 automatic switches, this board distributes power to 2 points:

- Step-up transformer TR-03
- Transformer TR-04

This board is responsible for controlling the power flow from the frequency converter, as well as protecting it in case of overload or short circuit. The short circuit analysis in this panel will be determined by the short circuit power that the converter can provide, a data provided by the manufacturer, which, if not available, will be assumed as a transformer with zero impedance with a ratio of 500/475 V.

Therefore, the resulting short circuit is 55 kA. The internal connections of this board will be made through busbars due to the high power with which it operates.

Assuming an adjustment of the circuit breakers, the calibers would be as follows:

- Q8: In = 3200 A    Isc = 66 kA
- Q9: In = 1250 A    Isc = 66 kA
- Q10: In = 3200 A    Isc = 66 kA

All adjustments will be made according to their nominal current.

- o **Services switchboard (LV06)**

Board located downstream of the main switchboard, consisting of 16 automatic switches and 6 RCD (Residual Current Device), this board distributes power to 6 points:

- Lighting
- Ventilation
- Control
- Outlets of general purpose
- HV Supplies
- Spares

This board also includes a transformer that can provide 400V/230V with a neutral wire. It will have a spare circuit for general use. The short circuit that can occur in this board will depend on the short circuit power of the transformer. Therefore, the resulting short circuit is 6 kA.

Assuming an adjustment of the circuit breakers, the calibers would be as follows:

- Q22: In = 50 A    Isc = 10 kA
- Q23: In = 25 A    Isc = 10 kA
- Q24: In = 25 A    Isc = 10 kA
- Q25: In = 16 A    Isc = 10 kA
- Q26: In = 16 A    Isc = 10 kA
- Q27: In = 20 A    Isc = 10 kA
- Q28: In = 25 A    Isc = 10 kA
- Q29: In = 10 A    Isc = 10 kA
- Q30: In = 10 A    Isc = 10 kA
- Q31: In = 6 A    Isc = 10 kA
- Q32: In = 16 A    Isc = 10 kA
- Q33: In = 16 A    Isc = 10 kA
- Q34: In = 10 A    Isc = 10 kA
- Q35: In = 10 A    Isc = 10 kA
- Q36: In = 10 A    Isc = 10 kA
- Q37: In = 16 A    Isc = 10 kA

All adjustments will be made according to their nominal current.

- **Selector switchboard (LV05)**

Board located downstream of both transformers TR-04 and TR-05, consisting of 2 circuit breakers and 4 contactors, this board distributes power to 2 points:

- LV03 Distribution switchboard
- LV04 Distribution switchboard

This board is responsible for commutating between 400 or 440V incoming feeder from transformers TR-04 and TR-05, depending of the ship to be powered. The selected voltage is transferred to LV03 and LV04 distribution switchboards. The voltage selection is independent for each distribution switchboard. This commutation is possible due to those 4 contactors with their respective interlocking. The short circuit that can occur in this board will depend on the short circuit power of both transformers, but in this case, we will consider the short with 400V due to its lower voltage which means slightly higher current. Therefore, the resulting short circuit is 20 kA.

Assuming an adjustment of the circuit breakers, the calibers would be as follows:

- Q11: In = 1600 A    I<sub>sc</sub> = 50 kA
- Q7: In = 1600 A    I<sub>sc</sub> = 50 kA

All adjustments will be made according to their nominal current.

- **LV03 distribution switchboard**

These boards manage the outlets of the shore connection by connecting or disconnecting them as needed. They also monitor the insulation or disconnect the vessel link of the shore connection. The internal connections of this board are made through busbars due to the high power with which it operates. The short circuit which can occur in this board will be according to the regulation, which is 25 kA. Although, the short-circuit calculated is lower than 25 kA it will be assumed to be 25 kA.

Assuming an adjustment of the circuit breakers, the calibers would be as follows:

- Q12: In = 320 A    I<sub>sc</sub> = 50 kA
- Q13 to Q16: In = 400 A    I<sub>sc</sub> = 50 kA

All adjustments will be made according to their nominal current.

- **LV04 distribution switchboard**

This board manage the outlets of the shore connection by connecting or disconnecting them as needed. They also monitor the insulation or disconnect the vessel link of the shore connection. The internal connections of this board are made through busbars due to the high power with which it operates. The short circuit which can occur in this board will be according to the regulation, which is 25 kA. Although, the short-circuit calculated is lower than 25 kA it will be assumed to be 25 kA.

Assuming an adjustment of the circuit breakers, the calibers would be as follows:

- Q17:  $I_n = 320 \text{ A}$     $I_{sc} = 50 \text{ kA}$
- Q18 to-Q21:  $I_n = 400 \text{ A}$     $I_{sc} = 50 \text{ kA}$

All adjustments will be made according to their nominal current.

- **GROUNDING AND EARTHING PROTECTION**

Due to the request of the rules, it is necessary to have an system designed in order to protect all accessible points of the electrical installation. This is how the system achieve to eliminate any dangerous voltage, which can be produced for an installation failure.

Therefore, the new transformation centre is composed of two independent system, earthing system and grounding system.

- **Earthing in HV**

The neutral point of HV star windings will be connected to earth trough a resistor. This refer to the TR-03 transformer, that is the only transformer wich secondary side es HV.

The breakers in HV cells have a position that, after the braker es open, connect the user side of installation to earth; so, any remanent energy in the user side is discharged to erth.

- **Earthing in LV.**

The chosen neutral distribution system for LV is IT system (isolated neutral), in this system the neutral of each transformer is insulated respect the earth. This system has many advantages such as the installation allows a permanent insulation control, where the first defect between phase-ground or phase-earth does not produce the appearance of dangerous contact voltages and there is continuity of service.

On the other hand, the appearance of a second defect in a different phase produces a short-circuit that is solved by the acting of a breaker. As resume, first defect does not produce a problem but must be detected because a second defect will produce a service disconnection.

- **Grounding protection**

The metal parts of the installation that are not normally under voltage but can become so due to faults or accidental causes, such as the chassis and frames of the switching devices, metal enclosures of the prefabricated cabins, and transformer casings, will be connected to this system. For the calculations to be performed, we will use the expressions and procedures according to the "Proceso de cálculo y justificación del sistema de puesta a tierra para CT conectado a una red de alta tensión de tercera categoría", published by UNESA.

Identification: UNESA earth calculation method code 8/36

The spikes will be disposed in rows. Each row will consist of three spikes in a linear arrangement, connected by a bare copper conductor with a section of 50mm<sup>2</sup>. The spikes will have a height of 6 meters and a diameter of 14mm and will be vertically buried at a depth of 0.8 meters with a separation of 9 meters between them. The total length of the row will be 27 meters.

Details of the calculation are given in the annex 2 Calculation of ground systems.

### 1.9.2.3 INTERIOR DISTRIBUTION NETWORKS IN LOW VOLTAGE

- **CABLES AND LAYOUT**

There are many low voltages power supply line

Low voltage cables						
Layout	Conductor	type	Insulation	Nominal voltage	Section	Installation
<b>From each transformer TR-01 and TR-02 of the transformer to the low voltage switchboard 500 VAC/ 50 Hz (CLV_01 and CLV_02)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	6x[3x(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup> ] for each transformer	Metallic perforated tray
<b>From the fuel cell to the TR-07 (CLV_03)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	5x[3x(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup> ]	Underground ducted conduit
<b>From the TR-07 to the low voltage switchboard 500 VAC/ 50 Hz (CLV_15)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	4x[3x(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup> ]	Metallic perforated tray
<b>From the general low voltage switchboard to the frequency converter (CLV_06)</b>	Copper	Busbar	POLYESTER FILM, CLASS B	0,6/1 kV	2x[3x(120x6)]	Busbar
<b>From the general low voltage switchboard to the transformer TR-05 (CLV_04)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	5x(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup>	Metallic perforated tray

<b>From the general low voltage switchboard to the transformer TR-06 (CLV_05)</b>	Copper	Multi-pole cable	XLPE	0,6/1 kV	3x16+16 mm <sup>2</sup>	Metallic perforated tray
<b>From the transformer TR-05 to the distribution switchboard 400 V / 50 Hz (CLV_07)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	5x[3x(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup> ]	Metallic perforated tray
<b>From the frequency converter to the output frequency converter switchboard (CLV_08)</b>	Copper	Busbar	POLYESTER FILM, CLASS B	0,6/1 kV	2x[3x(120x6)]	Busbar
<b>From the frequency converter output switchboard to the transformer TR-03 (CLV_10)</b>	Copper	Busbar	POLYESTER FILM, CLASS B	0,6/1 kV	2x[2x(120x6)]	Busbar

<b>From the frequency converter output switchboard to the transformer TR-04 (CLV_9)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	6x[3x(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup> ]	metallic perforated tray
<b>From the transformer TR-04 to the distribution switchboard 440 V / 60 Hz (CLV_11)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	6x[3x(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup> ]	metallic perforated tray
<b>From the distribution panel 440 VAC / 60 Hz to the socket box 440 / 1MVA (CLV_12)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	2x[3x(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup> ]	underground ducted conduit
<b>From the transformer TR-06 to the services switchboard 400/230 V and 50 Hz (CLV_14)</b>	Copper	Multi-pole cable	XLPE	0,6/1 kV	3x50+25 mm <sup>2</sup>	metallic perforated tray
<b>From the distribution panel 400 VAC / 50 Hz to the socket box 400 / 1MVA (CLV_13)</b>	Copper	Unipolar cable	XLPE	0,6/1 kV	2x[(1x240mm <sup>2</sup> ) + 120 mm <sup>2</sup> ]	underground ducted conduit

## SERVICE GROUNDING.

### - SERVICE GROUND (TR-01 AND TR-02)

This system will connect all the neutrals of both power and measurement cells transformers, for this case, the service grounding with the UNESA arrangement will be 8/34, The row will consist of three spikes in a linear arrangement, connected by a bare copper conductor with a section of 50mm<sup>2</sup>. The spikes will have a height of 4 meters and a diameter of 14mm and will be vertically buried at a depth of 0.8 meters with a separation of 6 meters between them. The total length of the row will be 18 meters.

Details of the calculation are given in the annex 2 Calculation of ground systems.

### - SERVICE GROUND FOR OUTPUT TRANSFORMERS (TR-03, TR-04, TR-05 AND TR-06)

There will be two grounding, one for the pull-up transformer (TR-03) and the other one for the other transformers (TR-04, TR-05, TR-06), the service grounding of both, with the UNESA arrangement will be 8/34, The row will consist of three spikes in a linear arrangement, connected by a bare copper conductor with a section of 50mm<sup>2</sup>. The spikes will have a height of 4 meters and a diameter of 14mm and will be vertically buried at a depth of 0.8 meters with a separation of 6 meters between them. The total length of the row will be 18 meters.

Details of the calculation are given in the annex 2 Calculation of ground systems.

#### 1.9.2.4 FUEL CELLS

This is the fuel cell selected for this project due to their characteristics are adequate for our necessities.

The figure below shows the 440 kW stack which has the ability to connect and synchronize with 400V / 480V networks at 50Hz / 60Hz. Its dimensions are 8.33 meters long, 2.54 meters wide, and 3.03 meters high. More details are provided in Annex IV.



**Figure 5. Cell external aspect (obtained from commercial datasheet)**

## 1.10 VENTILATION NEEDS

When a current pass trough a conductor, due to Joule effect, a part of the energy is converted to heat that must be evacuated to maintain the transformer station and its elements in an appropriate working temperature. Heat contribution of main items are calculated below.

### 1.10.1 TRANSFORMERS

For the heat contribution of the transformers, it has been considered that 5 of the 7 transformers are on duty.

Transformer	Core loss (w)	Cupper loss (w)	Total loss (w)
TR-01	2090	13500	15590
TR-02	2090	13500	15590
TR-07	1280	7100	8380
TR-03	3620	25000	28620
TR-05	1090	5780	6870
<i>Total</i>			<b>75050</b>

Considering an air output of 50°C (323,15°K), the expression to obtain the air flow is:

$$Q = \frac{C}{0.29x(t_i - t_e)} \text{ m}^3/\text{h}$$

Where:

- C= Amount of heat given up by transformers to the environment (W)
- $t_i - t_e$ = Maximum permissible difference between indoor and outdoor air temperature
- Q= Required air flow ( $\text{m}^3/\text{h}$ )

The expression that it has been used, it is by experts in ventilation, where it has been selected the ventilator necessary.

Considering and a maximum difference of temperature of 15 °C:

$$Q_1 = \frac{75050}{0.29x10} = 17107 \frac{\text{m}^3}{\text{h}}$$

### 1.10.2 BREAKERS

The datasheet of the breakers shows a value for the loss of power at its rating current value. This value can be in watts per pole or watts per breaker. In this study, due the expected amount of heat generated, only power breakers have been considered as the control breaker would be non-relevant apport. Summarising the high-power breakers of all switchboards, the power losses is:

- 10 x MCCB breakers up to 400 A: 65 W power losses = 650 W
- 8 x ACB breakers up to 3200 A: 250 W power losses = 2000 W
- 2 x MCCB breakers up to 1600 A: 125 W power losses = 250 W

Total amount of power losses: 2900 W

The amount of air flow require:

$$Q2 = \frac{2900}{0.29 \times 15} = 662 \frac{m^3}{h}$$

### 1.10.3 FREQUENCY CONVERTER

The frequency also has losses, as it is described in the datasheet of the manufacturer, the efficiency of the frequency converter, which is around the 98,5%.

The amount of power losses: 50000 W

The amount of air flow require:

$$Q3 = \frac{50000}{0.29 \times 15} = 11407 \frac{m^3}{h}$$

### 1.10.4 TOTAL FLOW REQUIRED

The air flow requires the centre:

$$Q1 + Q2 + Q3 = 17107 + 662 + 11407 = 29176 \frac{m^3}{h}$$

With this air flow, a wall mounted exhaust fan can be used.



**Figure 6. Exhaust fan for wall mounting**

## 1.11 FIRE SAFETY

It will be installed three fire extinguishers, two indoor and other outdoor of the CT, these fire extinguishers will be with a reference 89B, extinguishers of CO<sub>2</sub> suitable for electrical fires. They must be mounted in a free-obstacles site. The reglementary labels and the revision control form must be also included.



**Figure 7. Fire extinguisher and its support**

## 1.12 CONTROL AND AUTOMATION

The system for the control and automation will be a PEMS, which its meaning is Power and Energy Management System. It is composed of:

- Energy management
- Power management
- Control and safety

The function of each system is:

- The function of the energy management system is to organize the energy management for example to organize the number of the vessel, which can be supplied with the cold ironing installation depending on the power they consume and the time that they need and it also will control the consumption energy, for invoicing.
- The function of the Power management system is to determine the status of the power plant, monitoring electrical parameters of the system, connections and transformers in use, its load. Furthermore, it is responsible of the control and synchronization of the two power supplies (network and H<sub>2</sub>) in order to optimize the use of the H<sub>2</sub>.

- The function of the Control and safety system is monitoring all parameters which can produce an alarm or a shutdown of the shore connection. This system includes communication with the ship's control/safety system for the shore connection. In addition, this system is connected with the fuel cell control system, in order to centralize all the alarms and safety connections to the OPS.

The energy source control strategy is based on ensuring the previously planned service and regulating the contribution of energy from the grid or from H2, as described in the following table:

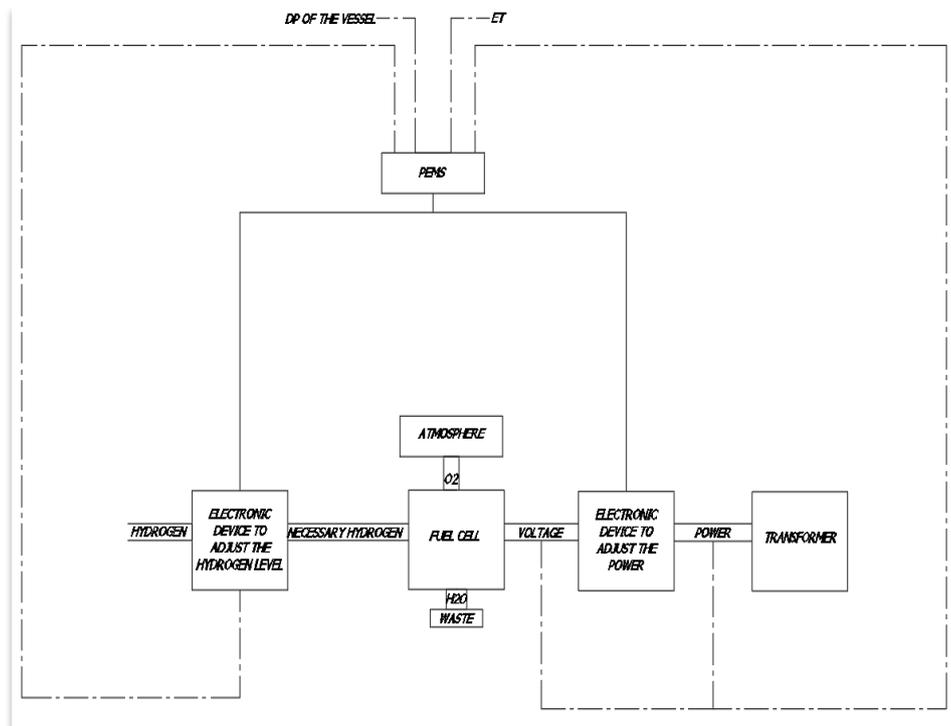
	D demanded power (MVA)	H2 NOT AVAILABLE				H2 SUFFICIENT FOR THE PLANNED SERVICE				H2 INSUFFICIENT FOR THE INTENDED SERVICE			
		Network (MVA)	Network (%)	Fuel cell (MVA)	Fuel cell (%)	Network (MVA)	Network (%)	Fuel cell (MVA)	Fuel cell (%)	Network (MVA)	Network (%)	Fuel cell (MVA)	Fuel cell (%)
1	2,5 up to 3	Operation NOT POSSIBLE				2 up to 2,5	80 up to 85	0,5	15 up to 20	Operation NOT POSSIBLE			
2	0,5 up to 2,5	0,5 up to 2,5	100	0	0	0 up to 2	0 up to 80	0,5	0 up to 20	Necessary less provided by fuel cell		Reduced contribution. See note 1	
3	0 up to 0,5	0 up to 0,5	100	0	0	0	0	0,5	100	Necessary less provided by fuel cell		Reduced contribution. See note 1	

#### Notes

1 If there is insufficient H2 for the planned duration of the service, the energy input of the fuel cell shall be reduced to a rate that allows the planned service to be completed.

2 The control system shall reduce the fuel cell input in case a subsequent operation with a requirement 2,5 MVA is scheduled.

The control of the fuel cell will be:



**Figure 8. Fuel cell control diagram**

The electronic device responsible for the control of the hydrogen level is the mass flow controller (MFC), which regulates the precise flow rates. For this purpose, it is used a sensor, which will control a valve in order to adjust the necessary flow.

### 1.13 SOCKET BOX

This Project will have two types of socket box:

- High voltage socket box prepares for 11 kV, 50/60 Hz and 2.5 MVA
- Low voltage socket box prepares for 400 V, 50 Hz, 1 MVA or 440 V, 60 Hz, 1 MVA

Around the “Dique Oeste” will be installed four socket boxes prepare for high voltage and 2 socket boxes prepare for the low voltage. See drawing Scope of action.

### 1.14 EXTENSIONS FOR FUTURE PROJECTS

#### 1.14.1 POSSIBLE FUTURE EXPANSIONS

With the current design, it would be possible an increase of the amount of power apported by the fuel cell with a limited change in the system. Also, the ability to simultaneously supply different voltage/frequency will be increased.

With a new fuel cell added to the system, considering the same model of 0.5 MVA, it will be required the addition of:

- New transformer 600 kVA which can be installed inside CT13 due to there is enough free space.
- New cable from the new fuel cell to CT13 with minimum interference over public spaces.
- New breaker in LV01. To be considered in the constructive project of the switchboard to have spare space for adding a new breaker in the future, also to be dimensioned the busbar to ampere total after upgrading.

The total available power will be 3,5 MVA instead of the actual 3 MVA, which increased the number of combinations as well as the power of the actual combinations. Nevertheless, the limitation for one ship will be the same but for more ships:

- 2 ships. Ship A = 11 kV, 50 or 60 Hz, 2.5 MVA; ship B = 400V, 50 Hz, 1 MVA
- 3 ships with 3 new possibilities:
  - Ship A = 11 kV, 60 Hz, 2 MVA; ship B = 440 V, 60 Hz, 0.5 MVA and ship C = 400 V, 50 Hz, 1 MVA
  - Ship A = 11 kV, 60 Hz, 1.5 MVA; ship B = 440 V, 60 Hz, 1 MVA and ship C = 400 V, 50 Hz, 1MVA
  - Ship A and Ship B = 11 kV, 50 or 60 Hz (Both ships working at the same frequency), 1.25 MVA and ship c = 400 V, 50 Hz, 1 MVA

### 1.14.2 FUTURE PROJECTS

Considering the limitation about maximum available power and the simultaneous use of different voltages/frequencies ships, the future projects can be based upon the following criteria:

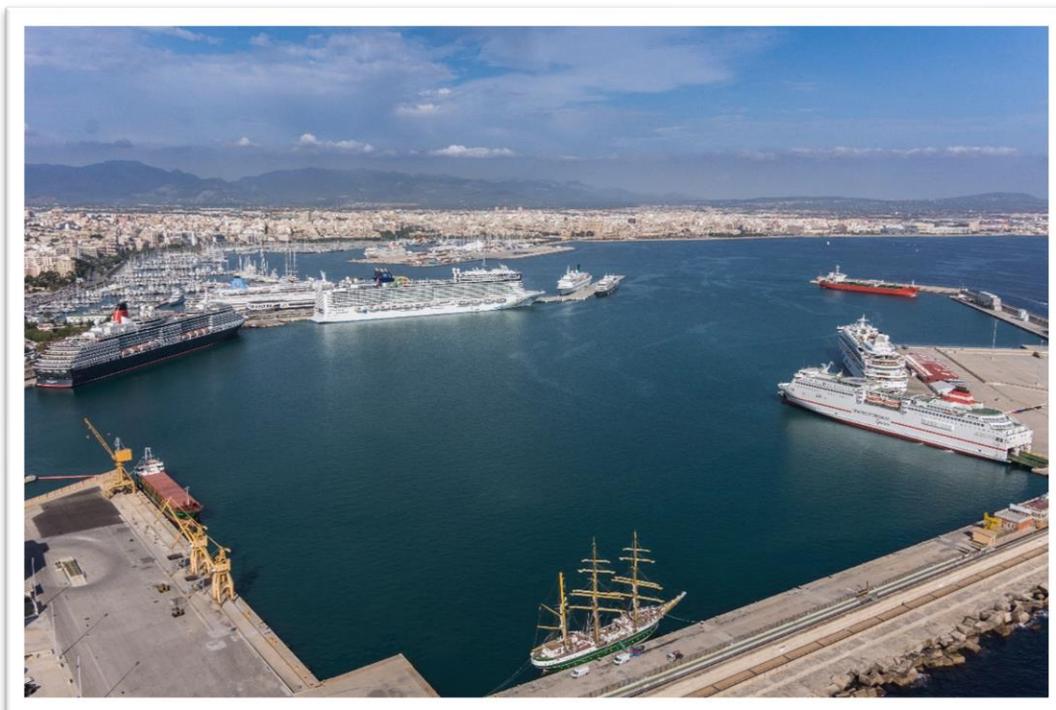
- One common low voltage switchboard (MSB), powered by all the power supply source through its correspondents' transformers.
- At least 2 transformers for adapt the HV grid to the MSB voltage.
- 1 transformer for each fuel cell for adapt the optimum voltage of the fuel cell to the MSB voltage
- MSB voltage will be the optimum for the frequency converter.
- Separate frequency converter for 11 kV ships and 440V ships

With these criteria, the limitation for supplying a ship is the elements needed (converters, transformers), but not the combination of voltage/frequency of the ships involved.

