Deployment of FC-based CHP & auxiliary power for industrial, commercial, and domestic buildings across Mallorca and the rest of the Balearic Islands

Deliverable 6.2

December 2023

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Reviewer(s)	Aitor Sanzo (FHa) Vicente Canals (Universitat de les Illes Balears) Víctor Encinas (ENAG REN)		
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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 1st January 2021, and will end on 31st 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_2) ecosystem covering all the value chain, from the production to the distribution and consumption of, at least, 330 tonnes per year of green H_2, traced through a Guarantee of Origin System. This hydrogen will be used in six different applications, as follows:

- The **H_2 pipeline and the injection point** of part of the H_2 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_2 vans** in the Alfill Logistics vehicle fleet as well as the search for rental car companies to incorporate H_2 vehicles in their **rental car fleets**.

The infrastructures which will be developed within the project are:

- The **green H_2 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 H2 produced in Lloseta's plant to the different applications.

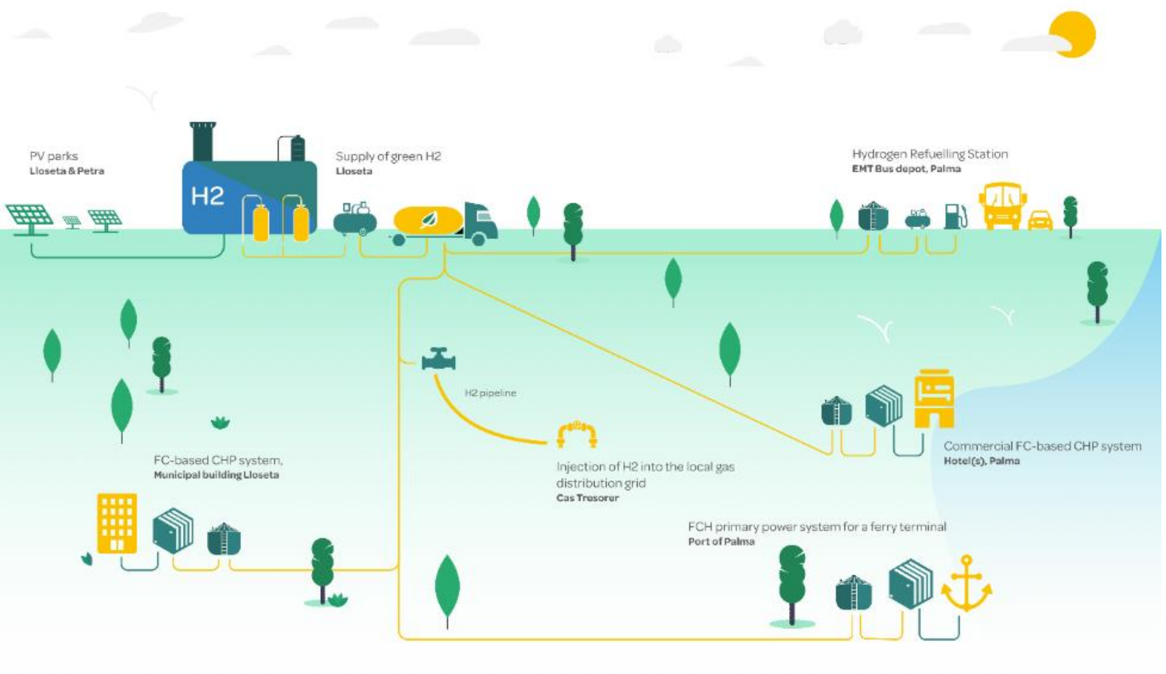
This initiative aims to reduce the CO_2 emissions of Mallorca up to 20,700 tonnes per year by the end of the project.

