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H2YDEA

Boosting the hydrogen transition in the Atlantic Area ports

Deliverable D 5.1.3

HYDEA case studies for France

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EXECUTIVE SUMMARY

The HYDEA D5.1.3 French case studies assess complementary pathways for deploying hydrogen within the Port of Brest and its surrounding port-city ecosystem. The first case study evaluates green hydrogen production from marine and other renewable energy sources, mainly onshore and floating photovoltaics and future offshore wind resources, to understand how local renewable electricity could cover projected hydrogen demand up to 2050. The second case study examines hydrogen production through modular steam methane/biogas reforming with CO2 capture and local distribution, associated with H2X fuel-cell/battery systems for port power uses.

Together, the case studies provide a dual perspective on hydrogen supply for Brest Port: renewable electrolysis as a long-term decarbonisation pathway tied to offshore wind and solar deployment, and modular reforming with carbon capture as a potentially lower-cost and near-term route using local gas or biogas resources. Both approaches aim to support the same demand basins, including port equipment, shore-side electrical supply, ship-repair activities, heavy mobility, refuelling infrastructure, and future maritime fuels.

The combined work would suggest that hydrogen deployment could be considered as an integrated port energy system rather than as isolated assets. Renewable generation capacity, hydrogen production technology, storage and distribution, port electrical needs, mobility demand and possible CO2/heat valorisation could be considered all together. The next assessment stage should compare scenarios on technical feasibility, cost, carbon footprint, social benefits, operational maturity and contribution to the HYDEA Decision Support Tool.

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ABBREVIATIONS AND ACRONYMS

BGL	Bretagne Grand Large – OWF planned at the far-Ouest of Brittany and that may be connected to BrestPort
BNO	Bretagne Nord Ouest – OWF planned at the North of Brittany
DST	Decision Support Tool
FEM	France Energies Marines
OWF	Offshore Wind Farm
PBrest	Port of Brest
TEU	Twenty Foot Equivalent Unit = typical unit for container traffic measurement

1 Introduction

The HYDEA project aims to accelerate the deployment and integration of hydrogen-based technologies in Atlantic Area ports, supporting their transition towards more efficient, resilient and decarbonised energy systems. Within this framework, deliverable D5.1.3 presents the French case studies developed for the Port of Brest.

The document analyses two complementary hydrogen production pathways: green hydrogen production from marine and other renewable energy sources, including solar photovoltaics and offshore wind, and hydrogen production through modular steam methane or biogas reforming with CO_2 capture and local distribution. Both case studies address the same broader objective: assessing how hydrogen can contribute to the decarbonisation of port activities, mobility, shore-side power, ship repair, refuelling infrastructure and future maritime fuels. By combining renewable energy potential, local energy needs, industrial partnerships and deployment scenarios, this document provides a basis for assessing technical, economic, environmental and social performance in the next stages of the HYDEA project.

2 Case Study 1 - H_2 production from marine and other renewable energy sources

2.1 Location

H_2 production from offshore wind and solar photovoltaics will be studied at **port of Brest**. The reasons supporting this study are twofold:

- The close vicinity of the port of Brest to future offshore wind farms
- The ambitions of the port of Brest to develop solar energy production, including innovative floating solar technologies

Located in the western part of the Brittany region, the Port of Brest is a gateway to both the Atlantic ocean and the Celtic Sea, and an important entry point for goods. It is also a major logistics hub to support the deployment of marine energy in the surrounding areas.

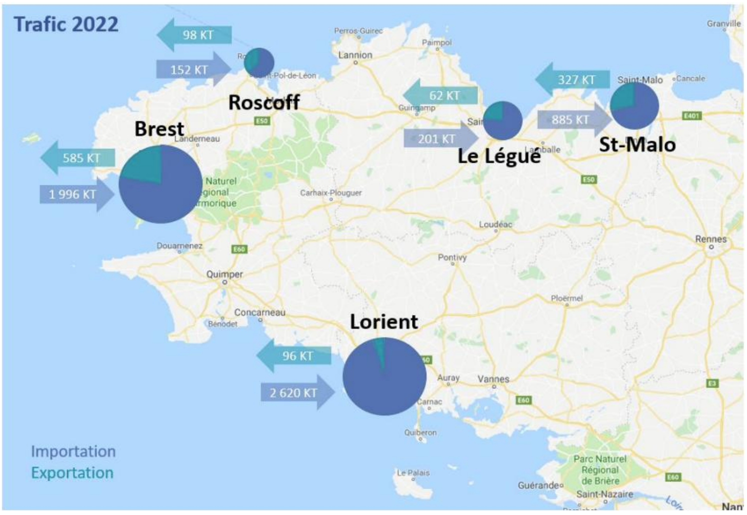

Figure 1: Import/Export volumes for Brittany ports in 2022 (source: Brittany ports annual report 2022[1])

Brest Port environment is appropriate for renewables energy deployment with :

- An important wind resource and offshore wind farms planned in the close vicinity of Brest Port
- A solar resource that could feed part of the direct uses of the port.

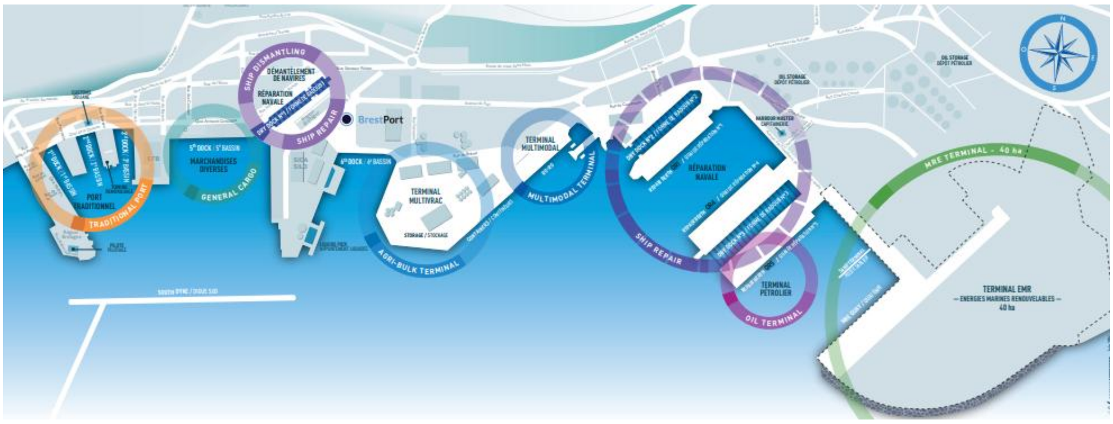

Figure 2. Map of terminals of Brest Port.

2.2 Partners

France Energies Marine (FEM) leads this case study and is the only partner involved in its development. FEM expertise covers marine renewable energy with a special focus on offshore wind. The institute has also developed an expertise in hydrogen production from offshore wind through Research and Development projects (OPHARM[2], OPHARM2[3]).

In addition, input data on consumption basins and generic information are provided by Port of Brest and Brittany Region.