Similar projects can be developed for different dock needs. In addition, the hydrogen could apport bigger proportion of the power consumption in the future by upsizing the fuel cell.

# COTENAVAL – GREEN HYSLAND

## REPORT ANNEX



**03973- E01\_02**

DESCRIPCIÓN

21/04/2023

# ANNEX I

## 2 HIGH VOLTAGE INSTALLATION

---

### 2.1 HYPOTHESIS

It is necessary that the high voltage conductor meet some hypothesis, for example the maximum admissible current, the maximum temperature of the conductor and the maximum voltage drop.

The conditions for the installation are:

- Copper conductors
- Land temperature :25°C
- Atmosphere temperature: 40°C
- Land resistivity: 1.5 Km/W
- Installation depth: 1 m
- Insulation of the conductor: XLPE whose maximum service temperature is 90°C
- Short-circuit power: 350 MVA

### 2.2 GENERAL CHARACTERISTICS

#### 2.2.1 MATERIALS: CABLES AND ACCESSORIES

- **General Conditions**

The materials and their installation will comply with the requirements and tests of the applicable UNE standards included in the ITC-LAT 02 and other applicable technical specifications and standards.

In the event that there is no UNE standard, the corresponding European Standards (EN or HD) shall be used, and in their absence, the corresponding IEC publication (International Electrotechnical Commission) is recommended.

- **Cables**

Cables used in underground networks shall have copper or aluminium conductors and shall be insulated with materials suitable for the installation and operation conditions, generally maintaining the same type of insulation as the cables of the network to which they are connected. They shall be properly shielded and protected against corrosion that may be caused by the ground where they are installed or by erratic currents and shall have sufficient mechanical strength to withstand the installation and laying actions, as well as those usual after installation. Except for mechanical aggressions from public works machinery such as excavators, drills or even picks. They may be single-core or three-core.

- **Accessories**

Accessories shall be suitable for the nature, composition, and section of the cables and shall not increase their electrical resistance. The accessories shall also be suitable for the environmental characteristics (interior, exterior, pollution, etc.).

### 2.2.2 INSTALLATION OF INSULATED CABLES

The information in this section is valid for installations whose nominal voltage of the network is not higher than 30 kV. For higher voltages, the designer will determine and justify in each case the installation conditions and distances.

The conduits will be generally located on public domain land in urban areas or in the course of urbanization that has the level heights planned in the urbanization project (alignments and levels), preferably under the sidewalks, and sharp angles will be avoided. The layout will be as straight as possible, preferably parallel over its entire length to the facades of the main buildings or, failing that, to the curbs. Likewise, the minimum curvature radii that the cables can support without deteriorating, to be respected in changes of direction, must be considered.

In the project stage, it will be necessary to contact public service companies and possible owners of services to know the position of their installations in the affected area. Once known, before proceeding with the opening of the trenches, the installation company will open inspection pits to confirm or rectify the planned layout in the project. The opening of inspection pits can be replaced by the use of detection equipment, such as ground penetrating radar, which allows to compare the plans provided by service companies and at the same time prevent risky situations.

The cables can be installed in the following ways.

- **In ducted conduit**

The depth, to the top of the nearest tube to the surface, shall not be less than 0.6 meters on pavement or soil, nor less than 0.8 meters on roadway.

They shall be constructed of synthetic material, cement and derivatives, or metallic tubes, either cast in the trench or precast, provided they have sufficient mechanical strength. The inside diameter of the tubes shall not be less than one and a half times the outside diameter of the cable or the apparent diameter of the circuit in the case of multiple cables installed in the same tube. The inside of the tubes shall be smooth to facilitate the installation or replacement of the cable or faulty circuit. No more than one circuit shall be installed per tube. If a single unipolar cable is installed per tube, the tubes shall be made of non-ferromagnetic material.

Before laying, the interior of the tubes shall be cleaned of dirt or soil, ensuring the passage of cables by means of mandrel bending according to the interior section of the tube or equivalent system. During laying, they shall be correctly joined to prevent the entry of soil or concrete.

Where possible, changes of direction in ducted conduits shall be avoided, respecting the curvature changes indicated by the cable manufacturer. At points where they occur, access chambers with or without inspection covers may be installed to facilitate cable handling. In order not to exceed the tensile stresses indicated in the applicable standards for each type of cable, intermediate access chambers, either with inspection covers or without, or simply cable-pulling spaces shall be installed in straight sections where required. At the entry to the access chambers, the ducted conduits shall be properly sealed at their ends.

The ducted conduit shall be marked in the same way as indicated in the previous section to warn of the presence of high voltage cables.

- **In trays, supports, clamps, or directly attached to the wall**

Normally, this type of installation will only be used in substations or other high voltage electrical installations (indoor or outdoor) where access is restricted to authorized personnel. When the areas where the cable runs are accessible to people or vehicles, mechanical protections should be provided to make access difficult.

In installations frequented by unauthorized personnel, trays, protective tubes, or channels can be used as the installation system, whose cover can only be removed with the help of a tool. The trays will be placed flush with the wall or in overhead mounting, always at a height greater than 4 m to ensure their inaccessibility. For installations located at a height lower than 4 m, protective tubes or channels will be used, whose cover can only be removed with the help of a tool.

In the case of outdoor installations, the cables will be suitable for the environmental conditions to which they are subjected (sun, cold, rain, etc.), and the mechanical protections and cable fastenings will prevent water from accumulating in contact with the cables.

The corresponding signs and identifications will also be placed.

All metal elements for cable fastening (trays, supports, clamps, ties, etc.) or other accessible metal elements for personnel (flooring, railings, structures, or metal pipes, etc.) will be electrically connected to the installation's grounding system. The conductive channels will be connected to ground every 10 meters at most and always at the beginning and end of the channel.

### **Electrical tests after installation**

Once the installation has been completed, it is necessary to verify that the cable laying and the assembly of accessories (splices, terminals, etc.) has been carried out correctly, for which the tests specified for this purpose in the corresponding standards will be applicable, as established in ITC-LAT 05.

### **Grounding system**

The metal screens of the cables will be connected to ground, at least in one of their extreme terminal boxes.

### **2.2.3 CROSSINGS**

The following are the conditions that underground high voltage cable crossings must meet for each of the indicated cases:

- **Streets and highways**

The cables shall be placed in concrete ducts throughout their length. The depth to the top of the nearest tube to the surface shall not be less than 0.6 meters. Whenever possible, the crossing shall be made perpendicular to the axis of the road.

- **Railways**

The cables shall be placed in concrete ducts perpendicular to the track whenever possible. The top of the nearest tube to the surface shall be at a minimum depth of 1.1 meters from the bottom of the sleeper. These ducts shall extend beyond the railway tracks by 1.5 meters on each end.

- **Other high voltage cables**

Whenever possible, high voltage cables shall be routed below low voltage cables. The minimum distance between a high voltage cable and other high voltage cables shall be 0.25 meters. The distance from the crossing point to the junctions shall be greater than 1 meter. When these distances cannot be respected, the more recently installed cable shall be separated by tubes, ducts or dividers made of materials with adequate mechanical resistance, with a compression resistance of 450 N and able to withstand an energy impact of 20 J if the outer diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J when it is greater than 140 mm.

- **Telecommunications cables**

The minimum separation between high voltage cables and telecommunications cables shall be 0.20 meters. The distance from the crossing point to the junctions, for both the energy and telecommunications cables, shall be greater than 1 meter. When these distances cannot be respected, the more recently installed cable shall be separated by tubes, ducts or dividers made of materials with adequate mechanical resistance, with a compression resistance of 450 N and able to withstand an energy impact of 20 J if the outer diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J when it is greater than 140 mm.

- **Water pipelines**

The minimum distance between electrical power cables and water pipelines shall be 0.2 meters. Crossing over water pipeline joints or electrical pipeline splices shall be avoided by placing them at a distance greater than 1 meter from the crossing. When these distances cannot be maintained, the most recent pipeline shall be separated by tubes, conduits or partitions made of materials with adequate mechanical resistance, with a compression resistance of 450 N and capable of withstanding an impact of energy of 20 J if the outside diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J when it is greater than 140 mm.

- **Gas pipelines**

At crossings of high voltage underground lines with gas pipelines, the minimum distances established in table 3 shall be maintained. When these distances cannot be maintained for justified reasons, they may be reduced by placing a supplementary protection up to the minimums established in table 3. This supplementary protection, to be placed between services, shall be made of preferably ceramic materials (tiles, slabs, bricks, etc.).

In cases where the minimum distance established with supplementary protection cannot be met and it is deemed necessary to reduce this distance, the company owning the gas conduit shall be notified to indicate the measures to be taken in each case.

- **Sewer pipes**

Cables should be routed above sewer pipes. Incision into the interior of sewer pipes is not permitted. Incision into the wall of sewer pipes (for example, by installing tubes) is permitted as long as it is ensured that the wall has not been weakened. If this is not possible, the cables should be routed underneath, and separated from the pipes by tubes, conduits, or partitions made of materials with adequate mechanical strength, with a compressive strength of 450 N and capable of withstanding an impact energy of 20 J if the outer diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J if it is greater than 140 mm.

## 2.2.4 PROXIMITIES AND PARALLELISM

Underground H.T. cables must comply with the proximity conditions and distances indicated below, trying to avoid being in the same vertical plane as other conduits.

- **Other electric power cables**

High voltage cables can be installed in parallel with other low or high voltage cables, maintaining a minimum distance of 0.25 meters between them. When this distance cannot be maintained, the more recent conduit will be separated by tubes, ducts or partitions made of materials with adequate mechanical resistance, with a compression resistance of 450 N and capable of withstanding an impact of 20 J if the outer diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J when it is greater than 140 mm.

If the same owner channels several H.T. cables of the same voltage level at the same time, they may be installed at a shorter distance, but they must be kept separated from each other with any of the protections mentioned above.

- **Telecommunication cables**

The minimum distance between electric power cables and telecommunication cables will be 0.20 meters. When this distance cannot be maintained, the more recent conduit installed will be separated by tubes, ducts or partitions made of materials with adequate mechanical resistance, with a compression resistance of 450 N and capable of withstanding an impact of 20 J if the outer diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J when it is greater than 140 mm.

- **Water channels**

The minimum distance between electric power cables and water channels will be 0.20 meters. The minimum distance between cable joints and water channel joints will be 1 meter. When these distances cannot be maintained, the more recent conduit will be separated by tubes, ducts or partitions made of materials with adequate mechanical resistance, with a compression resistance of 450 N and capable of withstanding an impact of 20 J if the outer diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J when it is greater than 140 mm.

A minimum distance of 0.20 meters in horizontal projection will be maintained, and the water channel will also be placed below the level of the electric cable.

On the other hand, important water arteries will be arranged far enough away to ensure distances of more than 1 meter from H.T. electric cables.

- **Gas channels**

In the parallelism of underground H.T. lines with gas channels, the minimum distances established. When for justified reasons these distances cannot be maintained, they can be reduced by placing a supplementary protection to the minimum distances established. This supplementary protection to be placed between services will be made preferably of ceramic materials (tiles, bricks, etc.) or tubes with adequate mechanical resistance, with a compression resistance of 450 N and capable of withstanding an impact of 20 J if the outer diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J when it is greater than 140 mm.

### **2.2.5 SERVICE CONNECTIONS**

In the case that one of the two services that cross or run parallel is a service connection to a building, a minimum distance of 0.30 meters must be maintained between them. When this distance cannot be respected, the most recent conduit will be separated using tubes, ducts, or partitions made of materials with adequate mechanical strength, with a compression resistance of 450 N and capable of withstanding an impact energy of 20 J if the outer diameter of the tube is not greater than 90 mm, 28 J if it is greater than 90 mm and less than or equal to 140 mm, and 40 J when it is greater than 140 mm.

The entry of service connections to buildings, both low voltage and high voltage cables in the case of electrical connections, must be sealed to ensure their tightness.

## 2.3 EQUATIONS EMPLOYED

- **Design current**

$$I_b = \frac{S}{\sqrt{3} \cdot U}$$

Where:

- I<sub>b</sub>= operation current (A)
- S= power consumption (kVA)
- U= supply voltage (kV)

- **Design short-circuit current**

$$I_{cc} = \frac{1000 \cdot S_{cc}}{\sqrt{3} \cdot U}$$

Where:

- I<sub>cc</sub>= maximum short-circuit current
- U= Nominal voltage(kV)
- S<sub>cc</sub> = Short-circuit power (MVA)

- **Conductor resistance**

$$R_T = R_{20} \cdot [1 + \alpha \cdot (T - 20)]$$

Where:

- R<sub>T</sub>= Conductor resistance to the Temperature T (Ω)
- R<sub>20</sub>= Conductor resistance to the Temperature of 20°C (Ω)
- α=Temperature coefficient (°C<sup>-1</sup>)
- T=Temperature (°C)

If it is provided by the manufacture, that value shall be used.

- **Conductor resistivity**

$$\rho_T = \rho_{20} \cdot [1 + \alpha \cdot (T - 20)]$$

Where:

- $\rho_T$ = Conductor resistivity to the Temperature T ( $\Omega$ )
- $\rho_{20}$ = Conductor resistivity to the Temperature of 20°C ( $\Omega$ )
- $\alpha$ =Temperature coefficient ( $^{\circ}\text{C}^{-1}$ )
- T=Temperature ( $^{\circ}\text{C}$ )

If it is provided by the manufacture, that value shall be used.

- **Cable resistance**

$$X = 2 \cdot \pi \cdot f \cdot L$$

Where:

- X=Cable reactance ( $\Omega/\text{km}$ )
- f=Frequency (Hz)
- L=Mutual induction coefficient

If it is provided by the manufacture, that value shall be used.

- **mutual induction coefficient**

$$L = \left[ 4,6 \cdot \log\left(\frac{a}{r}\right) + 0,5 \right] \cdot 10^{-4}$$

Where:

- L= Mutual induction coefficient (H/km)
- a= Distance between conductor axes (mm)
- r=Radio of the conductor (mm)

If it is provided by the manufacture, that value shall be used.

- **Capacity**

$$C = \frac{0,0241 \cdot \varepsilon}{\log \frac{D}{d}}$$

Where:

- C=Cable capacity (μF/km)
- D=Diameter of the insulation (mm)
- d=Diameter of the conductor, including the semiconductor layer (mm)
- ε= Permittivity of the dielectric

If it is provided by the manufacture, that value shall be used.

- **Maximum temperature**

$$T = T_0 + (T_{max} - T_0) \cdot \left(\frac{I}{I_z}\right)^2$$

Where:

- T=Conductor temperature (°C)
- T<sub>0</sub>=Land temperature (°C)
- T<sub>max</sub>=Maximum admissible temperature of the conductor (°C)
- I<sub>z</sub>=Maximum admissible current in the conductor (A)
- I= Operational current (A)
- 

- **Voltage drop**

$$\Delta U = \sqrt{3} \cdot I \cdot (R \cdot \cos \varphi + X \cdot \sin \varphi) \cdot L$$

Where:

- ΔU=Voltage drop (V)
- I=Line current (A)
- R=Conductor resistance (Ω/km)
- X=Cable reactance (Ω/km)
- L=Length of line
- φ=Power factor

- **Power losses**

$$P_p = 3 \cdot R \cdot I^2 \cdot L$$

Where:

- $P_p$ =Power loss of the line (kW)
- R=Conductor resistance ( $\Omega$ /km)
- L=Length of the line (km)
- I=Design current (A)

## 2.4 RESULTS OF THE CALCULATIONS

### 2.4.1 PREVIOUS INFORMATION

- **Maximum admissible short circuit current.**

- Copper

Tipo de aislamiento	$\Delta\theta^*$ (K)	Duración del cortocircuito, $t_{cc}$ , en segundos									
		0,1	0,2	0,3	0,5	0,6	1,0	1,5	2,0	2,5	3,0
PVC: sección $\leq 300 \text{ mm}^2$ sección $> 300 \text{ mm}^2$	90	363	257	210	162	148	115	93	81	72	66
	70	325	229	187	145	132	102	83	72	65	59
XLPE, EPR y HEPR $U_0/U > 18/30 \text{ kV}$	160	452	319	261	202	184	143	116	101	90	82
HEPR $U_0/U \leq 18/30 \text{ kV}$	145	426	301	246	190	174	135	110	95	85	78

- **Air installations**

- Maximum admissible current. Air installations.

Sección (mm <sup>2</sup> )	EPR		XLPE		HEPR	
	Cu	Al	Cu	Al	Cu	Al
25	140	110	155	120	160	125
35	170	130	185	145	195	150
50	205	155	220	170	230	180
70	255	195	275	210	295	225
95	310	240	335	255	355	275
120	355	275	385	295	410	320
150	405	315	435	335	465	360
185	465	360	500	385	535	415
240	550	425	590	455	630	495
300	630	490	680	520	725	565
400	740	570	790	610	840	660

The table 13 of the ITC-LAT 06 allows you to identify the maximum admissible current in an air installation.

- Temperature correction factor

Temperatura de servicio, $\theta_s$ , en °C	Temperatura ambiente, $\theta_a$ , en °C										
	10	15	20	25	30	35	40	45	50	55	60
105	1,21	1,18	1,14	1,11	1,07	1,04	1	0,96	0,92	0,88	0,83
90	1,27	1,23	1,18	1,14	1,10	1,05	1	0,95	0,89	0,84	0,78
70	1,41	1,35	1,29	1,23	1,16	1,08	1	0,91	0,82	0,71	0,58
65	1,48	1,41	1,34	1,27	1,18	1,10	1	0,89	0,78	0,63	0,45

The table 14 of the ITC-LAT 06 allows you to identify the temperature correction factor.

- Grouping correction factor

Número de bandejas	Factor de corrección			
	Número de cables o ternos			
	2	3	6	9
1	0,84	0,80	0,75	0,73
2	0,80	0,76	0,71	0,69
3	0,78	0,74	0,70	0,68
6	0,76	0,72	0,68	0,66

The table 18 of the ITC-LAT 06 allows you to identify the grouping correction factor.

- **Underground installation under pipe**

Sección (mm <sup>2</sup> )	EPR		XLPE		HEPR	
	Cu	Al	Cu	Al	Cu	Al
25	115	90	120	90	125	95
35	135	105	145	110	150	115
50	160	125	170	130	180	135
70	200	155	205	160	220	170
95	235	185	245	190	260	200
120	270	210	280	215	295	230
150	305	235	315	245	330	255
185	345	270	355	280	375	290
240	400	310	415	320	440	345
300	450	355	460	365	500	390
400	510	405	520	415	565	450

The table 12 of the ITC-LAT 06 allows you to identify the maximum admissible current in an underground installation under pipe.

- Temperature correction factor

Temperatura °C Servicio Permanente $\theta_s$	Temperatura del terreno, $\theta_e$ , en °C								
	10	15	20	25	30	35	40	45	50
105	1,09	1,06	1,03	1,00	0,97	0,94	0,90	0,87	0,83
90	1,11	1,07	1,04	1,00	0,96	0,92	0,88	0,83	0,78
70	1,15	1,11	1,05	1,00	0,94	0,88	0,82	0,75	0,67
65	1,17	1,12	1,06	1,00	0,94	0,87	0,79	0,71	0,61

The table 7 of the ITC-LAT 06 allows you to identify the temperature correction factor.

- Correction factor for thermal resistance

Tipo de instalación	Sección del conductor mm <sup>2</sup>	Resistividad térmica del terreno, K.m/W						
		0,8	0,9	1,0	1,5	2,0	2,5	3
Cables directamente enterrados	25	1,25	1,20	1,16	1,00	0,89	0,81	0,75
	35	1,25	1,21	1,16	1,00	0,89	0,81	0,75
	50	1,26	1,21	1,16	1,00	0,89	0,81	0,74
	70	1,27	1,22	1,17	1,00	0,89	0,81	0,74
	95	1,28	1,22	1,18	1,00	0,89	0,80	0,74
	120	1,28	1,22	1,18	1,00	0,88	0,80	0,74
	150	1,28	1,23	1,18	1,00	0,88	0,80	0,74
	185	1,29	1,23	1,18	1,00	0,88	0,80	0,74
	240	1,29	1,23	1,18	1,00	0,88	0,80	0,73
	300	1,30	1,24	1,19	1,00	0,88	0,80	0,73
400	1,30	1,24	1,19	1,00	0,88	0,79	0,73	
Cables en interior de tubos enterrados	25	1,12	1,10	1,08	1,00	0,93	0,88	0,83
	35	1,13	1,11	1,09	1,00	0,93	0,88	0,83
	50	1,13	1,11	1,09	1,00	0,93	0,87	0,83
	70	1,13	1,11	1,09	1,00	0,93	0,87	0,82
	95	1,14	1,12	1,09	1,00	0,93	0,87	0,82
	120	1,14	1,12	1,10	1,00	0,93	0,87	0,82
	150	1,14	1,12	1,10	1,00	0,93	0,87	0,82
	185	1,14	1,12	1,10	1,00	0,93	0,87	0,82
	240	1,15	1,12	1,10	1,00	0,92	0,86	0,81
	300	1,15	1,13	1,10	1,00	0,92	0,86	0,81
400	1,16	1,13	1,10	1,00	0,92	0,86	0,81	

The table 8 of the ITC-LAT 06 allows you to identify the correction factor for thermal resistance.

- Grouping correction factor

		Factor de corrección								
Tipo de instalación	Separación de los ternos	Número de ternos de la zanja								
		2	3	4	5	6	7	8	9	10
Cables directamente enterrados	En contacto (d=0 cm)	0,76	0,65	0,58	0,53	0,50	0,47	0,45	0,43	0,42
	d = 0,2 m	0,82	0,73	0,68	0,64	0,61	0,59	0,57	0,56	0,55
	d = 0,4 m	0,86	0,78	0,75	0,72	0,70	0,68	0,67	0,66	0,65
	d = 0,6 m	0,88	0,82	0,79	0,77	0,76	0,74	0,74	0,73	-
	d = 0,8 m	0,90	0,85	0,83	0,81	0,80	0,79	-	-	-
Cables bajo tubo	En contacto (d=0 cm)	0,80	0,70	0,64	0,60	0,57	0,54	0,52	0,50	0,49
	d = 0,2 m	0,83	0,75	0,70	0,67	0,64	0,62	0,60	0,59	0,58
	d = 0,4 m	0,87	0,80	0,77	0,74	0,72	0,71	0,70	0,69	0,68
	d = 0,6 m	0,89	0,83	0,81	0,79	0,78	0,77	0,76	0,75	-
	d = 0,8 m	0,90	0,86	0,84	0,82	0,81	-	-	-	-

The table 10 of the ITC-LAT 06 allows you to identify the grouping correction factor.

- Depth correction factor

Profundidad (m)	Cables enterrados de sección		Cables bajo tubo de sección	
	≤185 mm <sup>2</sup>	>185 mm <sup>2</sup>	≤185 mm <sup>2</sup>	>185 mm <sup>2</sup>
0,50	1,06	1,09	1,06	1,08
0,60	1,04	1,07	1,04	1,06
0,80	1,02	1,03	1,02	1,03
1,00	1,00	1,00	1,00	1,00
1,25	0,98	0,98	0,98	0,98
1,50	0,97	0,96	0,97	0,96
1,75	0,96	0,94	0,96	0,95
2,00	0,95	0,93	0,95	0,94
2,50	0,93	0,91	0,93	0,92
3,00	0,92	0,89	0,92	0,91

The table 10 of the ITC-LAT 06 allows you to identify the depth correction factor.

## 2.4.2 RESULT OF EACH CONDUCTOR

Place and connection	Line name	CHV_01	CHV_02	CHV_03	CHV_04
	Connection	PG-TR-01	PG-TR-02	TR-03-HV02	HV02-HVSC_01
Initial data	U nominal (kV)	15	15	11	11
	Frequency (Hz)	50	50	50	50
	S nominal (kVA)	1250	1250	2500	2500
	Power factor	0,8	0,8	0,8	0,8
	P nominal (kW)	1000	1000	2000	2000
	Length (m)	15	22	19	585
Short and current	I design (A)	48,11	48,11	131,22	131,22
	Ics design (kA)	16	16	25	25
Conductor design	Material	Copper	Copper	Copper	Copper
	section (mm <sup>2</sup> )	120	120	185	185
	Reference	Air installation	Air installation	Air installation	Underground intall. Under pipe
	I max conductor	385	385	500	355
	Conductor resistance (ohm/km)	0,1964	0,1964	0,1275	0,1275
	Conductor Reactance (ohm/km)	0,1131	0,1131	0,1101	0,1101
	N circuits	1	1	1	1
	I max (A)	385	385	500	355
Correctors factors	F1	1	1	1	1
	F2	1	1	1	1
	F3	1	1	1	1
	F4	0,8	0,8	0,8	0,7
	F con	0,80	0,80	0,80	0,70
Criteria for selection	Iz (A)	308,00	308,00	400,00	248,50
	Voltage drop (%)	0,0019	0,0027	0,0066	0,2031
Losses	P loss (W)	20,46	30,01	125,13	3852,66
Short conductor	Icc (1s) cond kA	17,16	17,16	26,455	26,455
	Icc (0,1s) cond (kA)	54,24	54,24	83,62	83,62

Place and connection	Line name	CHV_05	CHV_06	CHV_07
	Connection	HVSC_01- HVSC_02	HVSC_02- HVSC_03	HVSC_03- HVSC_02
Initial data	U nominal (kV)	11	11	11
	Frequency (Hz)	50	50	50
	S nominal (kVA)	2500	2500	2500
	Power factor	0,8	0,8	0,8
	P nominal (kW)	2000	2000	2000
	Length (m)	150	400	150
Short and current	I design (A)	131,22	131,22	131,22
	Ics design (kA)	25	25	25
Conductor design	Material	Copper	Copper	Copper
	section (mm <sup>2</sup> )	185	185	185
	Reference	Underground intall. Under pipe	Underground intall. Under pipe	Underground intall. Under pipe
	I max conductor	355	355	355
	Conductor resistance (ohm/km)	0,1275	0,1275	0,1275
	Conductor Reactance (ohm/km)	0,1101	0,1101	0,1101
	N circuits	1	1	1
	I max (A)	355	355	355
Correctors factors	F1	1	1	1
	F2	1	1	1
	F3	1	1	1
	F4	0,7	0,7	0,7
	F con	0,70	0,70	0,70
Criteria for selection	Iz (A)	248,50	248,50	248,50
	Voltage drop (%)	0,0521	0,1389	0,0521
Losses	P loss (W)	987,86	2634,30	987,86
Short conductor	Icc (1s) cond kA	26,455	26,455	26,455
	Icc (0,1s) cond (kA)	83,62	83,62	83,62

# ANNEX II

## 3 TRANSFORMATION CENTRE

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### 3.1 DESCRIPTION OF THE INSTALLATION

#### 3.1.1 GENERAL CHARACTERISTICS

The objective of this point is to specify the conditions of the new transformation centre whose purpose is to supply electrical power by the installation of transformers and other electrical components.

The new transformation centre will be built according to the rules in order to minimise the environmental impact.

#### 3.1.2 GENERAL CHARACTERISTICS OF TRANSFORMATION CENTRE

The transformation centre will be of interior, and it will use prefabricated cells under metal enclosure according to standard UNE-EN 62271-200 for their switchgear.

Its connection will be an underground connection and it will be supply by the High Voltage network and the power supply will be an operating voltage of 15 kV and a frequency of 50 Hz.

On the other hand, their cells will use sulphur hexafluoride as a cutting and arc-extinguishing element. And its compartment will be switchgear compartment, bar set compartment, cables connection compartment control compartment and power compartment.

## 3.2 ELECTRICAL INSTALLATION

### GENERAL CHARACTERISTICS OF HV CELLS:

- Assigned voltage: 24 kV.
- Industrial frequency: 50 Hz
- Assigned current for line functions: 400 A.
- Assigned current for automatic interruption: 400 A.
- Assigned current for fuse breaking: 200 A.
- Admissible nominal current for one second: 16 kA rms.
- Crest value of the admissible nominal current: 40 kA crest.
- Degree of protection of the enclosure: IP307 according to UNE 20324.
- Grounding: The grounding conductor will be arranged along the cells according to UNE-EN 62271-200 and will be sized to withstand the admissible short-duration current.
- - Busbar: The busbar will be oversized to withstand without permanent deformations the dynamic stresses that may occur in a short circuit, which are detailed in the calculation section.

It has a three-phase switch, E3 category according to standard IEC 62271-103 with SF6 gas interruption and 3 positions: connected, disconnected, and grounded, with an E2 (5 CC) category grounding switch with short-circuit closing capability according to standard IEC 62271-103. Both sequences, switch, and grounding switch, tested on the same element.

#### operational safety

- The switch can be in one of three positions: "closed", "open" or "ground", which represents a natural interlocking system that prevents incorrect manoeuvres. The rotation of the movable contacts is carried out by a fast-action mechanism that is independent of the operator's actions.
- The device combines cutting and disconnection functions.
- The SF6 grounding switch has closing power in short circuit, in accordance with the standards.
- Accidental overpressures are eliminated with the opening of the safety membrane, in which case the gas is directed to the bottom of the unit, away from the operator.

**HV CELL- CB+ISOLATOR 400A 16kA CIT busbar 400:**

- Rated supply voltage (Us) 15 kV.
- Industrial frequency: 50 Hz
- Rated current: 400 A.
- Admissible nominal current for one second: 16 kA rms.
- Crest value of the admissible nominal current: 40 kA crest.
- Dimensions: 940x375x1600 mm.
- Technology type: Air insulated switchgear.
- C11 motorized.

**HV CELL- CB+ISOLATOR 400A 16kA CIT busbar 400:**

- Rated supply voltage (Us) 15 kV.
- Industrial frequency: 50 Hz
- Rated current: 400 A.
- Admissible nominal current for one second: 16 kA rms.
- Crest value of the admissible nominal current: 40 kA crest.
- Dimensions: 940x750x1020 mm.
- Technology type: Air insulated switchgear.
- C11 motorized.

**HV CELL MEASUREMENT 400A 16KA with 3 CT's and 3 VT's**

- Rated supply voltage (Us) 24 kV.
- Industrial frequency: 50 Hz
- Rated current: 400 A.
- Admissible nominal current for one second: 16 kA rms.
- Crest value of the admissible nominal current: 40 kA crest.
- Dimensions: 940x750x1020 mm.
- Technology type: Air insulated switchgear.

### 3.3 JUSTIFIED CALCULATIONS

#### 3.3.1 NOMINAL CURRENT IN THE HIGH VOLTAGE LINE

The new transformation centre has two 2 transformers having both the same characteristics, which are:

- Power: 1250 kVA
- Ucc%: 6%
- U primary: 15 kV
- U secondary: 500 V

In the first three - phase transformer, the intensity of the primary circuit  $I_p$  is:

$$I_{p1} = \frac{S}{\sqrt{3} \times U_p}$$

Where:

- S = Transformer power (kVA)
- $U_p$  = Primary voltage (kV)
- $I_p$  = Primary current (A)

Result:

$$I_{p1} = I_{p2} = \frac{1250}{\sqrt{3} \times 15} = 48.11 \text{ A}$$

#### 3.3.2 NOMINAL CURRENT IN THE LOW VOLTAGE LINE

In the first three - phase transformer, the intensity of the secondary circuit  $I_{s1}$  is:

$$I_{s1} = \frac{S}{\sqrt{3} \times U_s}$$

Where:

- S = Transformer power (kVA)
- $U_s$  = Secondary voltage (kV)
- $I_s$  = Secondary current (A)

Result:

$$I_{s1} = I_{s2} = \frac{1250}{\sqrt{3} \times 0.5} = 1443.37 \text{ A}$$

### 3.3.3 SHORT-CIRCUIT CURRENT IN THE HIGH VOLTAGE SIDE

For the short-circuit calculation, it is determined a short-circuit power of 350 MVA in the distribution network.

$$I_{CCp} = \frac{S_{CC}}{\sqrt{3} \cdot U_p}$$

$I_{CCp}$ = short-circuit current (kA)

$U_p$ = Primary voltage(kV)

$S_{CC}$  = Short-circuit power of the network (MVA)

$$I_{CCp} = \frac{350}{\sqrt{3} \cdot 15} = 13.47 \text{ kA}$$

### 3.3.4 SHORT-CIRCUIT CURRENT IN THE LOW VOLTAGE SIDE

The short-circuit in the secondary of a three-phase transformer without the impedance of the High Voltage network is:

$$I_{CCs} = \frac{S}{\sqrt{3} \cdot \left(\frac{U_{CC}}{100}\right) \cdot U_s}$$

$U_s$ =Secondary voltage (V)

$U_{CC}$ = Short-circuit transformer voltage (%)

$S$  = Transformer power (kVA)

$I_{CCs}$ = Secondary short-circuit current (kA)

$$I_{CCs} = \frac{1250}{\sqrt{3} \cdot \left(\frac{6}{100}\right) \cdot 0,5} = 24.056 \text{ kA}$$

### 3.4 ELECTRICITY BUSBAR MEASURING

The busbar characteristics are:

- Current: 400 A
- Thermal limit (1s): 16 kA effective
- Electrodynamic limit: 40 kA
- Voltage: 24 kV

The busbar must therefore withstand the rated current without exceeding the steady-state temperature (current density test), as well as the electrodynamic and thermal stresses occurring during a short-circuit.

This electricity busbar shall support the rated voltage of 24 kV without exceeding the steady-state temperature and the thermal stresses short-circuit.

### 3.5 HIGH AND LOW VOLTAGE PROTECTION SELECTION

The breaker which is in charge of the protection of the High Voltage, it will have cut capacity for rated voltages and short circuit.

As well as the High Voltage line of the transformer, the Low Voltage switchboard will be protected with another breaker.

It is important to point out that all circuits will be protected against overcurrent.

Normally, this overcurrent is usually generated by short-circuit or because the system has defect in its insulation.

When choosing a breaker, it is important that the protection device can guarantee the operation current.

$$I_B \leq I_N \leq I_Z$$

Where:

- $I_B$ = Operation current (A)
- $I_N$ = Nominal current of the protection device (A)
- $I_Z$ = Maximum admissible current (A)

$I_b$  is the maximum output current with an overcurrent coefficient which the transformer could handle during a period without damages.

$$I_{BHv} = 48,2 A$$

$$I_{BLv} = 1443,4 A$$

With those values, we can select a suitable protection for the transformer:

$$I_{NHv} = 50 A$$

$$I_{NLv} = 1600 A$$

Those values are normalized currents.

The cable shall be able to handle currents above the nominal current of the protection device:

$$I_{zHv} = I_{max} * n^{\circ}circuits * F_{con} = 308 A$$

$$I_{zLv} = I_{max} * n^{\circ}circuits * F_{con} = 1887,80 A$$

Due to the tripping current of the high voltage switch being up to 400 A, there shall be a blocking design of any kind which can ensure that no one can change the tripping point of 50 A, with those values we can check:

$$48,2 \leq 50 \leq 308 \quad \text{for the HV side}$$

$$1443,4 \leq 1600 \leq 1887,8 \quad \text{for the LV side}$$

All circuits will have short-circuited protection with the cutting capacity according to the short-circuit current of the connection point.

$$I_{cu} \geq I_{cc}$$

Where:

- $I_{cu}$ = Cutting capacity of the protection device (kA)
- $I_{cc}$ = Short-circuit current (kA)

Therefore, due to the short-circuit current of the switchboard is up to 60 kA, the short-circuit cutting capacity will be bigger than this value, as well as the cable.

### 3.6 CALCULATION OF GROUND SYSTEMS

initial data provided by the company and the installation:

- floor resistance: 200  $\Omega \cdot m$
- Fault time: 0,1 seconds
- Fault current provided by the company: 300A
- Nominal voltage on the high side: 15kV

#### 3.6.1 INSTALLATION DESCRIPTION

The metal parts of the installation that are not normally under voltage but can become so due to faults or accidental causes, such as the chassis and frames of the switching devices, metal enclosures of the prefabricated cabins, and transformer casings, will be connected to this system. For the calculations to be performed, we will use the expressions and procedures according to the "Proceso de cálculo y justificación del sistema de puesta a tierra para CT conectado a una red de alta tensión de tercera categoría", published by UNESA (Association of Electricity Companies), according to the characteristics of the transformer station under consideration in this calculation, including the following:

Identification: UNESA earth calculation method code 8/36

Parameters characteristics:

- $K_r = 0.0516 \Omega / (\Omega \cdot m)$
- $K_p = 0,00583333 V / (\Omega \cdot m)(A)$

The row will consist of three spikes in a linear arrangement, connected by a bare copper conductor with a section of 50mm<sup>2</sup>. The spikes will have a height of 6 meters and a diameter of 14mm and will be vertically buried at a depth of 0.8 meters with a separation of 9 meters between them. The total length of the row will be 27 meters.

Any configuration with lowers parameters will be suitable.

The connection from the transformation centre to the first vertical stake will be with insulated copper cable of 0.6/1 kV protected against mechanical damage.

According to the specific technical specifications for substations and distributions centres provided by ENDESA, and considering the location of the transformer station, it was determined that the required grounding is a reactance along with a resistance. In addition, with the assigned fault current, the values of both impedances could be obtained in the same document:

- Neutral resistance ( $R_n$ ): 31,8  $\Omega$
- Neutral reactance ( $X_n$ ): 22  $\Omega$

### 3.6.2 CALCULATION OF GROUND RESISTANCE AND DEFECT CURRENT

To calculate the earth resistance of the masses at the transformation centre ( $R_t$ ), corresponding fault current and voltage ( $I_d$ ,  $U_d$ ), we will use the following expressions:

- Earth system resistance ( $R_t$ ):

$$R_t = K_r * \rho = 10,32 \Omega$$

Where:

$$R_t = K_r * \rho = 0,0516 * 200 = 10,32 \Omega$$

- Defect current,  $I_d$ :

$$I_d = \frac{U_1}{\sqrt{3} * \sqrt{(R_n + R_t)^2 + X_n^2}} = 182,3 A$$

Where:

- $U_1 = 15 \text{ kV}$
- $R_n = 31.8 \Omega$
- $X_n = 22 \Omega$

### 3.6.3 CALCULATION OF THE VOLTAGES OUTSIDE THE INSTALLATION

In order to prevent the appearance of high contact tensions on the outside of the installation, the metal doors and ventilation grilles that face the exterior of the facility will not have any electrical contact with conducting masses that, due to defects or malfunctions, may be subjected to voltage.

With these safety measures, it will not be necessary to calculate the contact voltages outside, as they will be practically negligible. On the other hand, the step voltage outside will be determined by the characteristics of the electrode and the resistivity of the terrain, by the expression:

$$U_p = K_p * \rho * I_d = 0,005833 * 200 * 182,3 = 212,4 V$$

### 3.6.4 CALCULATION OF THE VOLTAGES INSIDE THE INSTALLATION

The floor of the centre will be made up of a welded mesh with round bars with a diameter of no less than 4 mm, forming a grid no larger than 0.30 x 0.30 m. This mesh will be connected at least at two points, preferably opposite to the grounding of the transformation centre protection. With this arrangement, the person who needs to access a part that may become energized, occasionally, will be on an equipotential surface, eliminating the inherent risk of contact and internal step voltage. This mesh will be covered with a layer of concrete at least 10 cm thick.

Therefore, it will not be necessary to calculate the step and contact voltages inside the installation since their value will be practically zero. However, depending on the calculation method used, the existence of an equipotential mesh connected to the grounding electrode implies that the access step voltage is equivalent to the value of the fault voltage, which is obtained by the expression:

$$U_{pacc} = U_{defect} = R_t * I_d = 10,32 * 182,3 = 1880,8V$$

### 3.6.5 CALCULATION OF APPLIED VOLTAGES

To determine these same voltages applied to a person, we must consider the person's resistance, which will be applied in a general context of 1000 Ω. In turn, the person's footwear will be considered, which will affect the total resistance of the analysis point, a value that is stipulated in the high-voltage regulations as 2000 Ω.

According to the table 1 of the ITC-RAT 13 of earth installations, it is obtained that the maximum allowable contact voltage applied to the human body,  $U_{CA} = 633$  V with the current duration of 0,1 seconds.

In the same way, we calculate the access voltage applied to the person. In this case, a concrete resistivity value of 3000 Ω will be considered. Due to the thickness of the concrete, it can be assumed that its value is the surface resistivity of 3000 Ω without the need to apply a correction factor.

For the determination of the maximum permissible values of step voltage in outdoor areas and at the access to the centre, we will use the following expressions:

$$U_{p'} = \frac{U_p}{1 + \frac{2 * R_{a1} + 6 * \rho}{Z_b}}$$

$$U_{pacc'} = \frac{U_{pacc}}{1 + \frac{2 * R_{a1} + 3 * \rho + 3 * \rho_h}{Z_b}}$$

Where:

- $R_{a,1}$  = Footwear resistance = 2.000 Ω·m
- $\sigma$  = Earth resistivity = 200 Ω·m
- $\sigma_h$  = concrete resistivity = 3.000 Ω·m

Where we obtain the following result:

$$U_{p'} = \frac{212,6}{1 + \frac{2 * 2000 + 6 * 200}{1000}} = 34,3V$$

$$U_{pacc'} = \frac{1880,8}{1 + \frac{2 * 2000 + 3 * 200 + 3 * 3000}{1000}} = 128,9V$$

To verify these obtained values, we need the maximum allowable contact voltage for a person, a voltage that will be given by the protection tripping time, which as mentioned before, will be 0,1 seconds.

This voltage is included in the ITC-RAT 13:

Duración de la corriente de falta, $t_F$ (s)	Tensión de contacto aplicada admisible, $U_{ca}$ (V)
0.05	735
0.10	633
0.20	528
0.30	420
0.40	310
0.50	204
1.00	107
2.00	90
5.00	81
10.00	80
> 10.00	50

In this situation, the value of this voltage will be 633 V. The maximum allowable step voltage represents the maximum step voltage applied to a person's feet without considering additional impedances such as footwear or ground contact. This value is 10 times the allowable contact voltage.

$$U_{pmax} = 10 * U_{ca} = 6330V$$

This value represents the maximum regulatory value to validate the installation, which, as can be seen:

$$U_{p'} = 34,3 < U_{pmax} = 6330V$$

$$U_{pacc'} = 128,9V < U_{pmax} = 6330V$$

We can conclude that the regulatory requirements are met.

### 3.6.6 SERVICE GROUND (TR-01 AND TR-02)

This system will connect all the neutrals of both power and high transformers. For this grounding, there is only one requirement to meet, which is that a voltage higher than 24V cannot be caused when there is a ground fault in the low-voltage installation. Due to this, and the fact that the protection against indirect contacts in low voltage will be provided by a 650 mA RCD, it is obtained that the value of the grounding resistance should not be higher than  $37\Omega$ .

For this case, the service grounding with the UNESA (Association of Electricity Companies) arrangement will be 8/34, with the coefficients  $K_r$  and  $K_p$ :

- $K_r = 0,073 \Omega/(\Omega \cdot m)$
- $K_p = 0,0087 V/(\Omega \cdot m)(A)$

The row will consist of three spikes in a linear arrangement, connected by a bare copper conductor with a section of  $50\text{mm}^2$ . The spikes will have a height of 4 meters and a diameter of 14mm and will be vertically buried at a depth of 0.8 meters with a separation of 6 meters between them. The total length of the row will be 18 meters.

Any value below this will be suitable for the use of that grounding as a service grounding. For the described case, we obtain:

$$R_t = K_r * \rho = 0,073 * 200 = 14,6 \Omega$$

$$V_{grnd} = 0,650 * R_t = 9,49 V$$

Due to:

$$V_{grnd} = 9,49V < V_{max} = 24$$

The service grounding is suitable.

### 3.6.7 SERVICE GROUND FOR OUTPUT TRANSFORMERS (TR-03, TR-04, TR-05 AND TR-06)

There will be two grounding systems for independent output transformers, using the same layout as described previously:

For the step-up transformer, the grounding system with the UNESA (Association of Electricity Companies) arrangement will be 8/34, with the coefficients  $K_r$  and  $K_p$ :

- $K_r = 0,073 \Omega/(\Omega \cdot m)$
- $K_p = 0,0087 V/(\Omega \cdot m)(A)$

For the described case, we obtain:

$$R_t = K_r * \rho = 0,073 * 200 = 14,6 \Omega$$

$$V_{grnd} = 0,650 * R_t = 9,49 V$$

Since:

$$V_{grnd} = 9,49V < V_{max} = 24$$

The grounding system is suitable, but according to the IEC ISO IEEE 80005 standard, a resistance with a value of 540  $\Omega$  must be provided to limit the fault current.

For the 400V, 440V output transformers and the service transformer, the grounding system with the UNESA arrangement will also be 8/34, with the same coefficients  $K_r$  and  $K_p$ . The resulting values are the same as those calculated for the step-up transformer.

The grounding systems will be separated from each other by a distance greater than the previously calculated value, which is 6 meters.

### 3.6.8 PHYSICAL SEPARATION BETWEEN GROUNDS

A distance  $D$  will separate the service grounding of the protection grounding to avoid the induction of currents and voltages from other electrodes. This voltage should not be higher than 1000V. This separation will be determined by the following expression:

$$D \geq \frac{\rho * I_d}{2 * U_{max} * \pi} = \frac{200 * 182,3}{2 * 1000 * \pi} = 5,8 m$$

There must be a physical separation between both grounds greater than 6 meters to ensure that no higher voltages are induced in the protection electrodes.

# ANNEX III

## 4 LOW VOLTAGE INSTALLATION

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### 4.1 HYPOTHESIS

It is necessary that the low voltage conductor meet some hypothesis, for example the maximum admissible current, the maximum voltage drop, maximum admissible short-circuit current, etc.