[1] https://www.bretagne.bzh/app/uploads/sites/4/2023/09/Bilan-portuaire-2022.pdf
[2] https://www.france-energies-marines.org/en/projects/opharm/
[3] https://www.france-energies-marines.org/en/projects/opharm2/

2.3 Objectives and scope

The goal of this case study is to assess how much H_2 production from renewables (offshore wind and solar photovoltaics) may contribute to the overall energy consumption of the port of Brest, to ultimately reduce its carbon footprint, considering renewable energy and energy consumption development projections until 2050. The benefits and limitations of adopting such measures compared to a reference scenario will be investigated, with a focus on the technical, economical, environmental and social aspects.
This case study will ideally be compared with the reference case (reaching the forecasted traffics by using fossil fuels and network electricity exclusively).

2.4 Use cases that the case study covers

The case study covered by this report is focused on the production part of the H_2 value chain Table 1. Secondary use cases (in grey) can be directly linked to this first use case but they will not be developed extensively. They are only mentioned to estimate the consumption volumes of H2 needed for the port activities and therefore the required volumes of H_2 production for the port.

Table 1. Use cases covered by the study

PIORITY	USE CASES	DESCRIPTION
1	Production of H_2 from marine and other renewable energies	Hydrogen production from renewable energy sources, such as offshore wind or solar power
2	Hydrogen based fuels for vessels	Projection of H_2 volumes for port vessels decarbonation
3	H_2 FC application for vehicles and equipment	Projection of H_2 volumes for vehicles and handling equipment within port perimeter

2.5 Case study description

The case study is investigating how much hydrogen production from marine and renewable energies may meet Brest Port's hydrogen consumption, considering both the production and consumption scenarios until 2050.

2.5.1 Energy consumption

The Port of Brest is a multimodal port with seven main activities:

- A **general cargo terminal** equipped to manage various types of goods including machinery and industrial equipment
- A **bulk cargo terminal** equipped to handle liquid bulk (oil wharf) and solid bulk (import of agricultural products)
- A **multimodal / container terminal** providing efficient loading and unloading services, equipped with Mobile Harbour Cranes (MHC) for ship-to-shore operations and reachstackers for yard management. The terminal is also equipped with 400 reefer plugs for cold goods management.

- A **ship repair terminal** composed of three dry docks and two quays for afloat repairs. The ship repair terminal equipped with some of the largest dry docks for ship repair of Europe and around 60 vessels repaired by year.
- An **offshore renewable energies terminal** composed of a 380-m long heavy duty quay dredged at -12 mCM and 40 ha
- A **cruise terminal** with around 25 commercial calls per year
- A **traditional port** located in the urban center of Brest **with fishing activities, a** marina for pleasure crafts.

Brest port activities generate significant truck traffic mainly for regional distribution.
¡Error! No se encuentra el origen de la referencia. shows the types and number of different vehicles that operates in port's activities compared with the total amount in the city of Brest.

Table 2. Number of vehicles that operate in the port and city of Brest.

	Number of equipment	
Vehicle	**In the Port of Brest**	**In the City of Brest**
Trucks	34	1 027
Garbage Truck	-	31
Bus	-	371
Utility vehicle	14	14
Private vehicle	50	115,5
Handling equipment	83	
TOTAL	**181**	**1 559**

The resulting fuel consumption and carbon footprint is estimated in **¡Error! No se encuentra el origen de la referencia.**.

Table 3 : Diesel consumption and carbon footprint in the port and the city

	Resulting estimated annual fuel consumption (m^3/year)		Resulting estimated carbon footprint[4] (tCO_2eq/year)	
Vehicle	**In the Port of Brest**	**in the City of Brest**	**In the Port of Brest**	**in the City of Brest**
Trucks	1 398	42 239	4 335	130 942
Garbage Truck		348		1 078
Bus		15 259		47 302
Utility vehicle	26	26	81	81
Private vehicle	93	216	290	669
Handling equipment	931		2 886	0
TOTAL	**2 449**	**58 088**	**7 592**	**180 072**

[4] Based on diesel emission factor – base Empreinte ADEME (2025): 3.10 kgCO2e/liter

Regarding auxiliary material and energy use, the cranes are the main equipment used by Brest Port for goods loading and unloading. There are currently more diesel-powered equipments, such as stackers, but this type of handling equipment is operated by other stakeholders working at the port of Brest, and little information on their consumption is available.

Port of Brest purchases 15 GWh of electricity/year distributed as follows:

- 50% is dedicated to powering Brest Port clients (Damen's naval shipyard, Brest fish auction facilities, AMB reefers, Boluda's tugs, MRE manufacturers, etc.)
- 50% is dedicated to powering Brest Port's own equipment/scope of activities (see **¡Error! No se encuentra el origen de la referencia.**):

Table 4. Equipment with its energy source and needed.

Brest Port Activity	Equipment	Energy source	Energy need (MWh/y)	Carbon footprint[5] (tCO2eq/y)
Naval repair facilities	7 cranes on rail	100% Electrical grid	150	7,8
	6 air compressors	100% Electrical grid	500	26,0
	50 water pumps: docks drying, water cooling, firefighting, ballasting	100% Electrical grid	2 000	104,0
	400 kVA Onshore power - Supply 440V / 60Hz	100% Electrical grid	150	7,8
Multi bulk Terminal	4 cranes on rails with hoppers	100% Electrical grid	300	15,6
	11 compressors	100% Electrical grid	200	10,4
	~10 bucket lifts ~50 conveyors ~100 filters, etc.	100% Electrical grid	1 000	52,0
Miscellaneous	6 mobile cranes	Diesel + electricity for motor heating and starter battery recharging	Unknown	
TOTAL			**4 300**	**223,6**

Regarding the refueling infrastructure of the port and the port environment, the data shared by the authorities indicate that the port lacks electric charging points (Table 4):

Table 5. Refueling infrastructures of the port.

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

[5] *With FR electricity mix emission factor at 0,052 kgCO2eq/kWh as per Ademe Base Carbone V23.0 (2023)*

Total Energies	Refueling station	Diesel	/	Trucks/Private/ Utility vehicles
Guyot	tank	Diesel	250	Trucks/handling equipment

2.5.2 Energy needs projection

Brest Port wants to develop its activities while meeting the European regulations requirements. In order to define the forecast of traffics and estimate the associated energy consumption within the port and its vicinity, BrestPort has subcontracted a renewable hydrogen potential study to Seya consulting and Cap Hydrogène [1]. The consumption volumes defined for the case study are based on this analysis and are presented in **¡Error! No se encuentra el origen de la referencia.**. They will be further developed in section 2.5.

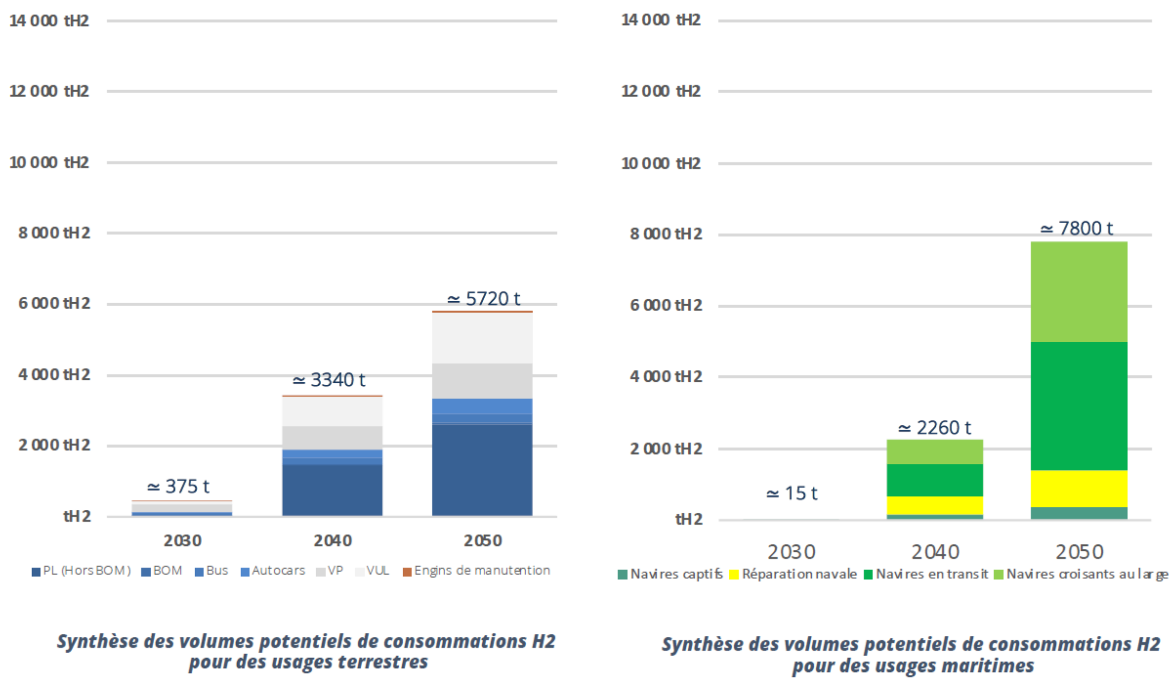

Figure 3 : Annual H2 volume for land uses (left panel. Legend: PL: Trucks; BOM: Garbage trucks; Bus/Autocars: Bus; VP: Private vehicle; VUL: Utility vehicle; Engins de manutention: Handling equipment) and for maritime uses (Right panel. Legend: Navires captifs: Captive ship (~190); Réparation Navale: Ship repair (~60/y); Navires en transit: Ship in transit (~700/y); Navires au large: Ship off shore (55,000/y)

2.5.3 Hydrogen needs projection

Hydrogen consumption by Brest Port has been broken down into 2 categories i) Road mobility including terminal trucks, light and utility vehicles, city buses and coaches, and port handling equipment and ii) Marine mobility including port fleet, ship repair, transit vessels and other vessels.

The annual estimates of hydrogen consumption provided by Brest Port for these specific needs are presented in Table 6.

Table 6 : Hydrogen consumption forecasts for vehicles (source: [1])

			2030	2040	2050
Trucks	**1027 trucks in the metropolis including 34 on the port***	Growth rate : + 50% by 2050	8 trucks	301 trucks	539 trucks
		Penetration ratio of H2 solutions: 1/3 by 2050	0,80%	23%	34%
		H2 consumption	36 t/yr	1,46 kt/yr	2,61 kt/yr
BOM	**31 BOM in the metropolis**	Decrease rate : 5% by 2050	1 BOM	9 BOM	19 BOM
		Penetration ratio of H2 solutions: 90% by 2050	3%	30%	90%
			4 t/yr	32 t/yr	67 t/yr
Bus	**371 Buses in the metropolis**	Growth rate: + 13% by 2050	14 bus-cars	129 bus-cars	234 bus-cars
		Penetration ratio of H2 solutions: 55% by 2050	4%	33%	55%
			41 t/yr	362 t/yr	671 t/yr
Light vehicles	**14 000 in the metropolis (14 in the port)**	Growth rate: none by 2050	247 VUL	2109 VUL	3587 VUL
		Penetration ratio of H2 solutions: 25% by 2050	1,70%	15%	25%
			99 t/yr	843 t/yr	1 435 t/yr
Cars	**115 500**	Growth rate: 35% by 2050	1133 units	3682 units	5562 units
		Penetration ratio of H2 solutions: 8% by 2050	0,90%	3,80%	7,40%
			204 t/yr	663 t/yr	1 001 t/yr
Port equipment	**83**	Growth rate: none by 2050	4 units	15 units	22 units
		Progressive conversion of the equipment to H2(the most powerful) with an acceleration after 2030	5%	18%	26%
			8 t/yr	23 t/yr	34 t/yr
		TOTAL H2 consumption needs	**392 t/yr**	**3383 t/yr**	**5818 t/yr**

The annual estimates of hydrogen consumption provided by Brest Port for maritime uses are presented in Table 7.

Table 7 : Hydrogen consumption forecasts for maritime uses (vessels) (source: [1])

				2030	2040	2050
Port fleet (tugs, pilots, etc.)	**186 vessels**	Bunkering at BrestPort	0 to 80% of H2 propulsion by 2050	15	200	400
Ship repair	**60 calls/y**	No bunkering / 10% of the calls	Increase of +20% of traffic by 2050 30% of port fleet converted to H_2 by 2050 Hypothesis: bunkering of 0% to 10% of the calls		500	1 000
Transit vessels	**700 calls/y**	No bunkering / 1% of the calls ~3 600 t/yr by 2050	Increase of bunkering activity (e-fuel) for vessels transiting in the vicinity of Brest Port		1 000	3 700
Other vessels (far away)	**55 000 vessels/y transiting in marine routes**	No bunkering / 0.01% of the calls ~2 700 t/yr by 2050			560	2 700
			TOTAL H2 consumption needs	**15**	**2 260**	**7 800**

Based on those different hypothesis, a minimum and maximum consumptions scenarios have been defined for H_2 needs at different horizons in Table 8.

Table 8 : Synthesis of global H_2 needs

	2030	2040	2050
Min	390 t_{H2}	3 570 t_{H2}	6 170 t_{H2}
Max		5 680 t_{H2}	13 600 t_{H2}

2.5.4 Renewable Energy Production facilities

Brest Port ambitions to deploy solar production capacity from both onshore (including on buildings) and floating photovoltaics.

2.5.4.1 Onshore photovoltaics

Regarding onshore photovoltaics, solar panels will primarily be deployed in the Brest Port, Réparation Navale and Polder areas (Figure 4), covering a surface of 50 m², 2500 m² and 8500 m² respectively. Using an average density of PV production capacity of 0.2 kWc/m², the onshore capacity reaches 50 kWc, 500 kWc and 1700 kWc in 2030 for the areas previously mentioned, delivering an annual yield of 54 MWh, 546 MWh and 1800 MWh if a capacity factor of 12.5% is adopted. The CAPEX for that operation is estimated to reach 0.175 M€, 1.15 M€ and 3.65 M€ for each respective area, for a total of 4.975 M€.