The conditions for the installation are:

- Aluminium conductors
- Land temperature :25°C
- Atmosphere temperature: 40°C
- Land resistivity: 1.5 Km/W
- Installation depth: 1 m
- Insulation of the conductor: XLPE whose maximum service temperature is 90°C

### 4.2 GENERAL CHARACTERISTICS

#### 4.2.1 ACTIVE CONDUCTOR

- **Nature of conductors**

The conductors and cables used in the installations shall be made of copper and shall always be insulated.

- **Section of the conductor. Voltage drop**

To low voltage installation, which are supplied directly with an own distribution transformer, it will be considered a maximum Voltage drop of 4,5 % for lighting and 6,5 % for other uses.

- **Maximum admissible currents**

The maximum admissible currents shall be governed entirely by the provisions of Standard UNE 20.460-5-523 and its National annex.

- **Conductor identification**

The conductor will be identified easily, especially the protection conductor. In relation to the protection conductors, will be applied to the rule UNE 20460-5-54.

## 4.2.2 CONNECTION

Under no circumstances will the joining of conductors by means of connections and/or derivations by simple twisting or winding of the conductors be allowed, but it must always be carried out using individually mounted connection terminals or by constituting connection blocks or strips; the use of connection ties may also be allowed. They must always be carried out inside junction and/or derivation boxes. If they are multi-wire conductors, the connections must be made so that the current is distributed among all the component wires and if the system adopted is a screw tightening between a metal washer under its head and a metal surface, conductors with a section greater than 6 mm<sup>2</sup> must be connected by means of suitable terminals, so that the connections are not subjected to mechanical stresses.

## 4.3 DISTRIBUTION LINES

In case of a distribution line, it is necessary to see the crossings and parallelisms necessities for this installation.

### 4.3.1 CROSSINGS

Below are the conditions that the low-voltage underground cable crossings must meet for each of the indicated cases.

- **Streets and roads**

The cables will be placed inside protective pipes in accordance with the provisions of ITC-BT-21, covered with concrete along their entire length at a minimum depth of 0.80 m. Whenever possible, the crossing will be made perpendicular to the axis of the roadway.

- **Railways**

The cables will be placed inside protective pipes in accordance with the provisions of ITC-BT-21, covered with concrete and whenever possible, perpendicular to the track, at a minimum depth of 1.3 m from the underside of the sleeper. These pipes will extend beyond the railway tracks by 1.5 m on each end.

- **Other electric power cables**

Whenever possible, low-voltage cables will be routed above high-voltage cables.

The minimum distance between a low-voltage cable and other electric power cables will be: 0.25 m with high-voltage cables and 0.10 m with low-voltage cables. The distance from the crossing point to the joints will be greater than 1 m. When these distances cannot be respected in directly buried cables, the most recently installed cable will be placed in ducts.

- **Telecommunication cables**

The minimum separation between electric power cables and telecommunications cables will be 0.20 m. The distance from the crossing point to the joints of both the power and telecommunications cables will be greater than 1 m. When these distances cannot be respected in directly buried cables, the most recently installed cable will be placed in ducts.

These restrictions do not apply to fibre optic cables with dielectric covers. Any type of cable covering protection must be insulating.

- **Water and gas channels**

Whenever possible, cables will be installed above water channels.

The minimum distance between electric power cables and water or gas channels will be 0.20 m. Crossing the vertical joints of water or gas channels, or the joints of the electrical channel, will be avoided by placing them at a distance greater than 1 m from the crossing. When these distances cannot be respected in directly buried cables, the most recently installed channel will be placed in ducts.

- **Sewer conduits**

Cables will be routed above sewer conduits whenever possible. Incision in their interior will not be allowed. Incision in their wall (for example, by installing tubes) will be allowed, as long as it is ensured that it has not been weakened. If not possible, cables will be routed underneath and placed in ducts.

- **Fuel tanks**

The cables will be placed in ducts and will be at least 0.20 m away from the tank. The ends of the pipes will extend beyond the tank, at least 1.5 m on each end.

#### **4.3.2 PROXIMITIES AND PARALLELISMS**

Low voltage underground cables directly buried must meet the following proximity and distance conditions, avoiding that they remain in the same vertical plane as other conduits.

- **Other electric power cables**

Low voltage cables may be installed in parallel with other low or high voltage cables, maintaining a minimum distance of 0.10 m from low voltage cables and 0.25 m from high voltage cables. When these distances cannot be respected in directly buried cables, the most recently installed cable shall be arranged in a ducted conduit.

In the event that the same owner channels several low voltage cables at the same time, they may be installed at a shorter distance, even in contact.

- **Telecommunication cables**

The minimum distance between electric power cables and telecommunication cables shall be 0.20 m. When these distances cannot be respected in directly buried cables, the most recently installed cable shall be arranged in a ducted conduit.

- **Water conduits**

The minimum distance between electric power cables and water conduits shall be 0.20 m. The minimum distance between cable splices and water conduit joints shall be 1 m. When these distances cannot be respected in directly buried cables, the most recently installed conduit shall be arranged in a ducted conduit.

A minimum horizontal projection distance of 0.20 m shall be maintained, and the water conduit shall be located below the level of the electric cable.

On the other hand, main water arteries shall be arranged in such a way as to ensure distances greater than 1 m from low voltage electric cables.

- **Gas conduits**

The minimum distance between electric power cables and gas conduits shall be 0.20 m, except for high pressure gas conduits (over 4 bar), where the distance shall be 0.40 m. The minimum distance between cable splices and gas conduit joints shall be 1 m. When these distances cannot be respected in directly buried cables, the most recently installed conduit shall be arranged in a ducted conduit.

A minimum horizontal projection distance of 0.20 m shall be maintained. On the other hand, important gas arteries shall be arranged in such a way as to ensure distances greater than 1 m from low voltage electric cables.

## 4.4 RESULT OF THE CALCULATION

### 4.4.1 PREVIOUS INFORMATION

- Air admissible current

**Tabla B.52.5 – Corrientes admisibles, en amperios, para los métodos de la tabla B.52.1 – Cables aislados con XLPE/EPR, tres conductores cargados, cobre o aluminio – Temperatura del conductor: 90 °C, temperatura ambiente 30 °C en el aire, 20 °C en el terreno**

Sección nominal del conductor mm <sup>2</sup>	Método de instalación de la tabla B.52.1						
	A1	A2	B1	B2	C	D	D2
1							
	2	3	4	5	6	7	8
Cobre							
1,5	17	16,5	20	19,5	22	21	23
2,5	23	22	28	26	30	28	30
4	31	30	37	35	40	36	39
6	40	38	48	44	52	44	49
10	54	51	66	60	71	58	65
16	73	68	88	80	96	75	84
25	95	89	117	105	119	96	107
35	117	109	144	128	147	115	129
50	141	130	175	154	179	135	153
70	179	164	222	194	229	167	188
95	216	197	269	233	278	197	226
120	249	227	312	268	322	223	257
150	285	259	342	300	371	251	287
185	324	295	384	340	424	281	324
240	380	346	450	398	500	324	375
300	435	396	514	455	576	365	419

Table B.52.5 of the UNE-HD-60364-5-52-2014, which allows you to identify the air admissible current.

- **Temperature correction factor**

**Tabla B.52.14 – Factores de corrección para temperaturas ambiente diferentes de 30 °C  
a aplicar a los valores de las corrientes admisibles para cables en el aire**

Temperatura ambiente <sup>a</sup> °C	Aislamiento			
	PVC	XLPE y EPR	Mineral <sup>a</sup>	
			Cubierta de PVC o cable desnudo y accesible 70 °C	Cable desnudo e inaccesible 105 °C
10	1,22	1,15	1,26	1,14
15	1,17	1,12	1,20	1,11
20	1,12	1,08	1,14	1,07
25	1,06	1,04	1,07	1,04
30	1,00	1,00	1,00	1,00
35	0,94	0,96	0,93	0,96
40	0,87	0,91	0,85	0,92
45	0,79	0,87	0,78	0,88
50	0,71	0,82	0,67	0,84
55	0,61	0,76	0,57	0,80
60	0,50	0,71	0,45	0,75
65	–	0,65	–	0,70
70	–	0,58	–	0,65
75	–	0,50	–	0,60
80	–	0,41	–	0,54
85	–	–	–	0,47
90	–	–	–	0,40
95	–	–	–	0,32

<sup>a</sup> Para temperaturas ambiente más elevadas, consultar al fabricante.

- **Grouping correction factor**

**Tabla B.52.17 – Factores de reducción para un circuito o un cable multipolar o para un grupo de más de un circuito, o más de un cable multipolar para usarse con las corrientes admisibles de las tablas B.52.2 a B.52.13.**

Punto	Disposición (En contacto)	Número de circuitos o de cables multipolares												Para usarse con las corrientes admisibles, referencia
		1	2	3	4	5	6	7	8	9	12	16	20	
1	Agrupados en el aire, sobre una superficie, empotrados o en el interior de una envolvente	1,00	0,80	0,70	0,65	0,60	0,57	0,54	0,52	0,50	0,45	0,41	0,38	B.52.2 a B.52.13 Métodos A a F
2	Capa única sobre pared, suelo o sistemas de bandejas de cables sin perforar	1,00	0,85	0,79	0,75	0,73	0,72	0,72	0,71	0,70	Sin factor de reducción suplementario para más de nueve circuitos o cables multipolares	B.52.2 a B.52.7 Método C		
3	Capa única fijada directamente bajo techo de madera	0,95	0,81	0,72	0,68	0,66	0,64	0,63	0,62	0,61				
4	Capa única sobre sistemas de bandejas perforadas horizontales o verticales	1,00	0,88	0,82	0,77	0,75	0,73	0,73	0,72	0,72				
5	Capa única sobre sistemas de bandejas de escalera, o bridas de amarre, etc.	1,00	0,87	0,82	0,80	0,80	0,79	0,79	0,78	0,78	B.52.8 a B.52.13 Métodos E y F			

- **Section of the protection conductor**

Secciones de los conductores de fase o polares de la instalación (mm <sup>2</sup> )	Secciones mínimas de los conductores de protección (mm <sup>2</sup> )
S ≤ 16	S (*)
16 < S ≤ 35	16
S > 35	S/2

Table 2 of the ITC-BT 19, which allows you to identify the section of the protection conductor.

- **Resistance and reactance**

Section	R (ohm/km) (20°)	R (ohm/km) (90°)	L (mH/km)	X (ohm/km) (50Hz)	X (ohm/km) (60Hz)
1,5	12,2	15,5556	0,54	0,1696	0,2036
2,5	7,56	9,6394	0,498	0,1565	0,1877
4	4,7	5,9927	0,463	0,1455	0,1745
6	3,11	3,9654	0,432	0,1357	0,1629
10	1,84	2,3461	0,402	0,1263	0,1516
16	1,16	1,4791	0,375	0,1178	0,1414
25	0,734	0,9359	0,358	0,1125	0,1350
35	0,529	0,6745	0,642	0,2017	0,2420
50	0,391	0,4985	0,332	0,1043	0,1252
70	0,27	0,3443	0,322	0,1012	0,1214
95	0,195	0,2486	0,309	0,0971	0,1165
120	0,154	0,1964	0,3	0,0942	0,1131
150	0,126	0,1607	0,295	0,0927	0,1112
185	0,1	0,1275	0,292	0,0917	0,1101
240	0,0762	0,0972	0,286	0,0898	0,1078
300	0,0607	0,0774	0,283	0,0889	0,1067

#### 4.4.2 SHORT CIRCUIT CURRENT

To calculate the short circuit in each switchboard, it is necessary to consider the corresponding impedances in each section, as well as the power contribution capability of each element to the short circuit. Additionally, it is specified that ENDESA provides the corresponding short circuit value for the 15 kV high voltage network input, which should be 16 kA for one second. Therefore, both the conductors and the protections of panel HV01 must be able to withstand this level of short circuit. Furthermore, ENDESA provides the short power for these kinds of transformations centers which is 350 MVA.

- **LV01**

For the LV01 switchboard, there are two transformers operating in parallel and another transformer supplying power generated by the hydrogen fuel cell. By knowing the short circuit voltage  $U_{cc}\%$ , the power, and the transformation ratio, it is possible to estimate the amount of power that each transformer can contribute to the event of a short circuit:

$$X''_{eq} = \frac{V_p}{\sqrt{3} * I_{cc}}$$
$$X_{tr} = \frac{U_{cc}\% * V_p^2}{S_n}$$

Where:

- $X''_{eq}$ : Short circuit impedance

- $X_{tr}$ : Transformer impedance

- $I_{cc}$ : Short circuit current

- $V_p$ : Primary voltage

- $U_{cc}\%$ : Short circuit voltage

- $S_n$ : Nominal transformer power

The transformer impedance shall include the conductor's impedance where:

$$R_l = L * \frac{R_c}{N^2 C_{tr}}$$
$$X_l = L * \frac{X_c}{N^2 C_{tr}}$$

Where:

- $R_l$ : Conductor resistance

- $X_l$ : Conductor impedance

- L: Length of the conductor in m
- N°Cir: Number of circuits per section
- Rc. Conductor's resistivity
- Xl: Conductor's reactance

Assuming there is a single transformer with a capacity of 2,500 kVA and half of the circuits per section, we obtain the following results.

Rl pri	0,00196	Ω
Xl pri	0,00060	Ω
Rl sec	0,00016	Ω
Xl sec	0,00010	Ω
X"eq	0,64290	Ω
Xtr	5,40000	Ω
Z"eq	6,13485	Ω

So, the short circuit current of both transformers:

Iac,	42,35	kA
Ipeak	115,42	kA

That current does not include the power provided by the fuel cell, unknowing that, the current provided by the fuel cell:

$$I_{ccTR07} = \frac{Sn}{Vn * \sqrt{3} * Ucc\%} = \frac{600}{500 * \sqrt{3} * 6\%} = 11,54 \text{ kA}$$

The short current in LV01 will be approximately 54 kA. For a suitable protection of the breakers, it will be required a breaking capacity higher than 60 kA.

- **LV 04**

For the LV04 switchboard of 400V 50 Hz it will apply the same equations used in LV01, due to the proximity to LV05, it will be assumed the same current in both switchboards:

RI pri	0,00039	$\Omega$
XI pri	0,00012	$\Omega$
RI sec	0,00014	$\Omega$
XI sec	0,00009	$\Omega$
X"eq	0,0054	$\Omega$
Xtr	0,01500	$\Omega$
Z"eq	0,02062	$\Omega$

Knowing the current up-stream

I <sub>ac</sub>	17,50	kA
I <sub>peak</sub>	47,30	kA

Therefore, the short circuit rating for panel LV05 will be 17.5 kA. To ensure proper protection of the circuit breakers, a breaking capacity of 20 kA or higher will be required.

Since the short circuit that the installation must withstand should be higher than 25 kA, the protections for the Shore connection should be at least 25 kA.

- **LV06**

For the LV06 switchboard of 400/230V 50 Hz:

RI pri	0,01150	$\Omega$
XI pri	0,00071	$\Omega$
RI sec	0,00050	$\Omega$
XI sec	0,00007	$\Omega$
X"eq	0,0054	$\Omega$
Xtr	0,33333	$\Omega$
Z"eq	0,33973	$\Omega$

Knowing the current up-stream

lac	1,06	kA
lpeak	2,84	kA

Any protection exceeding 1 kA is suitable for this switchboard regardless of the auxiliary circuit it supplies.

- **LV02**

Since the connection between LV01 and LV02 is made through a frequency converter, the applicable short circuit value should correspond to the manufacturer's technical documentation. However, since this data is unknown, it will be assumed to be an ideal transformer without losses.

RI pri	0,00016	$\Omega$
XI pri	0,00010	$\Omega$
RI sec	0,00002	$\Omega$
XI sec	0,00001	$\Omega$
X"eq	0,0054	$\Omega$
Xtr	0,00000	$\Omega$
Z"eq	0,00547	$\Omega$

Knowing the current up-stream

lac	55,56	kA
lpeak	149,43	kA

The short current in LV02 will be approximately 55 kA. For a suitable protection of the breakers, it will be required a breaking capacity higher than 60 kA.

- **LV 03**

For the LV03 switchboard of 400V 50 Hz it will apply the same equations used in LV01, due to the proximity to LV05, it will be assumed the same current in both switchboards:

RI pri	0,00016	$\Omega$
XI pri	0,00010	$\Omega$
RI sec	0,00016	$\Omega$
XI sec	0,00010	$\Omega$
X"eq	0,0049	$\Omega$
Xtr	0,01354	$\Omega$
Z"eq	0,01871	$\Omega$

Knowing the current up-stream

I <sub>ac</sub>	17,40	kA
I <sub>peak</sub>	47,66	kA

Therefore, the short circuit rating for panel LV05 will be 17.5 kA. To ensure proper protection of the circuit breakers, a breaking capacity of 20 kA or higher will be required.

Since the short circuit that the installation must withstand should be higher than 25 kA, the protections for the Shore connection should be at least 25 kA.

#### 4.4.4 RESULTS

Place and connection	Line name	CLV_01	CLV_02	CLV_03	CLV_04	CLV_05
	Connection	TR-01-LV01	TR-02-LV01	FUCEL-TR-07	LV01-TR-05	LV01-TR-06
Initial data	U nominal (kV)	500	500	480	500	500
	Frequency (Hz)	50	50	50	50	50
	S nominal (kVA)	1250	1250	550	1000	30
	Power factor	0,8	0,8	0,8	0,8	0,8
	P nominal (kW)	1000	1000	440	800	24
	Length (m)	9	9	50	18	14
Short and current	I design (A)	1443,38	1443,38	661,55	1154,70	34,64
	Ics design (kA)	60	60	60	60	60
Conductor design	Material	Copper	Copper	Copper	Copper	Copper
	section (mm <sup>2</sup> )	240	240	240	240	16
	Reference	B1	B1	D	B1	B2
	I max conductor	461	461	324	461	80
	Conductor resistance (ohm/km)	0,09716	0,09716	0,09716	0,09716	0,4985
	Conductor Reactance (ohm/km)	0,08985	0,08985	0,08985	0,08985	0,10430
	N circuits	6	6	5	5	1
	I max (A)	2766	2766	1620	2305	80
Correctors factors	F1	0,91	0,91	0,91	0,91	0,91
	F2	0,73	0,73	0,6	0,75	1
	F3	1	1	1	1	1
	F con	0,66	0,66	0,55	0,68	0,91
Criteria for selection	Iz (A)	1837,45	1837,45	884,52	1573,16	72,80
	Voltage drop (%)	0,10	0,10	0,31	0,19	0,08
Losses	P loss (kW)	5,47	5,47	6,38	7,00	0,03
Short conductor	Icc (1s) cond kA	205,92	205,92	171,6	171,6	2,288
	Icc (0,1s) cond kA	650,88	650,88	542,4	542,4	7,232

\* According to IEC ISO IEEE 80005, all shore connections shall be able to handle shorts up to 25 kA.

Line name	CLV_06	CLV_07	CLV_08	CLV_09	CLV_10	CLV_11
Connection	LV01-FC	TR-05-LV05	FC-LV02	LV02-TR-04	LV02-TR-03	TR-04-LV05
U nominal (kV)	500	500	475	475	475	440
Frequency (Hz)	50	50	50/60	50/60	50/60	50/60
S nominal (kVA)	2500	1000	2500	1000	2500	1000
Power factor	0,8	0,8	0,8	0,8	0,8	0,8
P nominal (kW)	2000	800	2000	800	2000	800
Length (m)	10	15	12	19	10	8
I design (A)	2886,75	1154,70	3038,69	1215,47	3038,69	1312,16
Ics design (kA)	60	60	60	60	60	20
Material	Copper	Copper	Copper	Copper	Copper	Copper
section (mm <sup>2</sup> )	4000 A	240	4000 A	240	4000 A	240
Reference	Bus-bar	B1	Bus-bar	B1	Bus-bar	B1
I max conductor	4000	461	4000	461	4000	461
Conductor resistance (ohm/km)	0,00280	0,09716	0,00280	0,09716	0,09716	0,09716
Conductor Reactance (ohm/km)	0,00800	0,08985	0,00800	0,10780	0,10780	0,10780
N circuits	2	5	2	6	2	6
I max (A)	4000	2305	4000	2766	4000	2766
F1	0,91	0,91	0,91	0,91	0,91	0,91
F2	1	0,75	1	0,73	1	0,73
F3	1	1	1	1	1	1
F con	0,91	0,68	0,91	0,66	0,91	0,66
Iz (A)	3640,00	1573,16	3640,00	1837,45	3640,00	1837,45
Voltage drop (%)	0,04	0,16	0,05	0,20	0,79	0,10
P loss (kW)	0,70	5,83	0,93	8,18	26,91	4,01
Icc (1s) cond kA	160	171,6	160	205,92	160	205,92
Icc (0,1s) cond kA	352	542,4	352	650,88	352	650,88

Line name	CLV_12	CLV_13	CLV_14	CLV_15	CLV_16	CLV_17
Connection	LV04-LVSC_01	LV03-LVSC_02	TR-06-LV06	TR-07-LV01	LV05-LV03	LV05-LV04
U nominal (kV)	400	440	400	500	440	400
Frequency (Hz)	50	60	30	50	60	50
S nominal (kVA)	200	250	50	600	1000	1000
Power factor	0,8	0,8	0,8	0,8	0,8	0,8
P nominal (kW)	160	200	40	480	800	800
Length (m)	100	75	9	9	9	9
I design (A)	288,68	328,04	72,17	692,82	1312,16	1443,38
Ics design (kA)	25	25	1	60	20	20
Material	Copper	Copper	Copper	Copper	Copper	Copper
section (mm2)	240	240	50	240	240	240
Reference	D	D	B2	B1	B1	B1
I max conductor	351	351	154	461	461	461
Conductor resistance (ohm/km)	0,09716	0,09716	0,4985	0,09716	0,09716	0,09716
Conductor Reactance (ohm/km)	0,08985	0,10780	0,10430	0,10780	0,10780	0,10780
N circuits	2	2	1	3	6	7
I max (A)	702	702	154	1383	2766	3227
F1	0,91	0,91	0,91	0,91	0,91	0,91
F2	1	1	1	0,82	0,73	0,73
F3	1	1	1	1	1	1
F con	0,91	0,91	0,91	0,75	0,66	0,66
Iz (A)	638,82	638,82	140,14	1031,99	1837,45	2143,70
Voltage drop (%)	0,82	0,69	0,13	0,10	0,11	0,11
P loss (kW)	2,43	2,35	0,07	1,26	4,52	5,47
Icc (1s) cond kA	68,64	68,64	7,15	102,96	205,92	240,24
Icc (0,1s) cond kA	216,96	216,96	22,6	325,44	650,88	759,36

\* According to IEC ISO IEEE 80005, all shore connections shall be able to handle shorts up to 25 kA.

# ANNEX IV

## 5 WHY CHOOSE AN HYDROGEN FUEL CELL

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Fuel cells using green hydrogen are an emerging technology with a bright future ahead due to their numerous advantages in terms of energy efficiency, emissions reduction, and autonomy. Nowadays, the rise of this technology is due to our necessities of finding new ways to provide clean and reliable energy.