Polder parking area identified for solar panels deployment

Réparation Navale parking area identified for solar pannels deployment

Figure 4 : Aerial photography of the parking areas identified for the first deployment of solar panels (source: Brest Port)

The roof of selected buildings is also expected to be equipped with solar panels by 2040 according to Brest Port. They are presented in Figure 5. Note that rooftop PV are only planned on buildings that already exist.

Figure 5 : Aerial photograph of Brest Port's facilities. The buildings that can be fitted with solar panels are marked (source : Brest Port).

The total surface, capacity and corresponding annual yield are shown in Table 9.

Table 9 : Onshore PV deployment characteristics in Brest Port

Area	Effective surface (m²)	Installed PV capacity (kWc)	Annual yield (MWh/year)	Estimated CAPEX (M€)	Deployment horizon
Brest Port	250	50	54	0.175	2030
Réparation Naval	2 500	500	546	1.15	2030
Polder	8 500	1 700	1 800	3.65	2030
Rooftops	*17 000*	*3000*	*3000*	*5*	*2040*
TOTAL	**29250**	**5250**	**5400**	**9.975**	

2.5.4.2 Offshore floating photovoltaics

Offshore floating solar PV is also planned to be deployed by Brest Port, as it offers a space-efficient alternative to land-based systems. However, offshore systems face harsher conditions than inland technologies (waves, saltwater corrosion and strong winds) which makes the technology less mature and still in its early stages of development and testing. Further technical and economic progress, as well as a regulatory framework, need to be addressed before that technology can be considered. This is the reason why its deployment is planned at a later horizon of time, namely 2050.

The areas of deployment under consideration are presented in Figure 6 and their characteristics in Table 10. The largest one is located right offshore the southern jetty (Z4 Digue sud) and offers a surface of about 1.1 km². Smaller but more sheltered areas are also considered, with direct access to the docks (Z1 6e bassin, Z2 passerelle Ro-Ro, Z3 Ship repair). The capacity factor of the technology has been set to 10%, in order to account for possible lower maturity level and associated higher down-time compared to onshore technology. Similarly, the average density of PV capacity has been set to 0.1 kWc/m², which is half that of the onshore technology.

In 2023, Brest Port successfully hosted the prototype of a 25 kW-floating solar power plant, located in the area Z1 6e bassin in Figure 6.

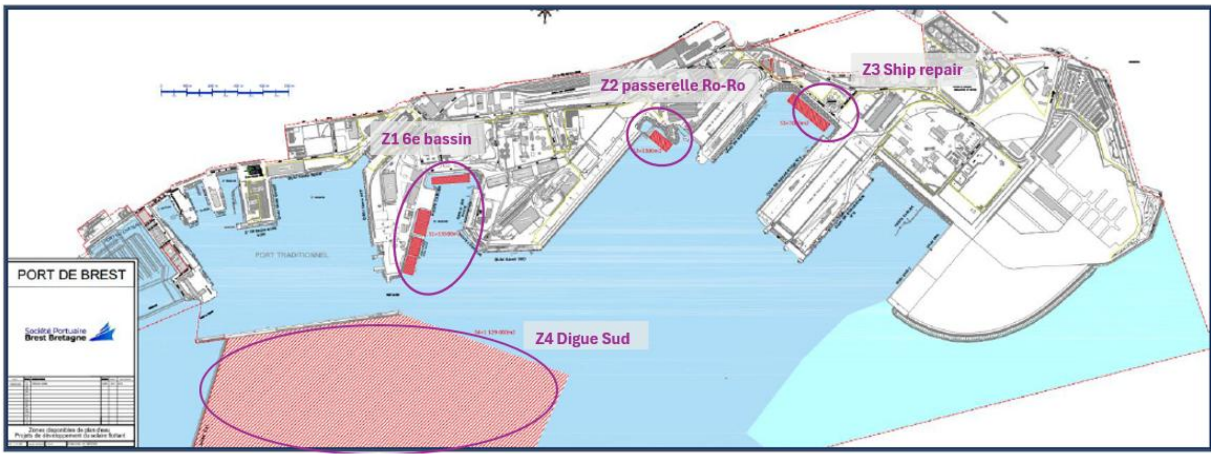

Figure 6 : Areas under consideration for the deployment of offshore floating PV

Table 10 : Offshore floating PV deployment characteristics in Brest Port

Area	Effective surface (m²)	Installed PV capacity (MWc)	Annual yield (MWh/year)	Deployment horizon
Z1 (6e bassin)	13 500	1.35	1185.67	2050
Z2 (passerelle Ro-Ro)	3 300	0.33	299	2050
Z3 (bassin QR1-QR4)	7 000	0.7	615	2050
Sub-total	**23 800**	**2.38**	**2085**	**2050**
Z4 (Digue sud)	*1 129 000*	*113*	*99 000*	*2050*
TOTAL	**1 313 800**	**115.38**	**101 100**	**2050**

2.5.4.3 Offshore wind

France has great ambitions in offshore wind deployment, targeting 45 GW of production capacity by 2050. Specifically, two deployment areas are foreseen in the 2040/2050 horizon in the vicinity of Brest Port.

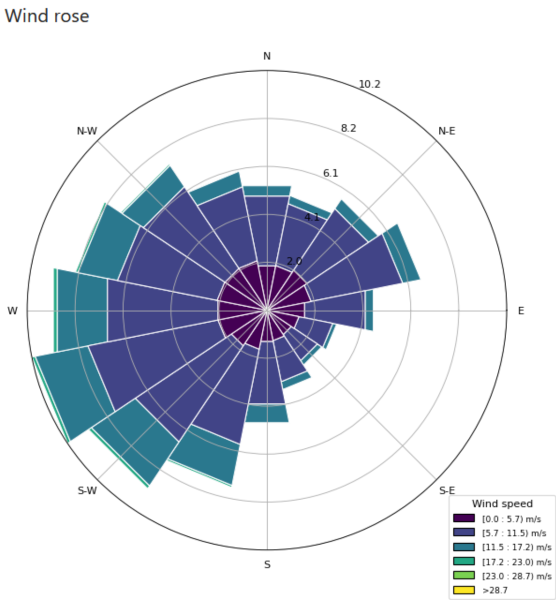

Figure 7 : Offshore wind statistics for Brest[6]

Bretagne Nord Atlantique (BNO) is located about 70 km away from the port, with a deployed capacity expected to reach 1.2 GW to 2 GW by 2040 or 2050. Electric connection is already planned between this offshore wind farm (OWF) and the port.

Bretagne Grand Large (BGL) is another area, located about 200 km offshore, West of Brest, with a capacity ranging between 10 GW to 15 GW by 2050. This amount of production capacity is very high compared to Brest Port's energy consumption, and the case study will investigate how much of this production capacity is necessary to complement the green hydrogen production from the solar energy previously presented. For this aspect, a capacity factor of 0.5 and 0.45 will be adopted for BGL and BNO respectively, using the information of the Global Wind Atlas[7].