By using hydrogen produced from renewable sources such as solar or wind energy, green hydrogen fuel cells are a clean and sustainable option for energy generation. Furthermore, there are more benefits for using a hydrogen fuel cell:

- **High efficiency and versatile use:** Hydrogen fuel cells are known for their high energy efficiency, which can reach around 60%. A significant amount of the generated energy is usable. Additionally, during the electricity generation process in the fuel cell, heat is produced as a subproduct. This residual heat can be utilized for other purposes, such as heating or regenerative processes, further increasing the overall system efficiency.

- **Low emissions:** Hydrogen extraction can be carried out using renewable energy sources, significantly reducing greenhouse gas emissions. Additionally, energy production does not generate pollutants, furthermore, the manufacturing process of fuel cell can be controlled to minimize environmental impacts. Those actions significantly reduce the carbon footprint and negative impacts on air quality.

- **Simple maintenance:** Hydrogen fuel cells generally requires simple maintenance compared to other energy sources. They do not require regular oil changes or filter replacements and maintenance task mainly involve inspections and cleaning. In addition, fuels cells do not have moving or mechanical parts, which reduces possible failures and simplifies the maintenance.

- **Diverse operating options:** There's various alternatives in terms of operation of fuel cells, all these types depending on how the chemical reaction is made of, so we can find hydrogen cells such as Proton Exchange Membrane Fuel Cells, Solid Oxide Fuel Cells, Molten Carbonate Fuel Cells...Each one has their advantages allowing versatility and different options depending in our needs.

- **Energy storage:** Fuel cells have the ability of storing energy for later use. The hydrogen can be stored and utilized when its need it, supplying energy during high demand periods. This storage contributes to greater stability and flexibility in energy management.

- **Silent:** Fuel cells operate silently and generate minimal vibrations. This makes them suitable for applications where noise and vibrations are problematic.

- **Durability and lifespan:** Fuel cells are known for their durability and efficiency throughout their lifespan. Unlike conventional batteries which degrades and losses capacity over the time, hydrogen cells can retain their efficiency and performance even after long periods of use. This is due to the electrochemical nature of hydrogen fuel cells, which allows the reaction to remain stable over extended periods without significant degradation.

- **Flexibility and adaptability:** Fuel cells can adapt to different environments due to their different encloses which can be configured to the specific needs of a particular application. Additionally, hydrogen cells can be integrated into a wide range of devices and systems making the suitable for different applications such as automotive, industry or construction. Some encloses are designed to be transported so it can be used anywhere.

## 5.1 DESCRIPTION OF THE FUEL CELL

Before choosing the fuel cell to be used in the onshore system, it is necessary to understand how it works and why it is being introduced into the system.

The basic idea of its operation is to obtain electrical energy by transforming the stored energy of some fuel, in our case pure hydrogen, through a chemical reaction. In the process of the chemical reaction inside the fuel cell, the stored fuel (hydrogen) and an oxidizing element (usually oxygen) captured from the atmosphere are used as reactants. There is no need for them to be stored.

The choice of hydrogen is due to its abundance in nature, and when combined with oxygen, no polluting emissions are produced, as the result of this reaction is the generation of water vapor.

- ANODE REACTION:  $2\text{H}_2 \rightarrow 4\text{H}^+ + 4\text{e}^-$
- CATHODE REACTION:  $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$

Usually, the reactant for the fuel cell is stored in a location separate from the fuel cell. From there, the fuel cell is supplied with the reactant, where the chemical reaction occurs.

There are different methods to supply hydrogen to the fuel cell, as it can be supplied directly (pure hydrogen) or through reforming a fuel such as methanol, ethanol, etc. The latter option is ruled out due to the objective of avoiding emissions into the atmosphere, since the use of green hydrogen implies zero emissions in the process.

## 5.2 MARKET DEVELOPMENTS

Nowadays, the development of fuel cells is on the rise due to their characteristics that allow for a reduction in external emissions.

The option to be chosen must have the condition of using green hydrogen. This allows for the supply of electrical current emitting zero emissions.

There are numerous types of fuel cells, which are basically differentiated by the electrolyte that separates the anode and cathode, the fuel they use, and the operating temperature.

Below is a table showing the main types of fuel cells.

Type	Electrolyte	Transport ion	Fuel	Temperature	Efficiency	Power per unit*	Start-up time
PEM	Solid polymer	H <sup>+</sup>	H <sub>2</sub>	60 - 120	40/50% or 85% (If it's used cogeneration)	1 W – 200 kW	>1 min
AFC	Aqueous solution KOH	OH <sup>-</sup>	H <sub>2</sub>	90 - 250	55% up to 70%	500 W – 10 kW	5-10 min
PAFC	H <sub>3</sub> PO <sub>4</sub> liquid	H <sup>+</sup>	H <sub>2</sub> hydrocarbon	175 - 200	40% or 80% (If it's used cogeneration)	10 kW – 1 MW	1-4 hour
MFCF	aqueous solution LIKCO <sub>3</sub>	CO <sub>3</sub> <sup>2-</sup>	H <sub>2</sub> hydrocarbon	650	60%	50 kW – 10 MW	5-10 hours
SOFC	Y-ZrO <sub>2</sub>	O <sup>2-</sup>	H <sub>2</sub> hydrocarbon	600-1000	60% or 75% (If it's used cogeneration)	1 kW – 10 MW	30-50 hours

\* Remark: Some fuel cells are capable of working in parallel with more cells, making it scalable.

As can be seen in the table, only MFCF, PAFC and SOFC can use hydrocarbons, in addition to pure hydrogen.

Going deeper into each type of fuel cell to see their characteristics, we can obtain that:

### **PEMFC (Proton Exchange Membrane Fuel cell)**

A Proton Exchange Membrane (PEM) fuel cell is a type of electrochemical device that converts chemical energy directly into electrical energy through a chemical reaction between hydrogen and oxygen. The PEM fuel cell operates at a relatively low temperature, usually between 60-120°C, which allows for fast start-up times and efficient operation. In this article, we will discuss the advantages and disadvantages of PEM fuel cells in detail.

#### **Advantages of PEMFC:**

- Efficiency: PEM fuel cells have a energy conversion efficiency of up to 50%. They are able to convert more than half of the energy in the hydrogen fuel into usable electrical energy, making them very efficient and cost-effective.
- Low operating temperature: One of the key advantages of PEM fuel cells is their low operating temperature. This enables them to start quickly and operate efficiently even in cold temperatures. This makes them ideal for use in vehicles, as they can quickly convert hydrogen fuel into electricity to power the vehicle.
- Low emissions: PEM fuel cells produce only water as a by-product, which makes them environmentally friendly and safe for use in enclosed spaces. Unlike internal combustion engines, they do not produce harmful pollutants, such as carbon monoxide and nitrogen oxides.
- Quiet operation: PEM fuel cells operate silently, making them ideal for use in noise-sensitive environments such as hospitals and residential areas.
- Modular design: PEM fuel cells can be easily combined to increase power output, making them suitable for a wide range of applications, from small portable devices to large-scale power plants.
- Longevity: PEM fuel cells have a longer lifespan than conventional batteries and can operate for thousands of hours without needing to be replaced.

#### **Disadvantages of PEMFC:**

- Cost: One of the main disadvantages of PEM fuel cells is their high cost. They are still relatively expensive to produce, making them less competitive in some markets.
- Durability: PEM fuel cells are sensitive to impurities in the hydrogen fuel and require high-purity hydrogen to operate effectively. They are also prone to degradation over time, which can affect their performance.
- Hydrogen storage: Hydrogen is not readily available and requires special storage and transportation methods, which can add to the cost and complexity of using PEM fuel cells.

- Fuel infrastructure: The lack of a hydrogen fuel infrastructure is a major barrier to the widespread adoption of PEM fuel cells. Without an infrastructure in place to produce, store, and distribute hydrogen, the cost of using PEM fuel cells remains high.
- Cold start-up issues: PEM fuel cells can experience start-up issues in cold weather conditions due to the need for a warm-up period to reach optimal operating temperatures.

## **AFC Fuel Cells (Alkaline Fuel Cells)**

Alkaline fuel cells (AFC) are a type of fuel cell that uses a basic electrolyte, usually potassium hydroxide (KOH), to convert chemical energy from a fuel source into electrical energy. AFCs have been used for decades, primarily in space exploration and military applications, due to their high energy efficiency and ability to operate at low temperatures. In this article, we will explore the advantages and disadvantages of AFCs in more detail.

### **Advantages of AFCs:**

- Efficiency: AFCs have a high energy efficiency; they can convert a large amount of the chemical energy in a fuel source into electrical energy. This is because the chemical reaction that takes place in an AFC is highly efficient and does not produce a large amount of waste heat.
- Low Operating Temperature: AFCs can operate at low temperatures, this makes them ideal for use in applications where high temperatures are not desirable, such as in residential and commercial buildings.
- Low Cost: AFCs are relatively low cost compared to other fuel cell technologies, such as solid oxide fuel cells (SOFCs) and proton exchange membrane fuel cells (PEMFCs). This is because they do not require expensive materials or catalysts.
- High Power Density: AFCs have a high-power density, which means that they can produce a large amount of power in a small amount of space. This makes them ideal for use in applications where space is limited, such as in vehicles.
- Long Lifetime: AFCs have a long lifetime, which means that they can operate for many years without the need for significant maintenance or replacement of parts.

### **Disadvantages of AFCs:**

- Limited Fuel Compatibility: AFCs are limited in terms of the types of fuels they can use. They are typically only able to use pure hydrogen or a hydrogen-rich gas as a fuel source. This limits their potential applications.
- High Purity Requirements: AFCs require a high purity of fuel and oxidant in order to operate efficiently. This can be challenging in some applications, such as in portable devices where a high purity fuel source may not be readily available.

- Corrosion: AFCs are susceptible to corrosion due to the presence of the alkaline electrolyte. This can lead to degradation of the cell over time and reduced efficiency.
- Limited Lifetime at High Power: AFCs have a limited lifetime when operated at high power levels. This is due to the fact that the electrodes in the cell can degrade over time, reducing the overall efficiency of the cell.
- Slow Start-up: AFCs have a slow start-up time, which means that they are not well-suited for use in applications where a rapid response is required.

### **PAFC Fuel Cells (Phosphoric Acid Fuel Cells)**

Phosphoric Acid Fuel Cells (PAFCs) are a type of fuel cell that uses phosphoric acid as an electrolyte. They are considered one of the most mature fuel cell technologies and have been in use since the 1980s. PAFCs are primarily used for stationary power generation, such as in industrial and utility applications.

#### **Advantages of PAFCs:**

- High efficiency: PAFCs can achieve an efficiency of up to 80%, making them one of the most efficient fuel cell technologies available. This high efficiency is due to the ability of PAFCs to generate both electricity and heat simultaneously, which can be used for heating or cooling purposes.
- Reliable: PAFCs are known for their reliability and long operational life. They can operate continuously for several years without any significant degradation in performance.
- Fuel flexibility: PAFCs can operate on a variety of fuels, including natural gas, propane, and biogas. This makes them a versatile option for power generation.
- Low emissions: PAFCs produce very low emissions of pollutants such as nitrogen oxides (NO<sub>x</sub>) and sulfur dioxide (SO<sub>2</sub>), making them an environmentally friendly option.
- Quiet operation: PAFCs operate quietly, making them suitable for use in urban areas or other noise-sensitive environments.

#### **Disadvantages of PAFCs:**

- High cost: PAFCs are currently more expensive than other fuel cell technologies, making them less attractive for some applications.
- Slow start-up time: PAFCs have a relatively slow start-up time, which can be a disadvantage in applications where power is needed quickly.
- Heavy and bulky: PAFCs are heavy and bulky, which can make them difficult to transport and install.
- Sensitive to temperature: PAFCs operate at a high temperature (around 175-200°C), and any significant deviation from this temperature range can result in reduced performance or damage to the fuel cell.

- Maintenance requirements: PAFCs require regular maintenance to ensure proper operation, including replacement of the phosphoric acid electrolyte and the fuel cell stack. This can be costly and time-consuming.

### **MCFC Fuel Cells (Molten Carbonate Fuel Cells)**

MCFC or Molten Carbonate Fuel Cells are a type of fuel cell that uses a molten carbonate electrolyte to conduct ions between the anode and cathode. The process of generating electricity occurs through the reaction between the fuel and the oxidant, which is usually air. The chemical reaction in MCFC fuel cells is exothermic, meaning it produces heat as well as electricity. MCFC fuel cells are one of the many types of fuel cells currently in use today, with a variety of advantages and disadvantages.

#### **Advantages of MCFC:**

- Efficiency: MCFC fuel cells can convert up to 60% of the energy in the fuel into electrical energy, compared to the 30-40% efficiency of traditional combustion-based power generation systems. This efficiency results in reduced fuel consumption and lower emissions.
- Low Emissions: MCFC fuel cells produce few emissions compared to other power generation systems. They release mainly water, carbon dioxide, and small amounts of pollutants such as nitrogen oxide and sulfur oxide, making them a cleaner energy source. This low emission profile makes MCFC fuel cells ideal for use in densely populated areas, as they produce fewer pollutants and contribute less to air pollution.
- Flexible Fuel Sources: Another advantage of MCFC fuel cells is their flexibility in using various fuels such as natural gas, biogas, methane, and even coal gas. MCFC fuel cells can generate electricity from many different fuels, making them an ideal power source in areas where renewable energy sources are limited or unavailable.
- Quiet and Vibration-Free Operation: MCFC fuel cells operate quietly and without producing vibrations. They produce electricity through an electrochemical process, rather than through the combustion of fuels, resulting in silent operation. This makes them a good option for use in residential areas, as they do not produce noise pollution.

**Disadvantages of MCFC:**

- **High Capital Costs:** One of the biggest drawbacks of MCFC fuel cells is their high capital costs. The cost of producing MCFC fuel cells is still relatively high, making them expensive to manufacture and purchase. However, as the technology becomes more widespread and the economies of scale improve, the costs are likely to decrease.
- **Slow Start-Up Time:** MCFC fuel cells have a slow start-up time compared to other power generation systems, making them less suitable for use in applications that require rapid response times, such as backup power supplies. The start-up time can take several minutes, and the system requires a constant heat source to keep the electrolyte in a molten state.
- **High Operating Temperatures:** MCFC fuel cells require high operating temperatures to work efficiently. The electrolyte in the fuel cell must be kept in a molten state, which requires temperatures of around 650°C. These high temperatures can cause thermal stress and lead to system failure if not managed correctly.
- **Sensitivity to Contaminants:** MCFC fuel cells are sensitive to contaminants in the fuel stream, such as sulfur and other impurities, which can cause degradation in performance and reduce the lifespan of the fuel cell. The fuel must be cleaned and purified before being fed into the fuel cell to ensure optimal performance.
- **Limited Lifetime:** MCFC fuel cells have a limited lifetime, typically around five to seven years. After this time, the performance of the fuel cell starts to degrade, and it becomes less efficient. Replacing.

**Solid oxide fuel cells (SOFC)**

Their operating principle is based on the ability of certain oxides to allow the transport of oxide ions at high temperatures, such as 600-1000°C.

The electrolyte they use is a solid oxide, typically ZrO<sub>2</sub>, stabilized with yttrium oxide (YSZ) or scandium oxide (SSZ). They also have the ability to operate with electrolytes that are proton conductors, thus avoiding fuel dilution at the anode.

**Advantages of SOFCs:**

- **Efficiency:** SOFCs can achieve energy efficiencies of up to 60-75%, making them one of the most efficient types of fuel cells available.
- **Fuel flexibility:** SOFCs can operate on a wide range of fuels, including natural gas, biogas, and even coal gas.
- **Low emissions:** SOFCs produce very low emissions, with only water and carbon dioxide released as by-products of the electrochemical reaction.
- **Durability:** SOFCs have a long lifespan, with some systems able to operate for over 40,000 hours. This makes them ideal for stationary power applications, such as backup power or distributed generation.

- Cogeneration capability: SOFCs can also be used for cogeneration, producing both electricity and heat simultaneously. This allows for even greater energy efficiencies and cost savings.

#### **Disadvantages of SOFCs:**

- High operating temperature: The high operating temperature of SOFCs can lead to thermal stress, which can cause degradation and failure of components over time. Additionally, the high temperature requires insulation and cooling systems to be in place, which can add to the overall system complexity and cost.
- Slow start-up time: SOFCs have a slow start-up time, which can limit their use in certain applications that require rapid power delivery.
- High cost: SOFCs are currently more expensive than other types of fuel cells due to the high temperature operation and use of expensive materials such as ceramics and metals.
- Fuel storage requirements: SOFCs require a supply of fuel to be readily available, which can be a challenge in remote or off-grid locations.
- Corrosive electrolyte: The corrosive nature of the electrolyte used in SOFCs can lead to degradation and corrosion of system components, which can reduce their overall lifespan and increase maintenance costs.

### **5.3 NEEDS TO BE MEET**

To make the best decision and select the most suitable fuel cell, it is important to analyse its usage and consider the following needs:

- **High energy density:** The application will require large amounts of energy to meet the power demand. Therefore, it is necessary to search for a battery with a high energy density to fulfil these requirements.
- **Use of hydrogen as the main fuel:** It is important to utilize hydrogen extracted through the use of renewable energy sources. This ensures a sustainable approach and contributes to the reduction of greenhouse gas emissions.
- **Reduced startup times:** Since the flow of ships is not constant, the energy demand will vary throughout the day. Hence, the selected battery must be capable of delivering the maximum amount of energy in the shortest possible time to quickly meet these fluctuations.
- **High performance:** A higher battery performance will enable better utilization of hydrogen, resulting in higher power output and greater energy efficiency.
- **Scalability:** Its important to this project that the fuel cell can be scalable with other cells in order to in a future upgrade the system

Given these needs, it is recommended to use a Proton Exchange Membrane (PEM) battery for this project. This type of battery offers adequate efficiency, low startup times, and high power. Additionally, PEM batteries are easily scalable, allowing for parallel operation with other batteries to efficiently meet the energy requirements.

## 5.4 OPTIONS COMPARATIVE

Once the market has been analysed and each of the types of fuel cells currently in existence has been understood, it is necessary to compare all types with the objective of arriving at a conclusion about which specific model is the most suitable for our application. Therefore, below we will detail the most convenient models for our system, analysing them one by one.

### PEM models

#### EH81 – Fuel Cell Stack (100Kw)

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Dimensions (mm)	Weight (kg)	Temp. (°C)
100	110	450	230 - 500	400*120*610	78	65-80

#### FCwave

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Dimensions (mm)	Weight (kg)
100	200	2*300 1*550	350 - 720	1220*738*2200	875

#### Marine System 200

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Dimensions (mm)	Weight (kg)	Efficiency
100	200	60 - 450	500 - 1000	700*900*2000	700	60%

### HD 180

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V) DC	Dimensions (mm)	Weight (kg)
100	180	1000	2*180-360 OR 360 - 720	1582*1085*700	720

### HyPM HD 100

Nominal Power (kW)	Peak Power (kW)	Current Range (A)	Voltage Range (V)	Dimensions (mm)	Weight (kg)
100	100	380	240 - 480	1150*1500*850	750

### GenSure HP

Minimum Power (kW)	Peak Power (kW)	Current Range (A)	Voltage (V)	Weight (kg)	Efficiency
60	1000	>80	480	<50.000	>50

## 5.5 FINAL SOLUTION



Characteristics	Units	M400 Natural Gas	M400 Hydrogen	M400 Dual (LPG/NG)	Tri-gen
Electric Power Output	kW	440	440	440	440
Electrical Connection		480VAC, 50/60HZ			
Heat Grade @ up to 100°C	Gcal/h	0.335	0.295	0.335	0.335
Peak Overall Efficiency	%	90	85	90	90
Electrical / Heat Efficiency	%	43 / 47	48 / 37	42 / 48 (LPG)	43 / 47
Length / Width / Height	Power Module, M	8.33 / 2.54 / 3.03		9.8 / 2.54 / 3.02	8.74 / 2.54 / 3.02
Length / Width / Height	Cooling Module, M	4.85 / 2.31 / 1.85		4.85 / 2.31 / 1.85	4.85 / 2.31 / 1.85
Fuel		Natural Gas	Hydrogen	Natural Gas & LPG	Natural Gas
Fuel Pressure	Bar	0.025 – 0.035	5	0.025 – 0.035	
Fuel Consumption	Nm <sup>3</sup> /h	99	297	98.4	
Water Consumption	Nm <sup>3</sup> /h	-	-	-	-
Hydrogen Output	Kg/day	-	-	-	0~220kg/day
Water Discharge	L/min	-	1.36	-	-
NOx	kg/MWh (lbs/MWh)	0.006 (0.013)	-	0.006 (0.013)	
CO <sub>2</sub>	kg/MWh (lbs/MWh)	453 (999)	-	453 (999)	
CO	kg/MWh (lbs/MWh)	0.009 (0.020)	-	0.009 (0.020)	
VOC	kg/MWh (lbs/MWh)	0.009 (0.020)	-	0.009 (0.020)	
SO <sub>2</sub>		Negligible	-	Negligible	
Noise	dB @ 10m				60
Code & Standard		ANSI/CSA FC1-2012 (System) , UL1741 (Inverter)			
Ambient Operation Temp	°C / °F	-29 to 45 °C / -20 to 104°F			

The M400 Hydrogen fuel cell of Doosan, it is an adequate fuel cell due to the possibility of being synchronised with the grid. Furthermore, it can supply 480 VAC and 50 Hz, with an electrical efficiency of 48%. Additionally, its electric power output is 440 kW and an ambient operation temp of -29°C to 45°C.

This fuel cell can be operated by a Remote Monitoring System (RMS), a remote access which allows any control of the fuel cell such as start-up, power output or shut-down commands. The communication between the operator and the fuel cell can be done through an internet connection. A wireless cellular modem its built-in this model. The RMS allows Ramps up/down up to 20 kW/sec during the regulation requirements of the grid.

A cooling module is required in order to cool the battery during its operation, and it will use glycol as the coolant liquid. The module can be installed on the fuel cell.

This fuel cell requires some auxiliary services such as H2 pipeline, N2 purge gas, water drain line, demi water supply and a cooling water line. Lifetime of the fuel cell under constant operation is around 20 years with a replacement of the cells stacks, as well as for a suitable condition during its lifetime, a maintenance is recommended.