[6] https://resourcecode.ifremer.fr/explore?pointId=136187

[7] https://globalwindatlas.info/

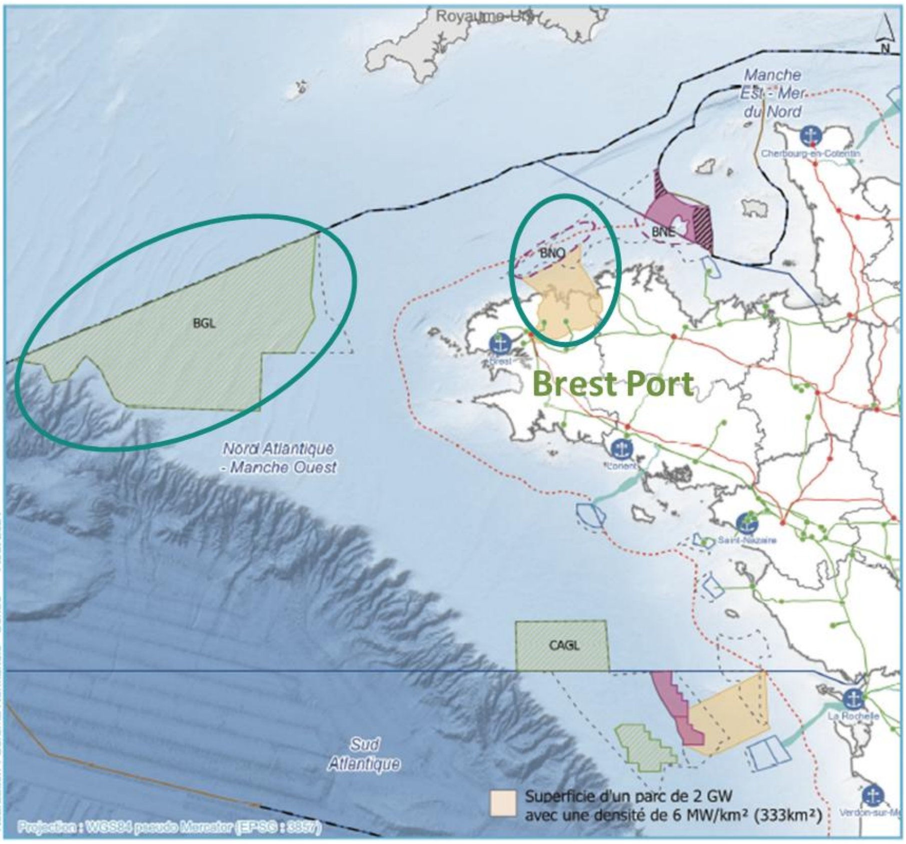

Figure 8 : Offshore wind deployment areas in western France. Areas of interest for the current case study are BNO and BGL.

2.5.4.4 Renewable energy deployment timeline

Based on the planification timeline for renewables energies in France and of the robustness of the technologies, the following timeline and associated capacities is proposed for Port of Brest.

Table 11 : Summary of the renewable energy deployment timeline. Gray capacities are not secured.

	Ground PV Capacity [MWc] / Annual yield [MWh]	Rooftop PV Capacity [MWc] / Annual yield [MWh]	Floating PV Capacity [MWc] / Annual yield [MWh]	Offshore Wind
2030	**2.250 / 2400**			
2040		3 / 3000		
2050			2.38 / 2085 113 / 99 000	Assessed to meet future Brest Ports needs for hydrogen production

2.6 Hydrogen production facilities

Considering the hydrogen consumption needs presented in Table 8, Table 12 shows the electrolysis capacity required to meet the forecasted H_2 needs, based on a PEM electrolyzer efficiency of 55%.

Table 12 : Resulting electrolysis capacity installed

	2030	2040	2050
Min	2.7 MW	25 MW	43 MW
Max		39 MW	94 MW

An overcapacity of 40% could be planned on those initial targets, to ensure that the production matches the intermittency of the demand. However, at this stage, it was decided not to integrate the intermittency aspect to the study. The storage is not addressed either and only the production capacities will be developed.

For PV, electrolysis will be performed within the port boundaries.
For offshore wind, two options are considered:

- For BNO, electrolysis could be performed onshore, at the vicinity of the offshore wind farm. We propose to plan the electrolysis within the port boundaries, to meet directly the port production requirements
- For BGL, electrolysis will most likely be performed offshore.

3 Case Study 2 - H2 production through SMR and local distribution

3.1 Location

The location of the case studied is the port of Brest, a medium size port located at the west of Brittany. BrestPort is the main commercial port of the Brittany Region. It development plan for the next 40 years, established in 2023, aims at diversifying its activities and decreasing its carbon footprint.

The port offers:

- 4,3 kms of berth to accommodate bulk carriers, container ships, cruise vessels
- A ship repairing infrastructure, offering large dry docks able to accommodate large and complex vessels (gas carriers, cruise vessels, …)
- A new terminal dedicated to offshore wind industry
- A traditional port area, under renovation, which will be developed a "Marine Service Area" (offices, workshops, tests facilities and a small size ship repairing area)

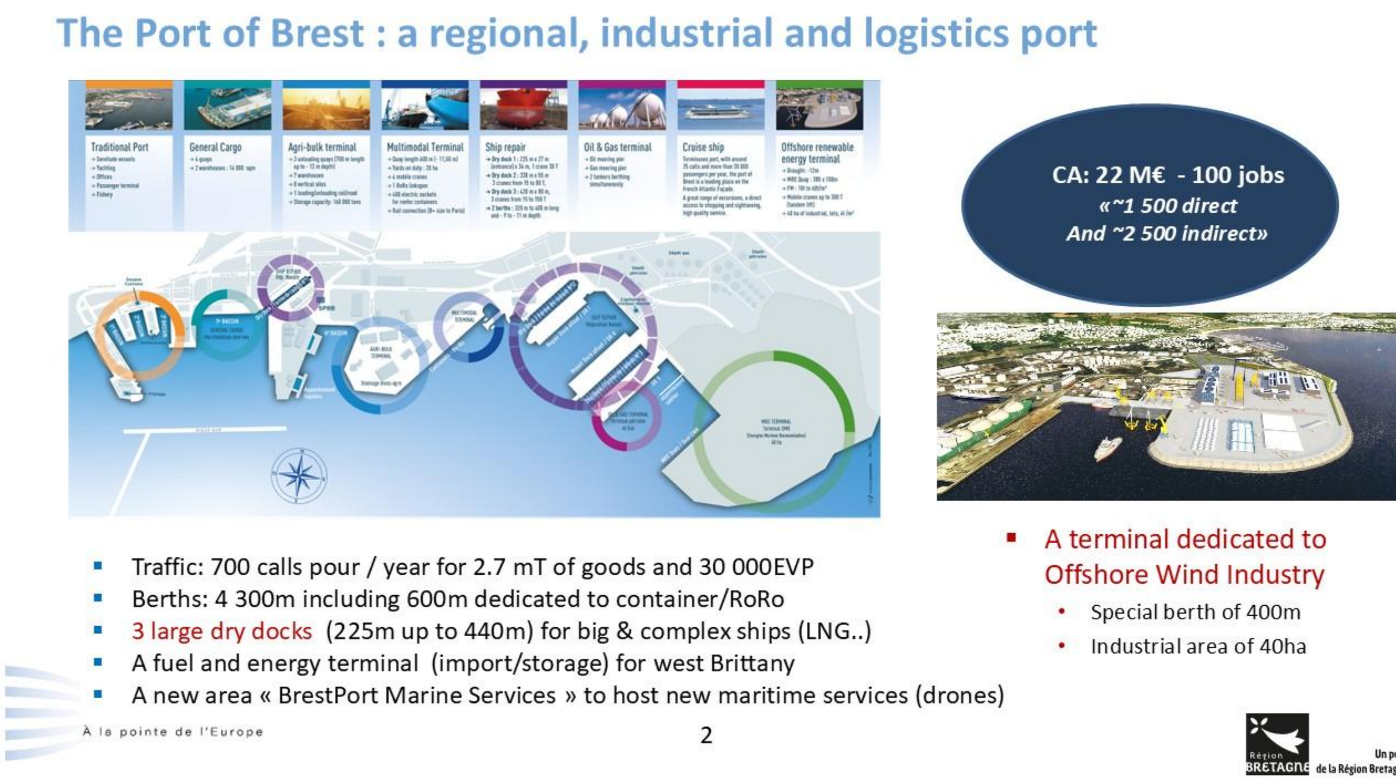

Figure 9: BrestPort - location of the case study

3.2 Goal and methodology

3.2.1 Goal of the case study

The goal of case study is to analyse the ports applications (use cases) of the steam reforming technology to provide multiple H2 use cases. Demonstration of the solution of hydrogen production and uses could be done with technology partners (VERDEMOBIL and H2X) on a site operated by VERDEMOBIL.

3.2.2 Assessment methology

As for any case study, a preliminary study of needs is necessary to define the case study. This assessment covers the following steps:

1. Explore all available and local resources
2. List of every potential use cases
    - Does hydrogen improve existing use cases served by another solution? Under which timeline?
    - Can hydrogen serve future use cases? Under which timeline?
3. Define final use cases for the case study based on point 2 and quantified needs
4. Based on point 1, define a process to produce hydrogen locally and dimension it.
5. Estimate ROI and prepare investment phase
6. Execution of the project

Brest Port, with technology partners (H2X and VERDEMOBIL, has analysed the local context and needs to develop a case study (Figure 2).

1. Hydrogen daily needs by 2030 (use cases 4, 6, and 7) estimated to 4 T and shared between:

- Ship repair supply— 2 T per day
- Onshore ships power supply 5th basin — 0.56 T per day
- Dry dock pump — 0.08 T per day
- Peak shaving of energy consumption — 0.36 T per day

- In 2030, it is foreseen to install a hydrogen refuelling station (use case 2) for trucks and vehicles for 1 T hydrogen per day (8 trucks, 1 000 cars, 250 light utility vehicles, 14 buses, 1 dumpster), representing 1% to 3% of the vehicle fleet around Brest Port.
- After 2030, new green fuels synthetised from hydrogen (use cases 1, 5 and 6), or hydrogen directly, could be considered.
- Use case 3 could also has been addressed with use of drones (automatization) of surveillance missions on the docks and at sea, using H2X UGV and USV hybrid battery-hydrogen powered drones.

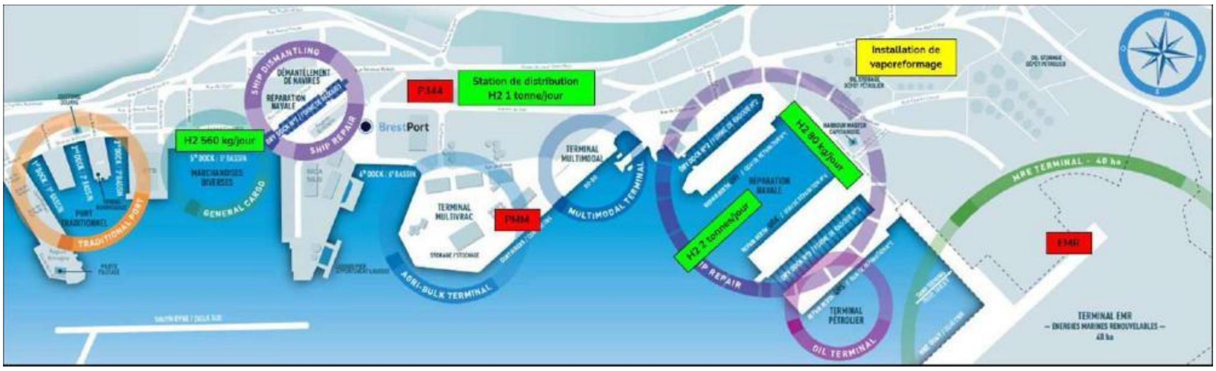

Figure 10 : Scope of the case study

For the HYDEA case study, the choice is to focus on use case no4 and deploy gradually hydrogen solutions by 2030:

- 2 T hydrogen usage per day, centralized or hub-an-spoke
- 3 T hydrogen usage per day, centralized or hub-an-spoke
- 4 T hydrogen usage per day, centralized or hub-an-spoke

3.3 Partners

BREST PORT: French company: Brest Port is the biggest port in Brittany region. We are at the meeting point of North Sea/Channel and Atlantic Regions. We are participating in several European projects aimed at decarbonizing the port industry and its energy management. As a partner in the HYDEA project, we actively support the integration of renewable hydrogen into the port energy value chain. We are collaborating with H2X, GRDF, and VERDEMOBIL on an initial study to assess needs.

H2X ECOSYSTEMS: French company. We specialize in smart energy ecosystems based on hybrid energies (renewable energy, batteries, hydrogen) and exploit multiple hydrogen production pathways. Due to a high total LCOH, from electrolysis of renewable energy to hydrogen storage (15-20 €/kg), electrolysis is reserved for isolated areas. For mass production, we exploit the conversion of biomass into biogas or the direct conversion of methane into hydrogen thanks to CCUS and the valorisation of bio-0O2. Our studies and ecosystems respond systemically to use cases and adapt production to these needs. As a partner in the European DIOL project, we are developing energy hubs for ports to serve offshore wind farms with hybrid energy-battery drones.

VERDE MOBIL: French company. VERDEMOBIL BIOGAZ and its subsidiaries design, manufacture, and maintain renewable gas recovery facilities. We also produce and exploit the renewable gas recovered at our production sites. Based in Montaigu-Vendée, VERDEMOBIL BIOGAZ has been a key player in the energy transition for 15 years. The company captures and locally recovers 100% of biogas into renewable energy and CO2.

3.4 Use cases covered

The use cases covered by the case study are listed below.