Spain



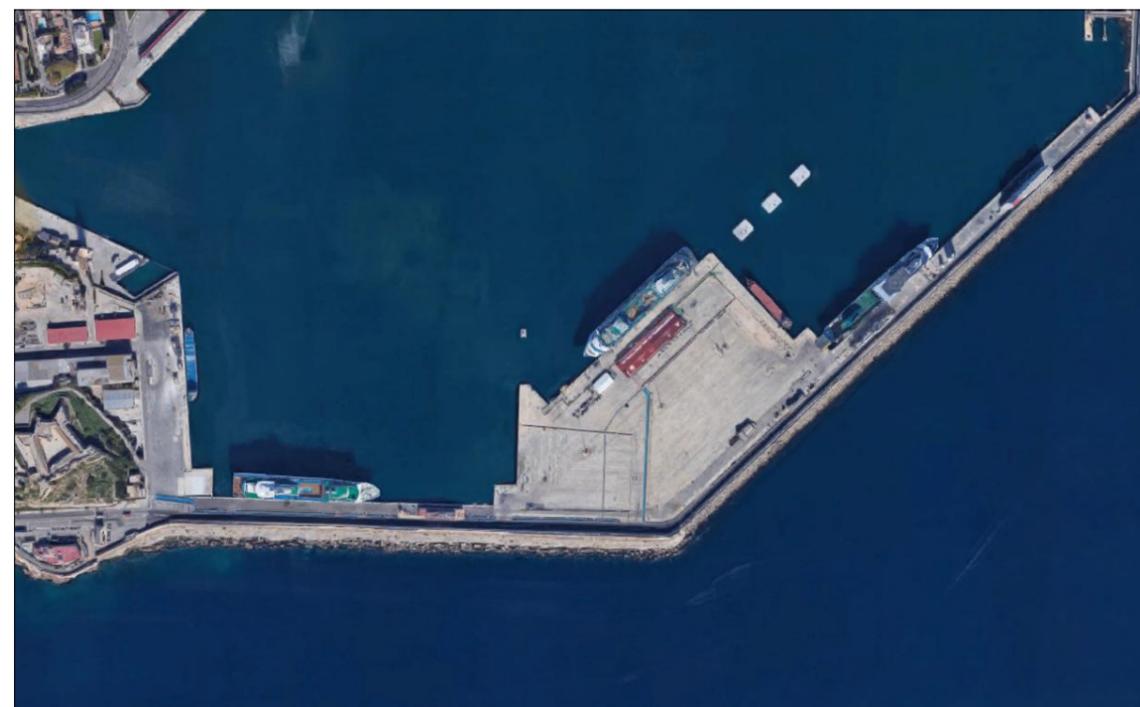
Baleares Island



Mallorca



Port of Palma de Mallorca

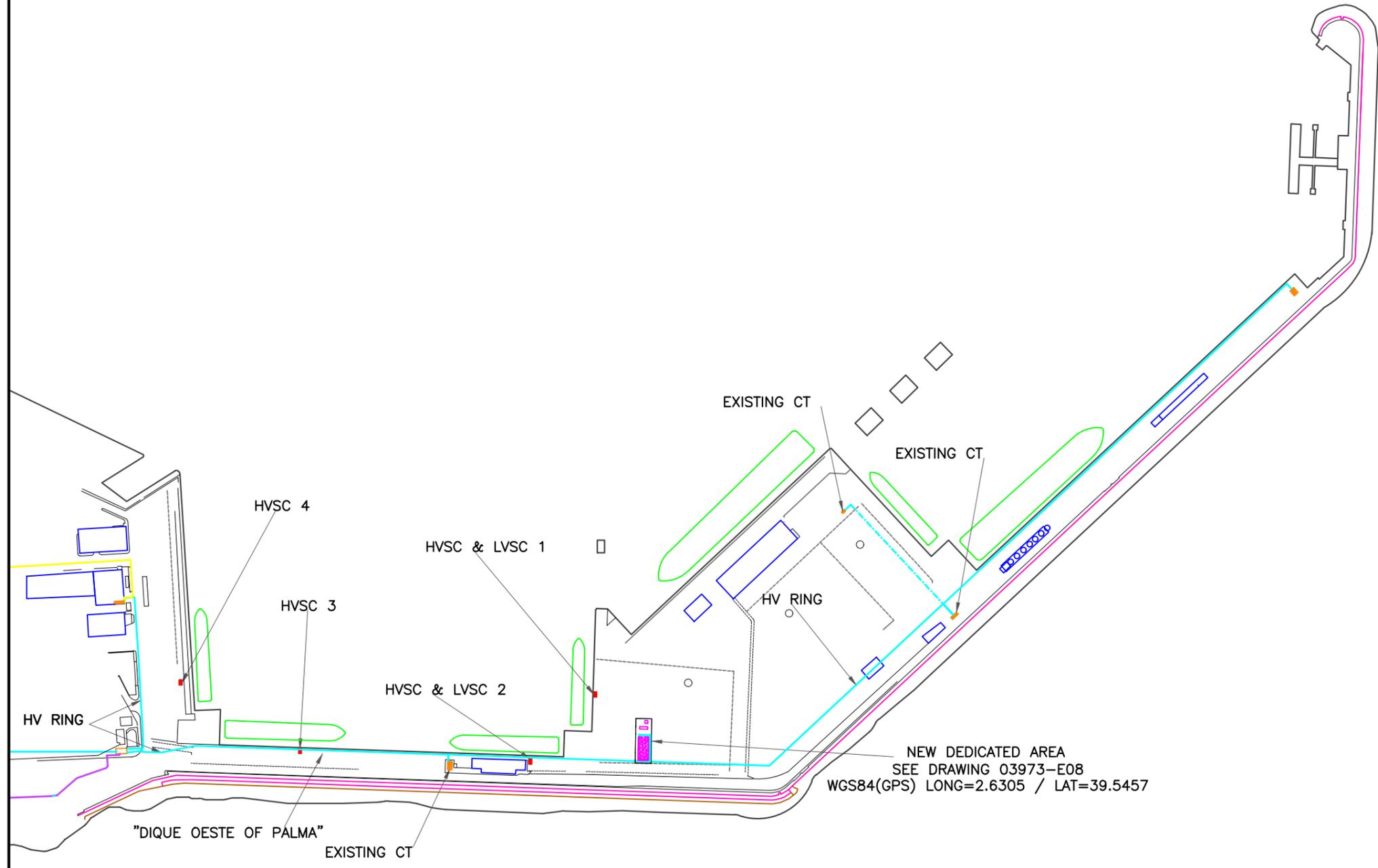


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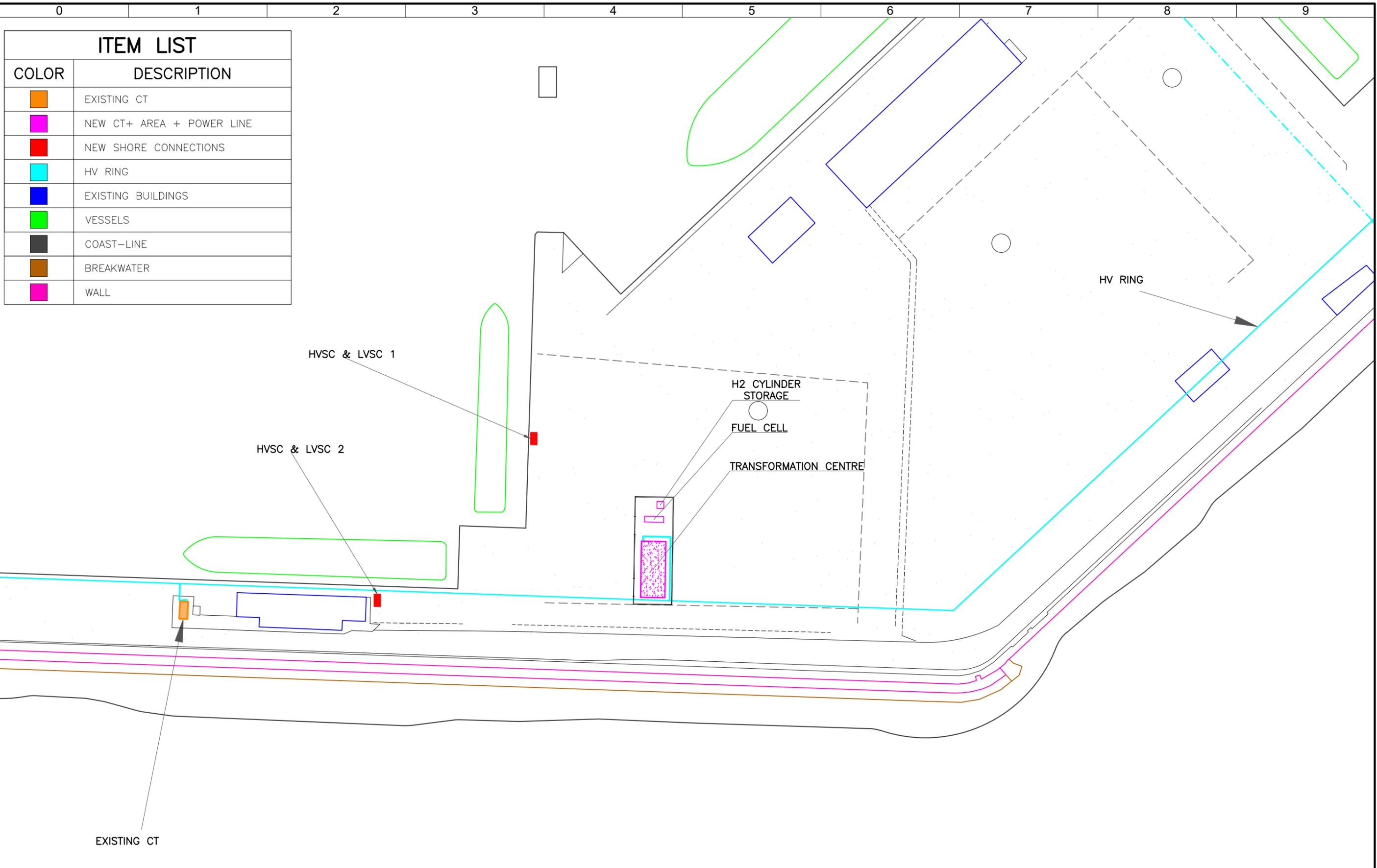
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ITEM LIST	
COLOR	DESCRIPTION
	EXISTING CT
	NEW CT+ AREA + POWER LINE
	NEW SHORE CONNECTIONS
	HV RING
	EXISTING BUILDINGS
	VESSELS
	POWER GRID
	COAST-LINE
	BREAKWATER
	WALL



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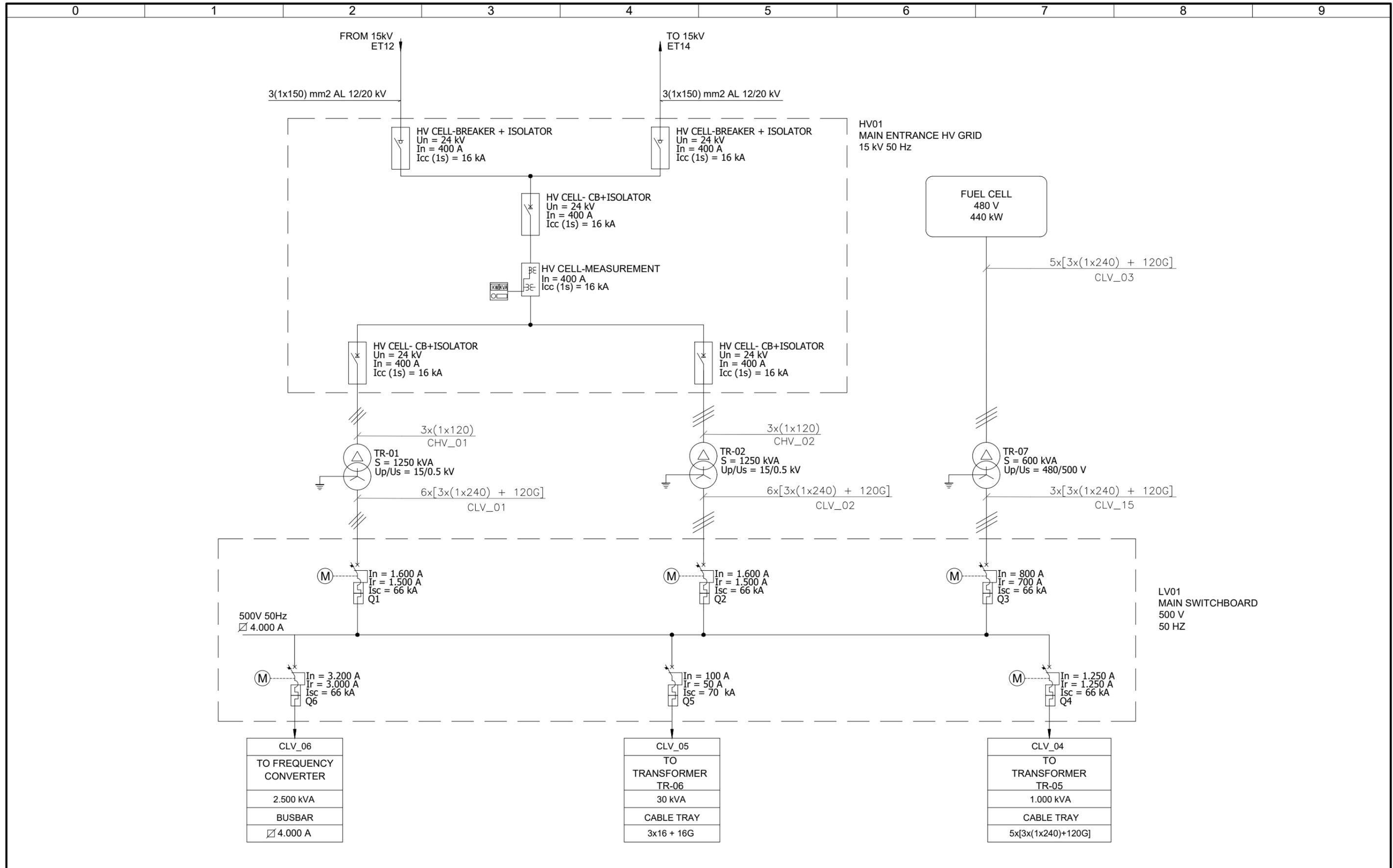
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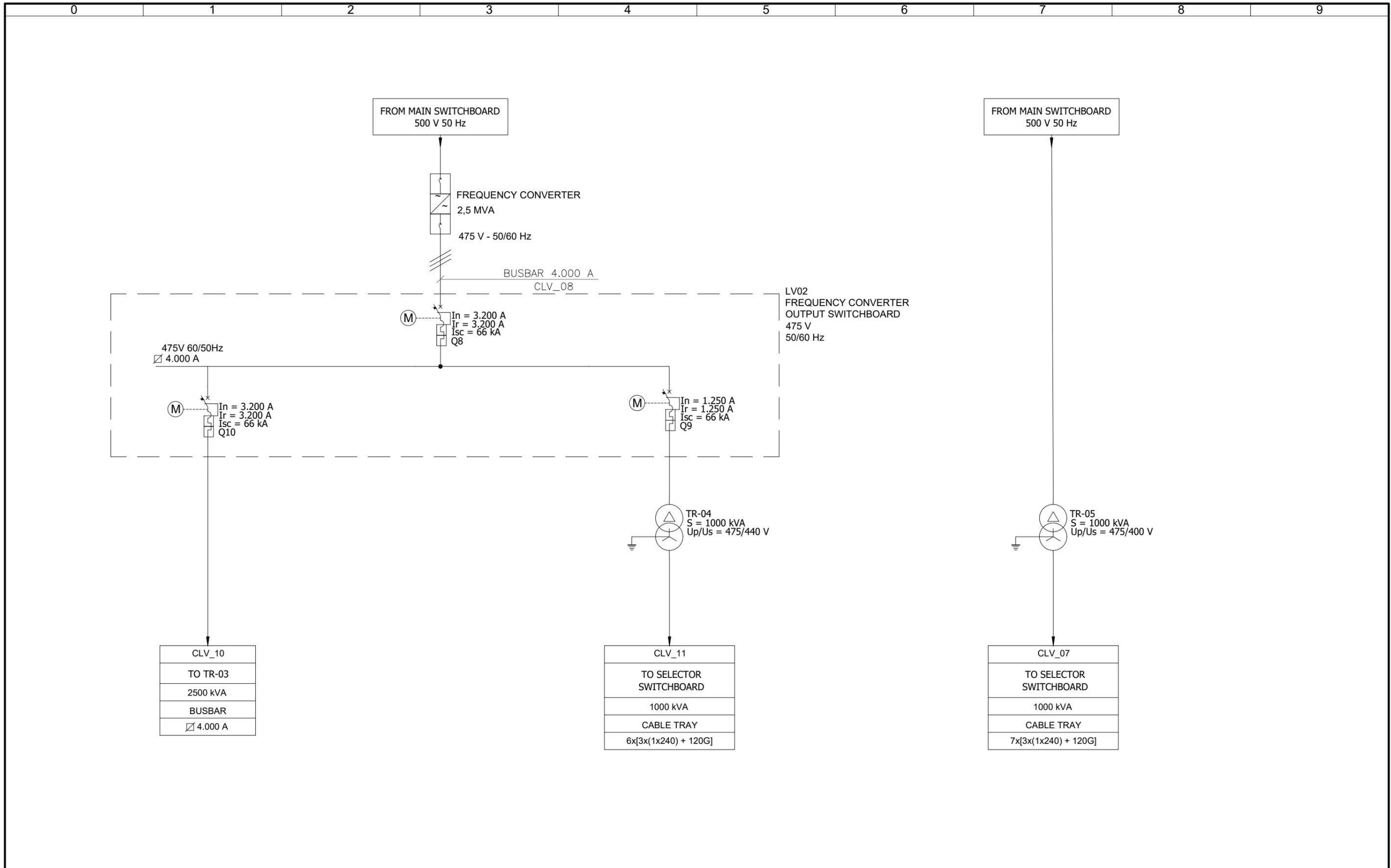
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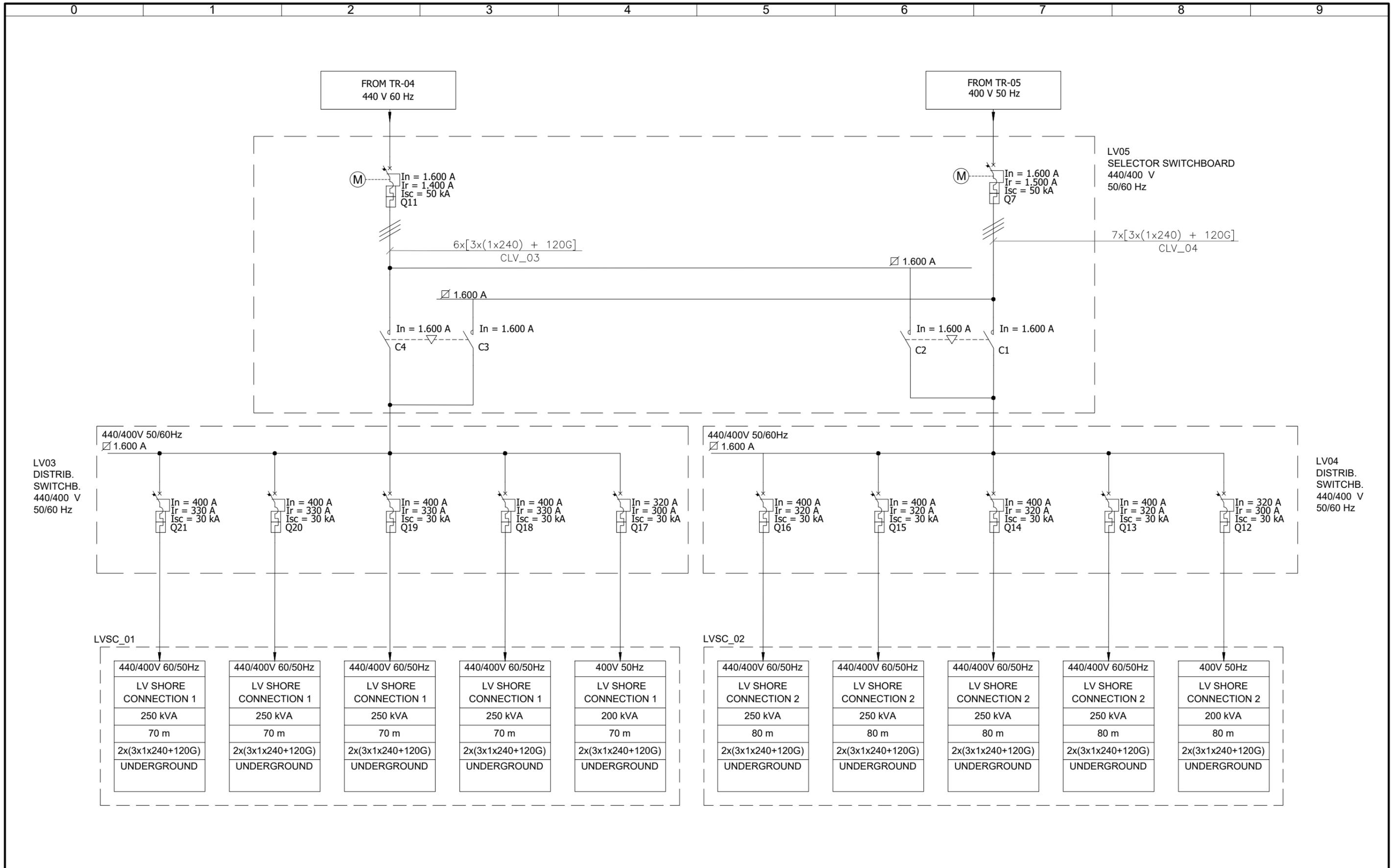
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HV Entrance + Main Switchboard		SCALE:	-	PROJECT NUMBER:	PRY03973	CLIENT DRAWING NUMBER:	-	INSTEIMED DRAWING NUMBER:	03973-E05_00
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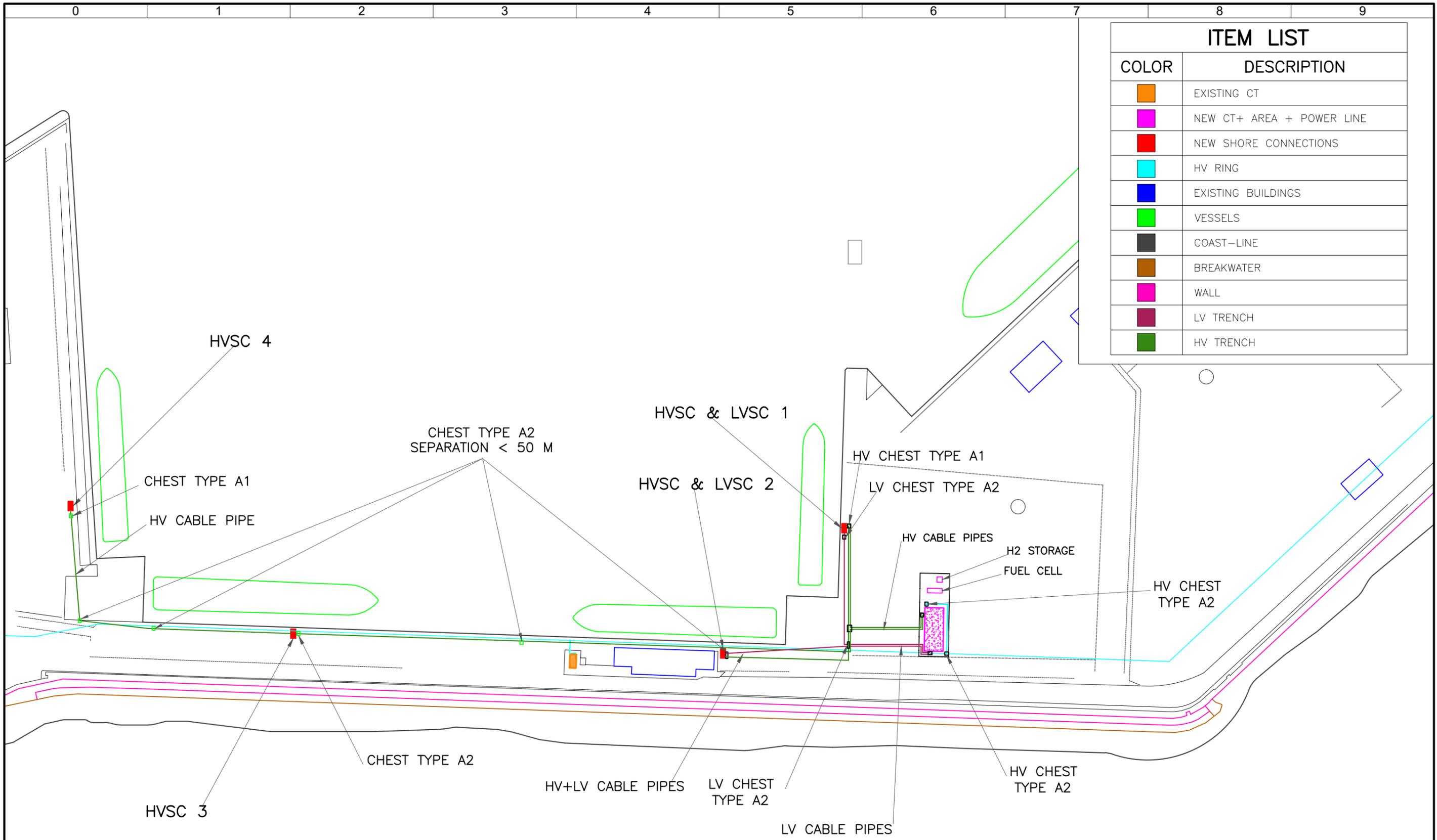
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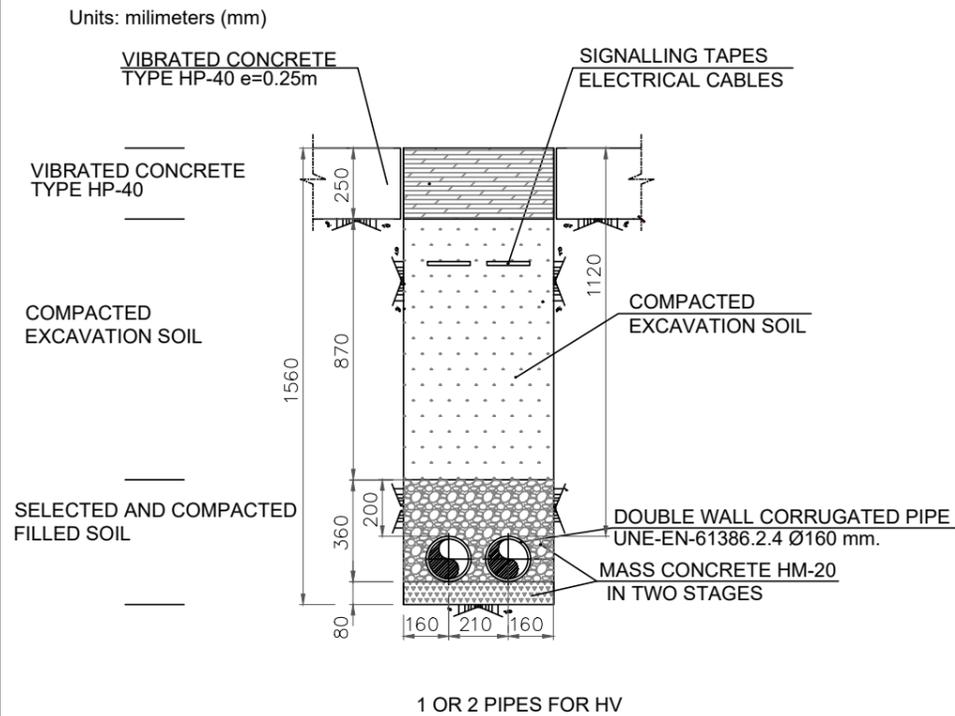


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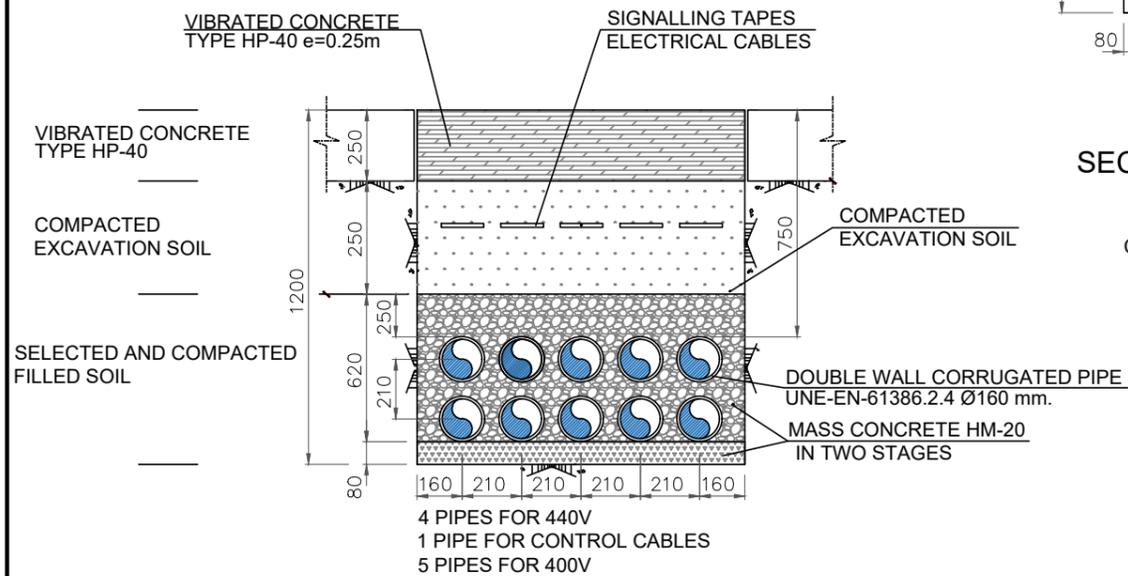
- All cable pipes will be on trench see details in dwg: 03973-E07.
- For chest details see drawing: 03973-E07.

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**TYPICAL DETAIL OF TRENCH  
TYPE 1 - MT**



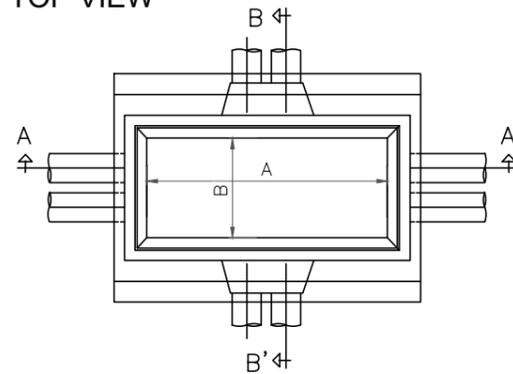
**TYPICAL DETAIL OF TRENCH  
TYPE 2 - LV**



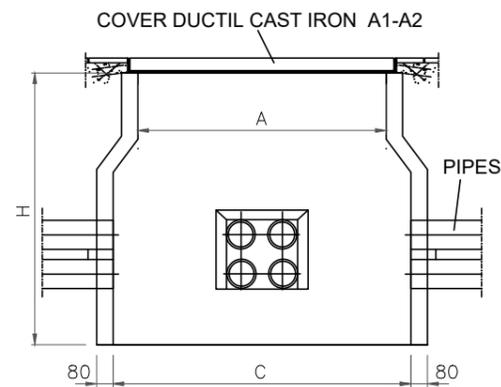
**DISTRIBUTION AND INSPECTION CHEST  
TYPE A1-A2**

TYPE A1 -> INSPECTION CHEST WITH SINGLE COVER  
TYPE A2 -> DISTRIBUTION CHEST WITH DOUBLE COVER

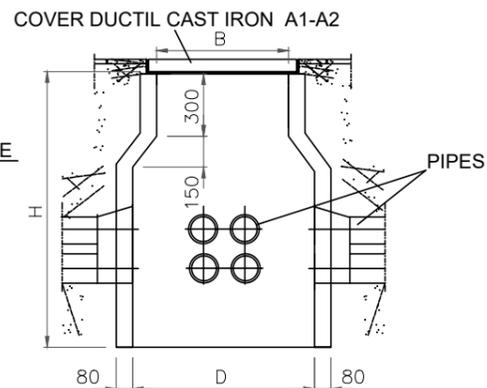
**TOP VIEW**



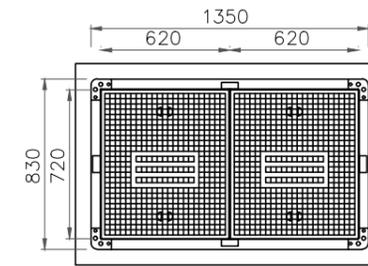
**SECTION A-A'**



**SECTION B-B'**

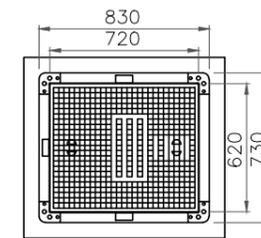


**COVER AND FRAMES**



**DOUBLE COVER DETAIL D-400**

(Ductile cast iron frame and cover)

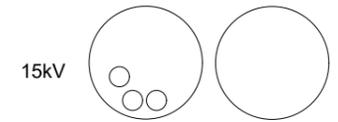


**SINGLE COVER DETAIL D-400**

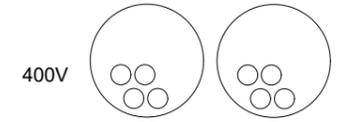
(Ductile cast iron frame and cover)

**TYPICAL PIPE DETAIL**

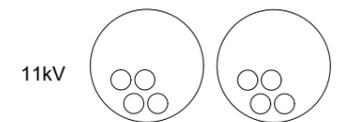
**HV RING CABLES**



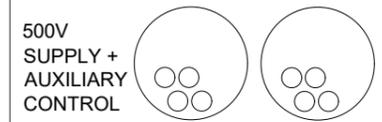
**LV SHORE CABLES**



**HV SHORE CABLES**



**LV CELL SUPPLY**



500V  
SUPPLY +  
AUXILIARY  
CONTROL

**DIMENSIONS OF CHEST CIVIL WORKS**

TYPE	A	B	C	D	H
A1 HIGH VOLTAGE (RING SUPPLY)	625	535	905	845	1560
A2 HIGH VOLTAGE (CONNECTION FROM RING)	1170	620	1450	900	1200
A1 LOW VOLTAGE (CELL SUPPLY)	625	535	905	845	1200
A1 LOW/HIGH VOLTAGE (SHORE CONNECTIONS)	625	535	905	845	1200 1560
A1 HIGH VOLTAGE (SHORE CONNECTIONS)	625	535	905	845	1560
A2 LOW/HIGH VOLTAGE (FINAL SHORE CONNECTIONS)	1170	620	1450	900	1200 1560

LAST UPDATE

DESIGNATION

TRENCH DETAILS

Details

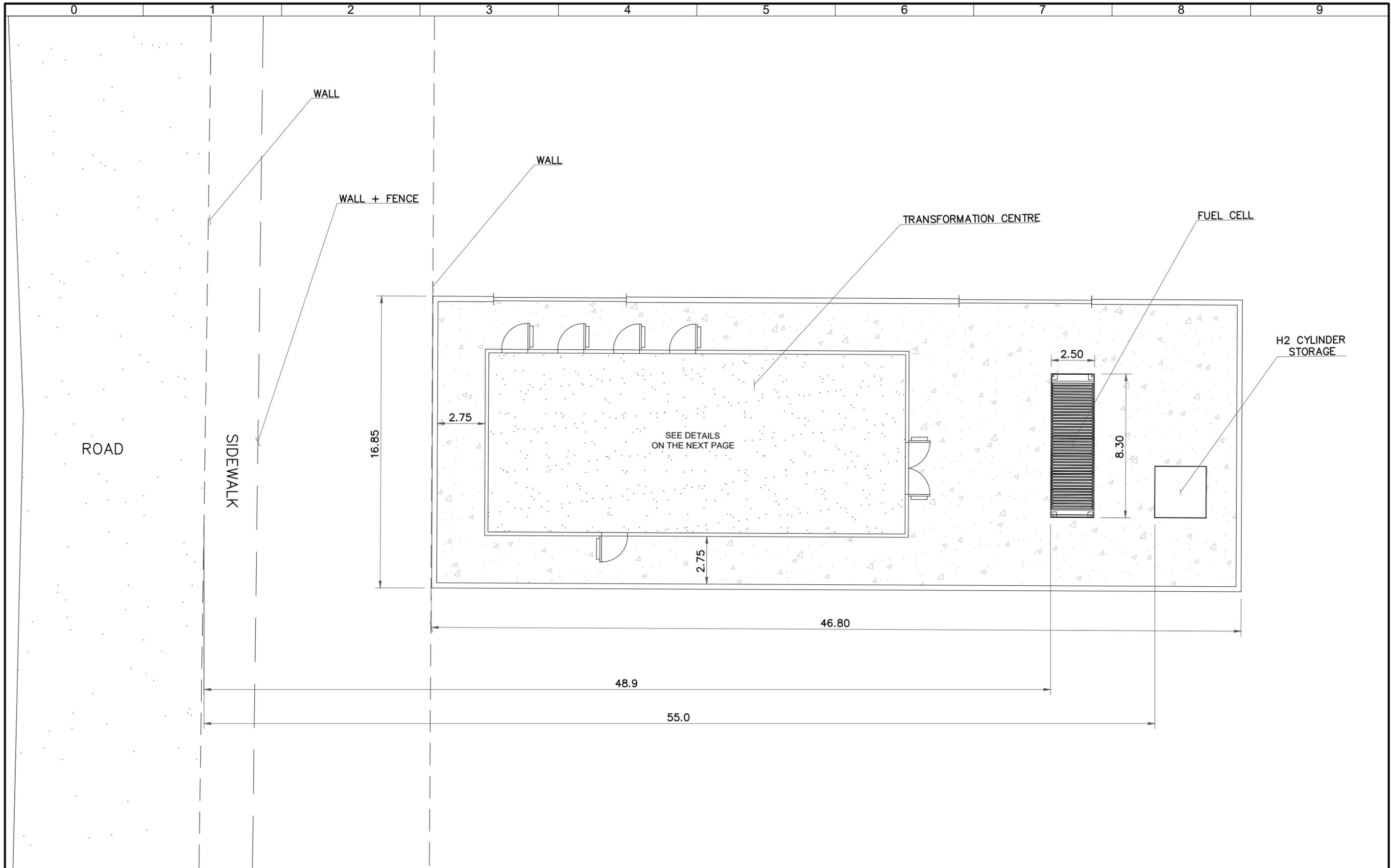


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CHECKED	JPA	18/05/2023
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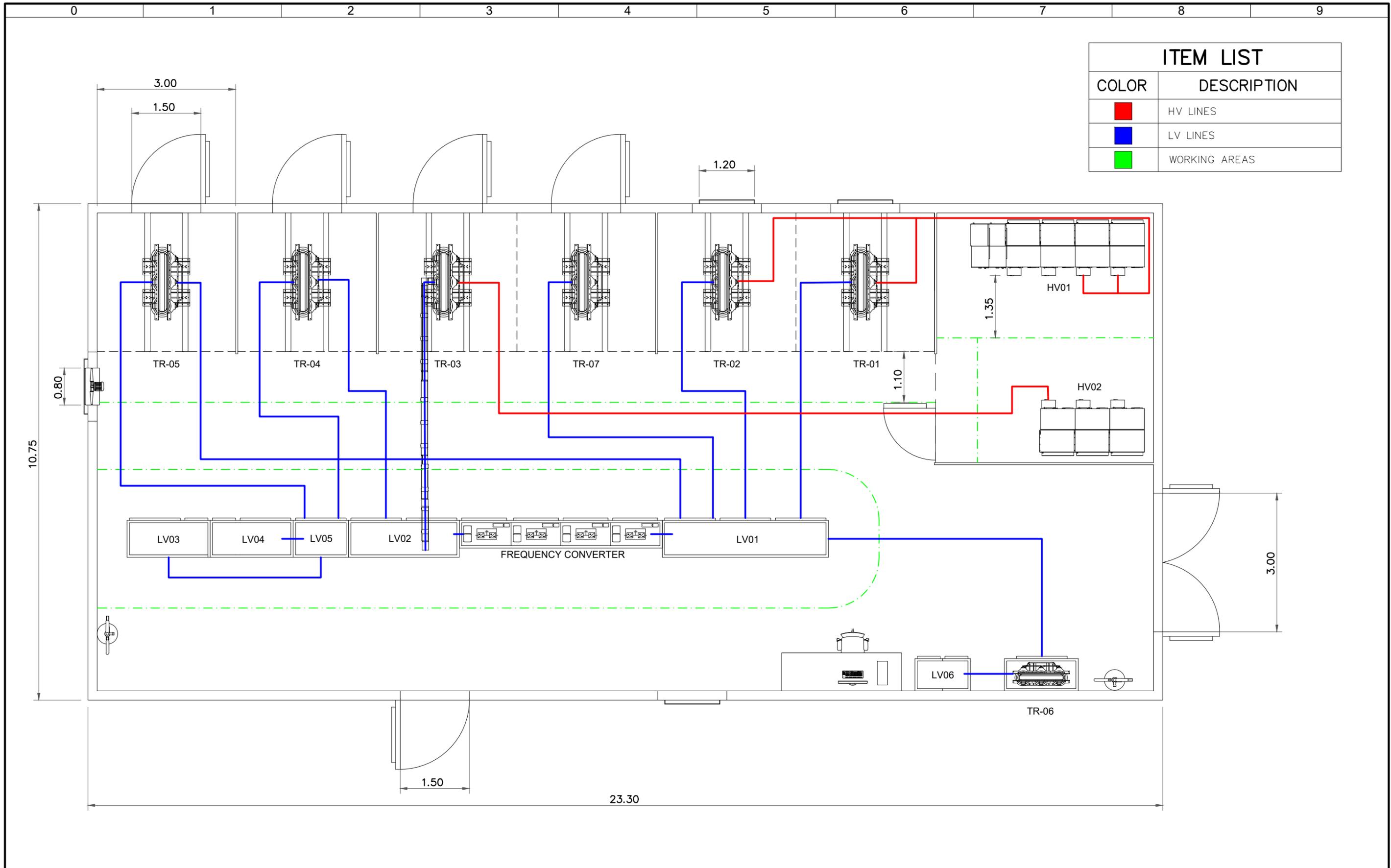
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Client:	COTENAVAL
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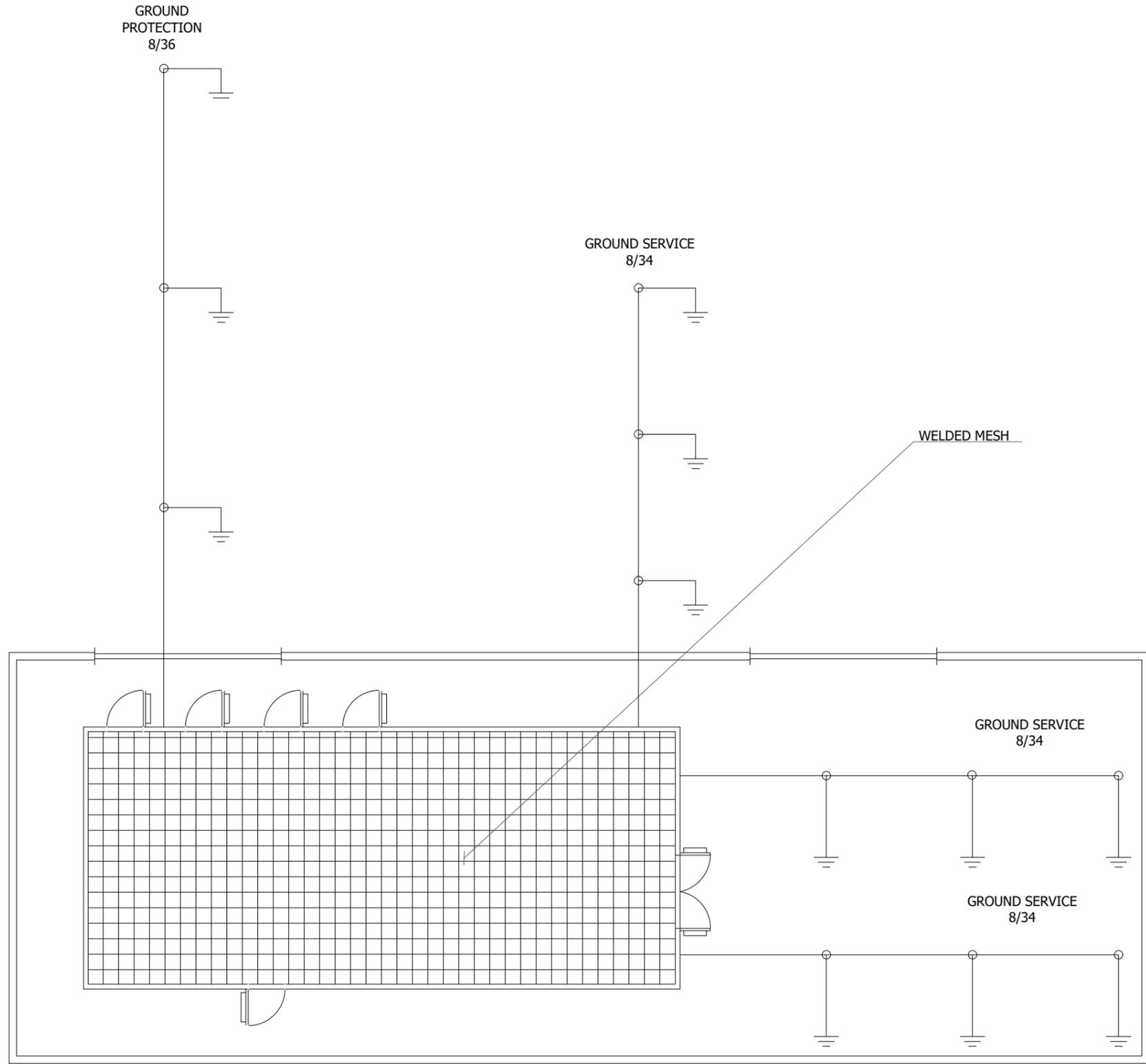


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		1:200	PRY03973	-	03973-E08_00				



LAST UPDATE	DESIGNATION	DRAWN	JMG	13/04/2023	Title:	GREEN HYSLAND	=	E08
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# PRELIMINARY BUDGET OF GREEN HYSLAND

**Project Number** PRY03973  
**Title** GREEN HYSLAND  
**Client** COTENAVAL  
**Site** PALMA DE MALLORCA  
**Drawing Number** 03973-E11  
**Revision** 0

Number of pages 7

LAST UPDATE	DESIGNATION		DRAWN	JGE	13/06/2023	Title:	<b>GREEN HYSLAND</b>			
	<b>PRELIMINARY BUDGET OF GREEN HYSLAND</b>		CHECKED	JAM	13/06/2023	Client:	<b>COTENAVAL</b>			
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			<b>PRY03973</b>	-	<b>03973-E11_0</b>	Of	7			