Table 13. Use cases covered

USE CASES	DESCRIPTION
H2 storage & distribution	A storage and H2 refuelling infrastructure
H2 FC for port equipment	Use of FC for pumps & equipment
Production of H2 from green energies	Renewable energies & biogas + carbon capture
H2 based electric power for port usage	Electricity generation for port energy needs

3.5 Technical description of the case study

3.5.1 General description

The figure below is an overview of the technical modules potentially involved in the case study H2 produced from gas/bio-gas and renewable energy sources and Co2 capture can be used for various use cases:

- H2 fuel cells used as batteries to reduce electric consumption pics
- Electricity for port equipment (example of pumps) and electric connection of ships at berth (On shore power supply)
- Co2 and heat can be used for greenhouses
- Heat and warm water can be used for port needs

All these use cases are not yet at the same degree of maturity or economic viability. These aspects will be analysed in the deliverable 5.2.3.

The interest of the system shown below is in its modularity and thus flexibility. It can adapt to many different consumption patterns and operational needs in ports.

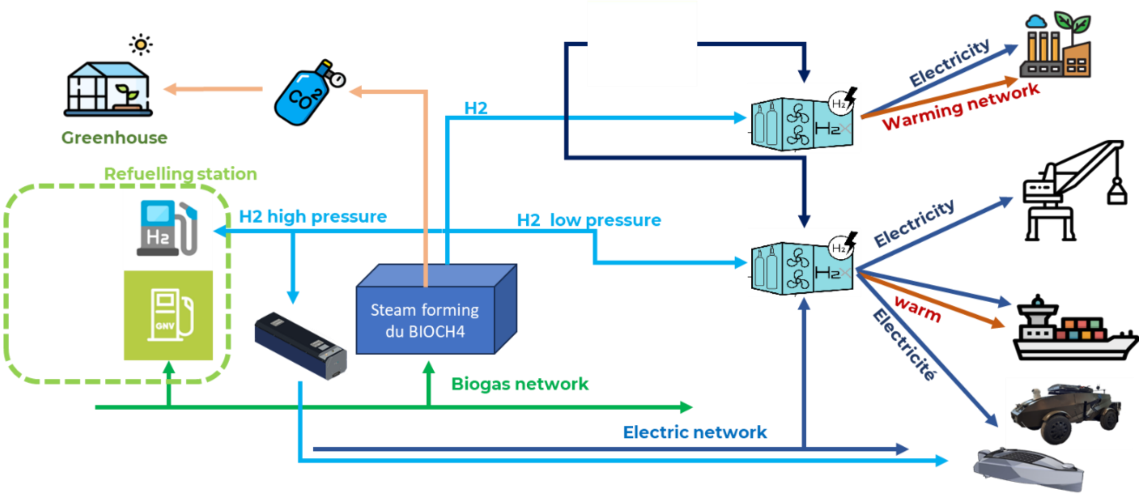

Figure 11 : Technical overview of the case study

3.5.2 Hydrogen production

The H2 production module is central to the positioning of the case study.
LCOH (Levelized Cost Of Hydrogen) is understood from primary energy resources to hydrogen storage and conditioning before use. The case study focuses on steam forming that must be compared with classic electrolysis technology to understand the interest of the case study.

H2 production by electrolysis of water splits water molecules into hydrogen and oxygen by providing electrolysis electrochemical stacks electrical power. Yields are 72 %. Complete LCOH for electrolysis from renewable energies or grid is over 15 €, from powering electrolyzer to compressing and storing H2. This cost is not decreasing due to the aging of the batteries and the inflation of the price of electricity. This technology requires 8.9 L of ultrapure water and 50 to 55 kWh to produce 1 kg of hydrogen, followed by 6 to 10 kWh to compress it. With efficiencies reaching 72%, this technology can split molecules of ultrapure water, a vital resource. Because of its costs this solution tends to limit adoption of H2 based solutions. Moreover, the technology requires ultrapure water to power the electrolyzers. This is another limiting factor.

In the current state of technology, steam forming using biogas or methane conversion appears as an alternative approach to produce H2 at lower costs. Methane conversion uses a steam reforming station to split methane into bio-CO2 and hydrogen, with the supply of heat (40 kWh) and tap water (9 L) (Figure 2). The hydrogen generated is then purified and compressed (6 to 10 kWh per kg) by the same processes as hydrogen generated by electrolysis. Bio-CO2 is recycled as a precious resource for agricultural greenhouse into carbon cycle. This allows plants to grow faster, including during winter. Complete LCOH from biomass wastes or methane network to hydrogen storage racks is between 5 € and 12€, depending on quantity of hydrogen stored and CO2 valorization capacities in the vicinity of the production site. This solution is merely adaptable to ports thanks to the existence of gas networks within ports. Moreover, this H2 production technique complies with H2X - AFNOR SPEC M58-007 standard by using local resources. In addition, ports transport a lot of waste that can be converted into methane. The latter can be injected into the gas network.

The H2 production and carbon capture module is represented below. The company VERDEMOBIL ,a company specialised on gas liquefaction and treatment is one developer and provider of such technologies. .

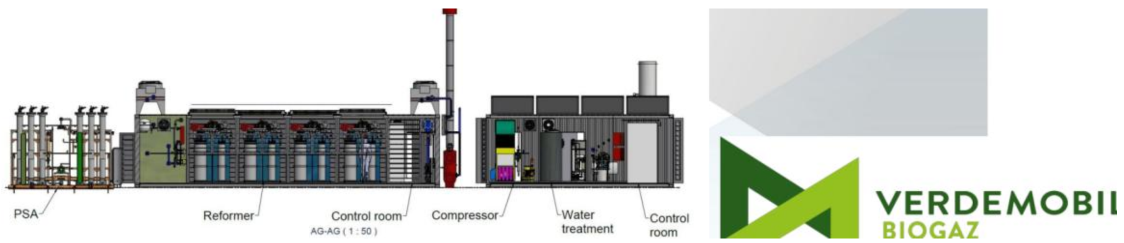

figure 12 : The H2 production module

The technology developed by **VERDEMOBIL BIOGAZ** (and similar modular SMR systems) works through a multi-stage chemical and physical process. While traditional industrial plants focus on large-scale fossil gas, the VERDEMOBIL approach is specifically optimized for **biogas** and **modular scalability**, often resulting in "BioH2."

The process can be broken down into four distinct "skidded" modules:

1. Feedstock Pre-treatment (Purification)

Before reforming, the raw gas (biogas or natural gas) must be cleaned.

- **Pollutant Removal:** Biogas contains hydrogen sulfide (H2S) and siloxanes that can "poison" (deactivate) the nickel catalysts used later.
- **Compression:** The gas is compressed to operating pressure (typically 8–25 bar) to facilitate the reaction and subsequent separation.

2. The Reforming Stage (The Chemical Core)

This happens in two main chemical steps inside a high-temperature reactor:

- **Steam Methane Reforming (SMR):** The methane (CH4) is mixed with superheated steam (H2O) and passed through tubes filled with a nickel catalyst. At temperatures between 700°C and 900°C, the molecules break apart to form "syngas" (a mixture of H2 and CO).
- **Water-Gas Shift (WGS):** To maximize hydrogen yield, the C0 is then reacted with more steam in a secondary reactor. This converts the toxic CO into CO2 while "liberating" more hydrogen from the water molecules.