# List of Updates

Revision	Date	Pages	Description
0	13/06/2023	All	Initial edition

LAST UPDATE		DESIGNATION			DRAWN	JGE	13/06/2023	Title: <b>GREEN HYSLAND</b>	
<small>INSTEIMED S.A. COPYRIGHT: ALL RIGHTS RESERVED. IT IS NOT ALLOWED THE USE OR REPRODUCTION OF ANY PART OF THIS DOCUMENT, OR DISEMINATION TO THIRD PARTIES WITHOUT WRITTEN PERMISSION.</small>		<b>PRELIMINARY BUDGET OF GREEN HYSLAND</b>  LIST OF UPDATES			CHECKED	JAM	13/06/2023	Client: <b>COTENAVAL</b>	
					SCALE:	PROJECT NUMBER:	CLIENT DRAWING NUMBER:	INSTEIMED DRAWING NUMBER:	Sheet 2
					<b>PRY03973</b>	-	<b>03973-E11_0</b>	Of 7	

ID	DESIGNATION	MODEL	TECHNICAL DATA	QUANTITY	UNITS	PRICE	TOTAL	COMMENTS
<b>1</b>	<b>MACHINERY &amp; PERSONAL</b>							
<b>1.1</b>	<b>TOTAL MACHINERY</b>							
1.1.1	Self-propelled telescopic crane 90 T			10	Unit	163,00	1.630,00	
1.1.2	Lattice boom crane / truck 60 T			10	Unit	205,00	2.050,00	
1.1.3	Discontinuous engraving plant			7	Unit	95,00	665,00	
1.1.4	Discontinuous hot asphalt plant			7	Unit	330,00	2.310,00	
1.1.5	Welding group			700	Unit	9,00	6.300,00	
1.1.6	Hydraulic excavator 100 Cv			50	Unit	51,00	2.550,00	
1.1.7	Manual breaker hammer			200	Unit	2,00	400,00	
1.1.8	Dumper 2 T			55	Unit	7,50	412,50	
1.1.9	Cement mixer 10 m3			55	Unit	63,00	3.465,00	
1.1.10	Trailed sweeper			11	Unit	12,00	132,00	
1.1.11	Tanker truck			11	Unit	43,00	473,00	
1.1.12	Motor grader			3	Unit	72,00	216,00	
1.1.13	Compacting roller			5	Unit	57,00	285,00	
1.1.14	Portable compressor			230	Unit	7,00	1.610,00	
	<b>TOTAL - TOTAL MACHINERY</b>						<b>22.498,50</b>	
<b>1.2</b>	<b>PERSONAL</b>							
1.2.1	Officer 1 <sup>a</sup>			1.700	Unit	19,42	33.014,00	
1.2.2	Specialised labourer			1.000	Unit	16,50	16.500,00	
1.2.3	Ordinary labourer			2.500	Unit	16,02	40.050,00	
1.2.4	Officer 1 <sup>o</sup> plumber			20	Unit	19,22	384,40	
1.2.5	Officer 2 <sup>o</sup> plumber			20	m	17,99	359,80	
1.2.6	Officer 1 <sup>o</sup> electrician			1.500	m	19,22	28.830,00	
1.2.7	Officer 2 <sup>o</sup> electrician			900	m	17,99	16.191,00	
1.2.8	Assistant electrician			800	Unit	17,21	13.768,00	
	<b>TOTAL - PERSONAL</b>						<b>149.097,20</b>	

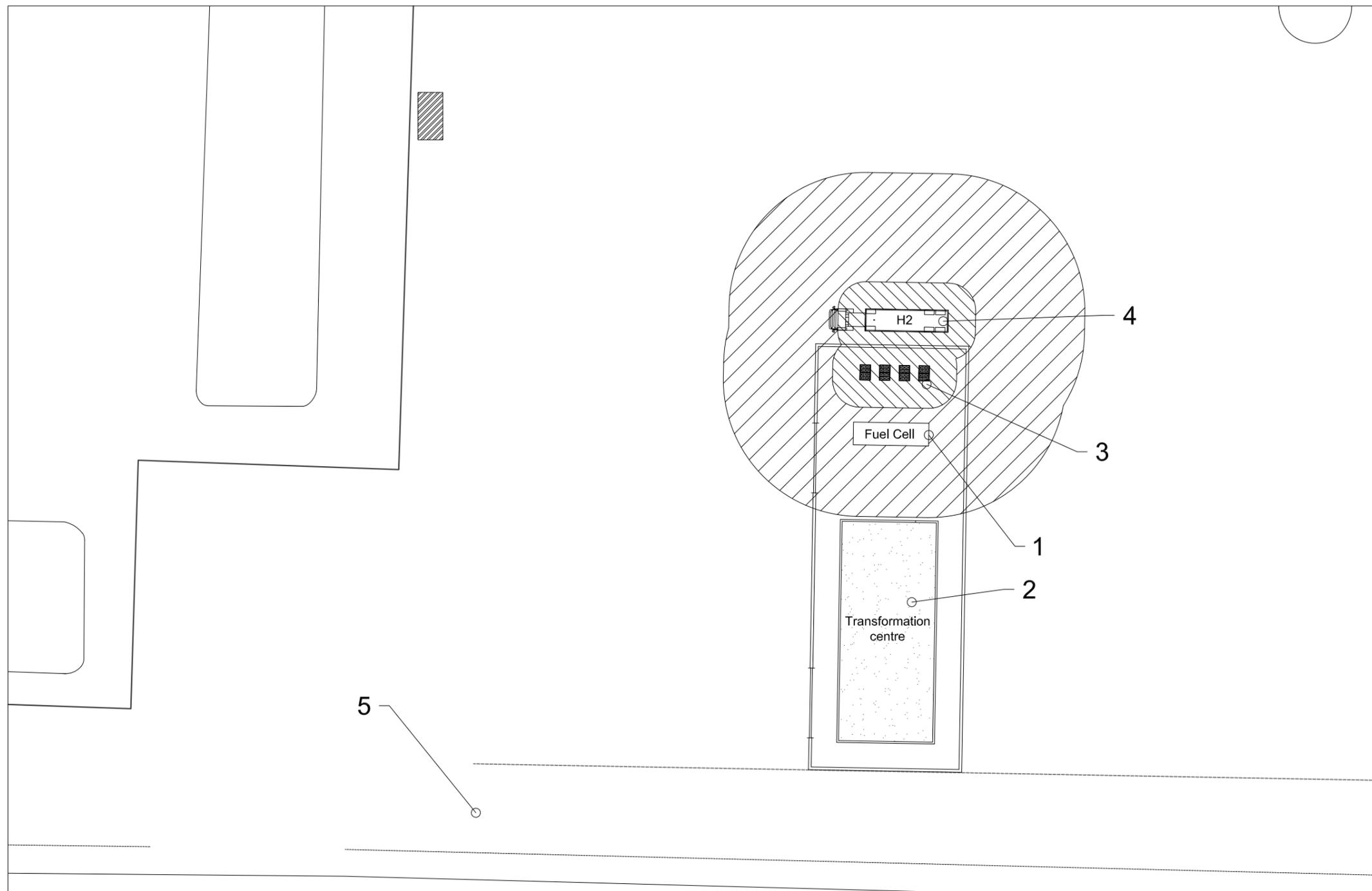
ID	DESIGNATION	MODEL	TECHNICAL DATA	QUANTITY	UNITS	PRICE	TOTAL	COMMENTS
<b>2</b>	<b>CIVIL WORK</b>							
<b>2.1</b>	<b>TRANSFORMATION CENTRE</b>							
2.1.1	Building manufactured on site, excavation included			1	Unit	175.000,00	175.000,00	
2.1.2	High voltage trenches			650	Unit	21,00	13.650,00	
2.1.3	High voltage chests			10	Unit	283,00	2.830,00	
2.1.4	Cable X-VOLT RHZ1 (S) Cu / OL / 2OL 1x185 mm2 + tubo			650	Unit	43,25	28.112,50	
2.1.5	Low voltage trenches			300	Unit	35,29	10.587,00	
2.1.6	Low voltage chests			7	Unit	150,00	1.050,00	
2.1.7	Cable RZ1-K (AS) CPR 0,6/1KV 1X240mm2 + Tube			1.200	Unit	60,00	72.000,00	
	<b>TOTAL - TRANSFORMATION CENTRE</b>						<b>303.229,50</b>	
<b>3</b>	<b>ELECTRICAL INSTALLATIONS</b>							
<b>3.1</b>	<b>HIGH VOLTAGE SWITCHGEAR</b>							
3.1.1	Cell SM6-24 GBC2C 400A 16KA with 3 TI's and 3 TT's			1	Unit	12.355,00	12.355,00	
3.1.2	Cell SM6-24 IM 400A 16kA CIT busbar 400A			2	Unit	4.650,00	9.300,00	
3.1.3	Cell SM6-24 DM1DS 400A 16KA VIP400 Mitop and coil 230Vca interlocking E11			6	Unit	20.968,00	125.808,00	
3.1.4	Auxiliary elements			1	Unit	5.000,00	5.000,00	
	<b>TOTAL - HIGH VOLTAGE SWITCHGEAR</b>						<b>152.463,00</b>	
<b>3.2</b>	<b>TRANSFORMERS</b>							
3.2.1	Dry transformer CLARKIA 2500 KVA 475 V/ 11kV			1		60.300,00	60.300,00	
3.2.2	Dry transformer CLARKIA 1250 KVA 15kV / 500 V			2	Unit	37.400,00	74.800,00	
3.2.3	Dry transformer CLARKIA 1000 KVA 500 V/ 400 V			1	Unit	23.400,00	23.400,00	
3.2.4	Dry transformer CLARKIA 1000 KVA 475 V/ 440 V			1	Unit	23.400,00	23.400,00	
3.2.5	Dry transformer CLARKIA 600 KVA 480 V / 500 V			1	Unit	16.500,00	16.500,00	
3.2.6	Dry transformer Clarkia 30 KVA 500 V / 400 V			1	Unit	4.650,00	4.650,00	
3.2.7	Frequency converter 2500 kVA			1	Unit	265.682,00	265.682,00	
	<b>TOTAL - TRANSFORMERS</b>						<b>468.732,00</b>	

ID	DESIGNATION	MODEL	TECHNICAL DATA	QUANTITY	UNITS	PRICE	TOTAL	COMMENTS
<b>3.3</b>	<b>LOW VOLTAGE SWITCHGEAR / MAIN SWITCHBOARD</b>							
3.3.1	VX modular enclosure system, An.Al.Pr.: 600x2200x600 mm, sheet steel, with mounting plate, front door			3	m	4.939,23	14.817,69	
3.3.2	MTZ2 3.200A type H1 3 Poles fixed			1	m	35.016,38	35.016,38	
3.3.3	Micrologic 5.0 X MTZ Fixed			5	m	5.253,00	26.265,00	
3.3.4	MTZ2 1.600A type H2 4 Poles fixed			2	m	26.793,90	53.587,80	
3.3.5	MTZ2 800A type H1 3 Poles fixed			1	Unit	10.598,71	10.598,71	
3.3.6	MTZ2 1.250A type H1 3 Poles fixed			1	Unit	11.838,26	11.838,26	
3.3.7	Circuit breaker ComPacT NSX100HB2 100kA AC 3P 63A TMD			1	Unit	3.820,00	3.820,00	
	<b>TOTAL - LOW VOLTAGE SWITCHGEAR / MAIN SWITCHBOARD</b>						<b>155.943,84</b>	
<b>3.4</b>	<b>LOW VOLTAGE SWITCHGEAR / OUTPUT FREQUENCY CONVERTER SWITCHBOARD</b>							
3.4.1	VX modular enclosure system, An.Al.Pr.: 600x2200x600 mm, sheet steel, with mounting plate, front door			2	Unit	4.939,23	9.878,46	
3.4.2	MTZ2 3.200A type H1 3 Poles fixed			2	Unit	35.016,38	70.032,76	
3.4.3	MTZ2 1.250A type H1 3 Poles fixed			1	Unit	11.838,26	11.838,26	
3.4.4	Micrologic 5.0 X MTZ Fixed			3	Unit	5.253,00	15.759,00	
	<b>TOTAL - LOW VOLTAGE SWITCHGEAR / OUTPUT FREQUENCY CONVERTER SWITCHBOARD</b>						<b>107.508,48</b>	
<b>3.5</b>	<b>LOW VOLTAGE SWITCHGEAR / SELECTOR SWITCHBOARD</b>							
3.5.1	VX modular enclosure system, An.Al.Pr.: 600x2200x600 mm, sheet steel, with mounting plate, front door			2	Unit	4.939,23	9.878,46	
3.5.2	Circuit breaker Compact NS1600N - Micrologic 2,0 - 1600 A - 3 poles 3d			1	Unit	17.393,80	17.393,80	
3.5.3	Circuit breaker Compact NS1250N - Micrologic 5.0 E - 1250 A - 3 poles 3t			1	Unit	17.512,81	17.512,81	
3.5.4	TeSys F - Contactor - 3P(3 NA) AC-3 - <=440 V 1600 A AC1 - coil 220 V CA ref. LC1F780M7 Schneider Electric			4	Unit	15.377,30	61.509,20	
	<b>TOTAL - LOW VOLTAGE SWITCHGEAR / SELECTOR SWITCHBOARD</b>						<b>106.294,27</b>	
<b>3.6</b>	<b>LOW VOLTAGE SWITCHGEAR / DISTRIBUTION SWITCHBOARD 1</b>							
3.6.1	VX modular enclosure system, An.Al.Pr.: 600x2200x600 mm, sheet steel, with mounting plate, front door			1	Unit	4.939,23	4.939,23	
3.6.2	NSX400N 50kA AC 3P3R 400A 4.3			5	Unit	7.509,88	37.549,40	
	<b>TOTAL - LOW VOLTAGE SWITCHGEAR / DISTRIBUTION SWITCHBOARD 1</b>						<b>42.488,63</b>	
<b>3.7</b>	<b>LOW VOLTAGE SWITCHGEAR / DISTRIBUTION SWITCHBOARD 2</b>							
3.7.1	VX modular enclosure system, An.Al.Pr.: 600x2200x600 mm, sheet steel, with mounting plate, front door			1	Unit	4.939,23	4.939,23	
3.7.2	NSX400N 50kA AC 3P3R 400A 4.3			5	Unit	7.509,88	37.549,40	
	<b>TOTAL - LOW VOLTAGE SWITCHGEAR / DISTRIBUTION SWITCHBOARD 2</b>						<b>42.488,63</b>	

ID	DESIGNATION	MODEL	TECHNICAL DATA	QUANTITY	UNITS	PRICE	TOTAL	COMMENTS
<b>3.8 LOW VOLTAGE SWITCHGEAR / SERVICE SWITCHBOARD</b>								
3.8.1	Breaker Acti9 iC60N; 4P; 50 A; C; 6000 A/10 kA			1	Unit	618,38	618,38	
3.8.2	Breaker Acti9 iC60N; 1P+N; 25 A; C; 6000 A/10 kA			3	Unit	99,64	298,92	
3.8.3	RCD breaker Acti9 iID; 2P; 25A; 30mA AC			1	Unit	108,54	108,54	
3.8.4	Breaker Acti9 iC60N; 1P+N; 10 A; C; 6000 A/10 kA			5	Unit	93,28	466,40	
3.8.5	Breaker Acti9 iC60N; 1P+N; 6 A; C; 6000 A/10 kA			1	Unit	101,58	101,58	
3.8.6	RCD breaker Acti9 iID; 2P; 25A; 30mA AC			4	Unit	304,60	1.218,40	
3.8.7	Breaker Acti9 iC60N; 1P+N; 16 A; C; 6000 A/10 kA			5	Unit	94,88	474,40	
3.8.8	Breaker Acti9 iC60N; 4P; 20 A; C; 6000 A/10 kA			1	Unit	225,45	225,45	
3.8.9	RCD breaker Acti9 iID; 4P; 40A; 300mA AC			1	Unit	474,77	474,77	
<b>TOTAL - LOW VOLTAGE SWITCHGEAR / SERVICE SWITCHBOARD</b>							<b>3.986,84</b>	
<b>3.9 EARTHING SYSTEM</b>								
3.9.1	Protection earthing system			3	Unit	654,00	1.962,00	
<b>TOTAL - EARTHING SYSTEM</b>							<b>1.962,00</b>	
<b>3.10 FUEL CELL</b>								
3.10.1	Fuel cell			1	Unit	1.200.000,00	1.200.000,00	
<b>TOTAL - FUEL CELL</b>							<b>1.200.000,00</b>	
<b>4 ELECTRICAL NETWORKS</b>								
<b>4.1 LOW VOLTAGE INDOOR</b>								
4.1.1	RZ1-K (AS) CPR 0,6/1KV 1X240 mm2			732	m	49,00	35.868,00	
4.1.2	RZ1-K (AS) CPR 0,6/1KV 1X50 mm2			9	m	55,53	499,77	
4.1.3	RZ1-K (AS) CPR 0,6/1KV 1X16 mm2			14	m	17,51	245,14	
<b>TOTAL - LOW VOLTAGE INDOOR</b>							<b>36.612,91</b>	
<b>4.2 HIGH VOLTAGE INDOOR</b>								
4.2.1	RHZ1 (S) Cu 12/20 KV 1X185 mm2			19	m	43,23	821,28	
4.2.2	RHZ1 (S) Cu 12/20 KV 1X120 mm2			40	m	28,33	1.133,20	
<b>TOTAL - HIGH VOLTAGE INDOOR</b>							<b>1.954,48</b>	
<b>5 SECURITY EQUIPMENT</b>								
<b>5.1 TOTAL EQUIPMENT</b>								
5.1.1	Extractor mural S&P HCFT/4-710/H			1	Unit	1.530,00	1.530,00	
5.1.2	Extinguisher 89B			3	Unit	78,45	235,35	
<b>TOTAL - TOTAL EQUIPMENT</b>							<b>1.765,35</b>	

## BUDGET SUMMARY

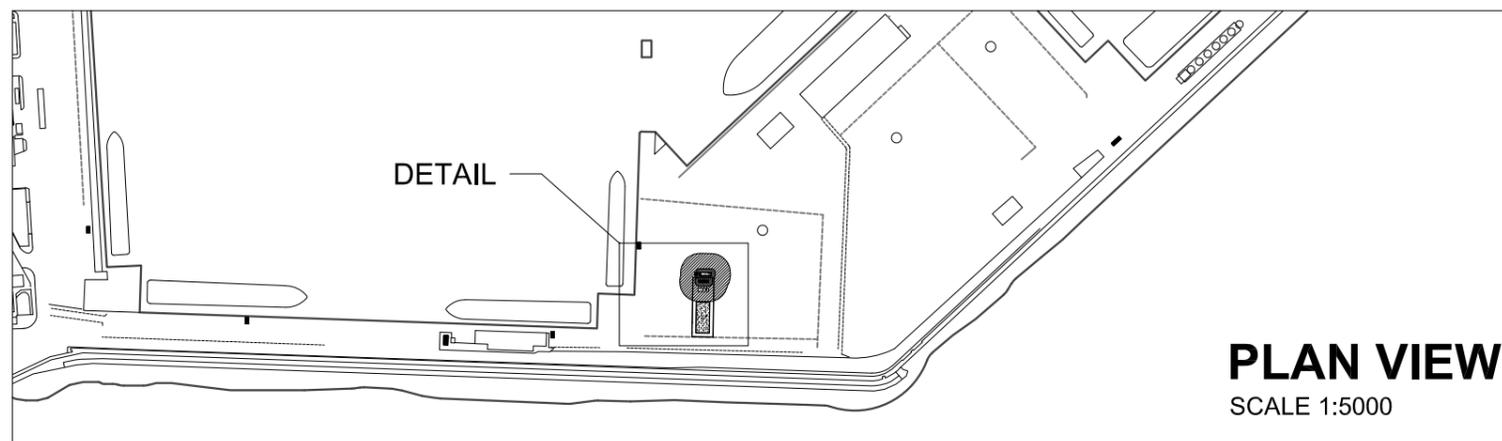
	SUBSYSTEM	SUBTOTAL	UNITS	SUBTOTAL	TOTAL
<b>1</b>	<b>MACHINERY &amp; PERSONAL</b>				
1.1	TOTAL MACHINERY	22.498,50	1	22.498,50	
1.2	PERSONAL	149.097,20	1	149.097,20	
	<b>TOTAL</b>				<b>171.595,70</b>
<b>2</b>	<b>CIVIL WORK</b>				
2.1	TRANSFORMATION CENTRE	303.229,50	1	303.229,50	
	<b>TOTAL</b>				<b>303.229,50</b>
<b>3</b>	<b>ELECTRICAL INSTALLATIONS</b>				
3.1	HIGH VOLTAGE SWITCHGEAR	152.463,00	1	152.463,00	
3.2	TRANSFORMERS	468.732,00	1	468.732,00	
3.3	LOW VOLTAGE SWITCHGEAR / MAIN SWITCHBOARD	155.943,84	1	155.943,84	
3.4	LOW VOLTAGE SWITCHGEAR / OUTPUT FREQUENCY CONVERTER	107.508,48	1	107.508,48	
3.5	LOW VOLTAGE SWITCHGEAR / SELECTOR SWITCHBOARD	106.294,27	1	106.294,27	
3.6	LOW VOLTAGE SWITCHGEAR / DISTRIBUTION SWITCHBOARD 1	42.488,63	1	42.488,63	
3.7	LOW VOLTAGE SWITCHGEAR / DISTRIBUTION SWITCHBOARD 2	42.488,63	1	42.488,63	
3.8	LOW VOLTAGE SWITCHGEAR / SERVICE SWITCHBOARD	3.986,84	1	3.986,84	
3.9	EARTHING SYSTEM	1.962,00	1	1.962,00	
3.10	FUEL CELL	1.200.000,00	1	1.200.000,00	
	<b>TOTAL</b>				<b>2.281.867,69</b>
<b>4</b>	<b>ELECTRICAL NETWORKS</b>				
4.1	LOW VOLTAGE INDOOR	36.612,91	1	36.612,91	
4.2	HIGH VOLTAGE INDOOR	1.954,48	1	1.954,48	
	<b>TOTAL</b>				<b>38.567,39</b>
<b>5</b>	<b>SECURITY EQUIPMENT</b>				
5.1	TOTAL EQUIPMENT	1.765,35	1	1.765,35	
	<b>TOTAL</b>				<b>1.765,35</b>
<b>PRELIMINARY BUDGET</b>					<b>2.797.025,63</b>



	Hazardous area 3m
	Hazardous area 15m

MARK	DESCRIPTION
1	H2 fuel cell
2	Transformation centre
3	H2 storage bottles
4	H2 truck
5	Access road

**DETAIL**  
SCALE 1:500



**PLAN VIEW**  
SCALE 1:5000

REV.	MODIFICATIONS	DATE	DRAWING
Project N.: GH-D6.4		Project: GREEN HYSLAND - H2 fuel cell system for cold ironing at Port of Palma	
Description:		<b>HAZARDOUS AREAS</b>	
	Size: A3	Name:	Date:
	Designed	LSS	14/09/23
	Checked		
	Approved		
Dwg N. GH-FC.01	Scale: 1/5000	File:	Sheet 1 of 1 Revision 00





# GREEN HYSLAND

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