3. Hydrogen Separation (PSA Unit)

At this stage, the result is a mixture of H2, CO2 and some unreacted methane. VERDEMOBIL uses **Pressure Swing Adsorption (PSA)**:

- The gas flows through tubes filled with "molecular sieves" (adsorbents).
- Under high pressure, these sieves trap CO$, CH4 and CO but allow the tiny H2 molecules to pass through.
- This results in **ultra-pure hydrogen (>99.999%)**, suitable for fuel cells.

4. CO_2 Capture and Liquefaction (The "BioCO2" Module)

Instead of venting the "off-gas" (the CO2 and impurities trapped by the PSA), VERDEMOBIL routes it to a dedicated capture module:

- **Cryogenic Distillation:** The gas is cooled to approximately **-30°C** and compressed to **18 bar**.
- **Separation:** At these temperatures, the CO2 liquefies while other gases remain gaseous. This allows to produce high-purity, **food-grade liquid CO2**.

Zero-Emission: Any residual methane in the off-gas is recirculated back into the system (often to the digester or burner), ensuring nearly 100% methane recovery and zero CO2 emissions to the atmosphere.

Containerisation

An added value of such modular steam reforming systems is the possibility to integrate the whole H2 production and Co2 capture functionalities into a small container (40 feets), what facilitates its manipulation and storage in ports.

Figure 13 :Containerisation of the H2 production

3.6 H2 conversion and consumption

While **VERDEMOBIL** focuses on *producing* hydrogen, companies like **H2X Ecosystems** (the French division of H2X Global) focus on *consuming* it to provide power.

H2X's technology is based on a **modular hybrid powertrain** that combines a hydrogen fuel cell with an energy storage system (batteries or supercapacitors) to generate high-power electricity for mobility or stationary generators.
The system is integrated into containers (6 m/ 20 feet) to facilitate the transport and storage in particular in ports. Each container can provide between 100 and 400 KW for 6,5 to 26 kg/h of H2.

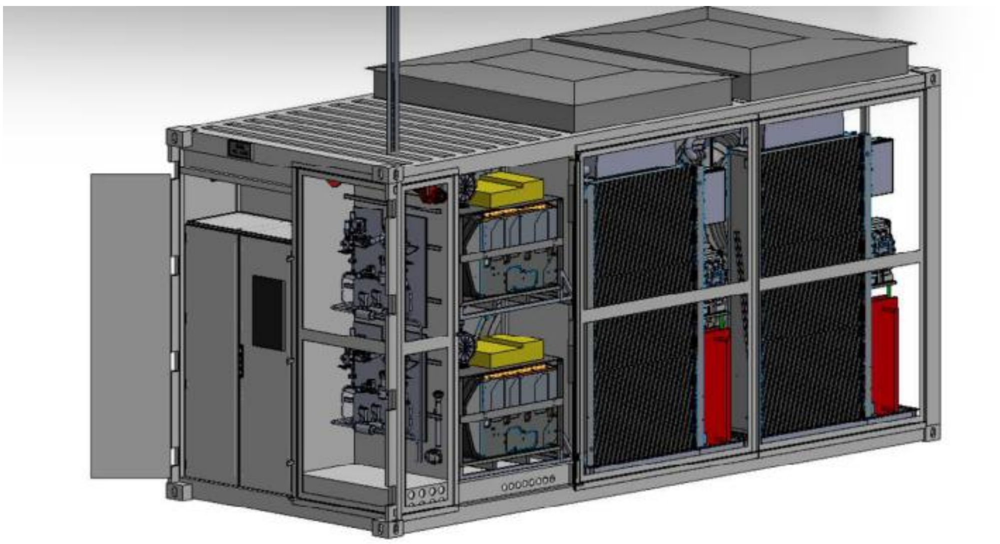

Figure 14 : The containerised H2X FC / battery system

3.6.1 The Core Component: PEM Fuel Cell

H2X uses **Proton Exchange Membrane (PEM)** fuel cell technology. This is the "engine" that converts chemical energy into electricity without combustion.

- **The Electrochemical Process: the Anode (Hydrogen Side):** Pure H2 gas is fed into the fuel cell. A catalyst (usually platinum) splits the hydrogen atom into two parts: **protons** (H+) and **electrons** (e-).
- **The Membrane:** The PEM membrane is a "gatekeeper." It allows the protons to pass through to the other side but blocks the electrons.
- **Circuit (Electricity):** Because the electrons cannot pass through the membrane, they are forced to flow through an external circuit. This flow of electrons **is the electricity** that powers the motor.
- **Cathode (Oxygen Side):** Oxygen from the ambient air enters the cathode. It meets the protons (that came through the membrane) and the electrons (that came through the circuit). They combine to form **pure water (H2O) and heat.**

3.6.2 The H2X "Hybrid" Architecture

A unique feature of H2X (specifically in their **Warrego** truck or their **PowerBox** generators) is the use of a hybrid system.

- **H2-XCap (Supercapacitors/Batteries):** Fuel cells are great at providing steady power but are "slow" to respond to sudden spikes (like accelerating a heavy truck). H2X integrates supercapacitors or high-discharge batteries to handle these **peak loads**.
- **The VCU (Vehicle Control Unit):** This is H2X's proprietary "brain." It constantly decides whether the electricity for the motor should come from the fuel cell, the battery, or both, ensuring the fuel cell stays in its most efficient operating range.

3.6.3 Case study: association of H2X & VERDEMOBIL technologies

The two companies represent the "Full Loop" of a local hydrogen economy:

- **VERDEMOBIL** takes local organic waste (biogas), extracts the H2, and captures the CO2.
- **H2X** takes that H2 and converts it back into electricity to power vehicles, H2 batteries or H2 generators.

The result is to provide energy from local waste, with zero tailpipe emissions and a net-negative carbon footprint for the whole cycle, with reduced investments compared to H2 production by electrolysers.

The key objective and added value of such a system for ports is to use hydrogen as a hub between electrical, mobile, and chemical uses between the resources and needs of the port (Figure 3).

The case study will then define each deployment scenario within the perspective of effective, credible future use cases.

Table 14 : From case study to use cases

Case study scenarios	Use cases	Timeline/ tonnage
Scenario 1	- H2 generators for ship repair electricity supply	2027/2T
	- Deployment for electric power peaks management (batteries)	2028 +1 T
	- H2 refuelling station	2030 +1 T
Scenario 2	Perspectives- ammonia and methanol demands	2035
Scenario 3	Perspectives- use of drones for the surveillance of the port	2035
Scenario 4	Perspectives - cranes electrification by 2040	2040

4 Conclusion

The merged French HYDEA case studies show that Brest Port has strong potential to become an integrated hydrogen hub. They assess two case studies: renewable electrolysis from solar and offshore wind resources, and hydrogen production from biogas or methane reforming with CO_2 capture. Together, these options could support port equipment, ship repair, shore-side power, mobility, refuelling and future maritime fuels. The analysis highlights the need to consider hydrogen as part of a wider port energy system, combining production, storage, distribution, conversion and demand management. The next step will investigate the performances of these solutions using common technical, economic, environmental and social indicators to assess the realism of the presented case studies.

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