The project will also deliver **a roadmap towards 2050** that compiles a long-term vision for the **development of a widespread H_2 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_2 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_2

production, interconnecting infrastructure and local H_2 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	enagas renovable
2	ACCIONA ENERGIA S.A.	ACCIONA ENER	ES	acciona energía
3	REDEXIS GAS S.A.	REDEXIS GAS SA	ES	Redexis
4	Empresa Municipal de Transports Urbans de Palma de Mallorca S.A.	EMT-PALMA	ES	EMT Empresa Municipal de Transports de Palma de Mallorca
5	CALVERA HYDROGEN S.A.	CALVERA	ES	CALVERA Hydrogen
6	AJUNTAMENT DE LLOSETA	Lloseta Council	ES	Ajuntament de Lloseta
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11	UNIVERSITAT DE LES ILLES BALEARS	UIB	ES	UIB Universitat de les Illes Balears
12	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON	FHa	ES	Ha FUNDACIÓN PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGÍAS DEL HIDRÓGENO EN ARAGÓN
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14	ASOCIACION ESPANOLA DEL HIDROGENO	AeH2	ES	AeH2 SPANISH HYDROGEN ASSOCIATION
15	COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	CEA	FR	cea
16	ENERCY BV	ENER	NL	Enercy
17	HYENERGY TRANSSTORE BV	HTS	NL	HyEnergy
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21	NATIONAL UNIVERSITY OF IRELAND GALWAY	UGalway	IE	Ollscoil na Gaillimhe University of Galway
22	THE EUROPEAN MARINE ENERGY CENTRE LIMITED	EMEC	UK	EMEC HYDROGEN

23	GASNAM - ASOCIACION IBERICA DE GASNATURAL Y RENOVABLE PARA LA MOVILIDAD	GASNAM	ES	
24	UNIVERSIDAD DE LA LAGUNA	ULL	ES	
25	ENERGY CO-OPERATIVES IRELAND LIMITED	En.Coop.Ireland	IE	
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27	GEMEENTE AMELAND	Gem.Ameland	NL	
28	DIKTYO AEIFORIKON NISON TOY AIGAIOU AE	DAFNI	EL	
29	ASOCIACION CHILENA DE HIDROGENO	H2 CHILE	CL	
30	Association Marocaine pour l'Hydrogène et le Développement Durable	AHMYD	MA	
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32	ENAGÁS S.A.	ENAGAS	ES	
33	Power to Green Hydrogen Mallorca S.L.	P2GH2M	ES	

1 Table of Contents

2 Executive Summary

As countries around Europe and the world commit to deep decarbonisation goals by 2030 and net-zero greenhouse gas emissions by 2050, the focus of policymakers is moving beyond the deployment of renewable electricity generation. Renewables coupled with electrification of transport and heating, as well as energy efficiency improvements will undoubtedly play a major role. Hard-to-abate sectors including heavy duty transport, high-temperature heat, among others will present particular challenges. Issues around electricity grid stability, seasonal storage of renewables and reduction of curtailment and constraint will also need to be addressed. Hydrogen can play a central role in integrating the electricity, transport and heating sectors, storing, and transmitting large volumes of variable renewables, while also stimulating new innovative industries and economies.

Whilst much of this activity has focused on the role that mainland European regions can play, Mallorca and the wider Balearic Islands have uniquely positioned themselves to become a pioneer in the deployment of innovative hydrogen technologies. The work carried out within the Green Hysland project is providing the region with a world-leading understanding of how hydrogen can be utilised to tackle decarbonisation within isolated regions. Identifying how the region's abundant renewable potential can be converted into hydrogen, transported via road-based and pipeline mechanisms, and utilised across the islands' most crucial end-uses.

The analysis in this report presents scenarios for the development of fuel-cell hydrogen end-uses past those deployed within the Green Hysland project. This involves the evaluation of scenarios for three application areas across defined 2030 and 2050 times:

- Industrial use of hydrogen in areas such as high-temperature heat
- Potential green hydrogen uses in District Heating and Cooling (DHC) systems
- FC-based road transport applications and the relevant infrastructure

These scenarios, built through technical and legislative literature reviews, combined with the knowledge base and research of local project partners Universitat de les Illes Balears (UIB) and Instituto Balear de la Energía (IBE), has provided a comprehensive overview of the scale-up potential of technologies across these three areas. This analysis has shown that hydrogen has considerable opportunity to increase its penetration, from Green Hysland's embryonic activities to a considerable proportion of the energy consumed across each sector. Within transport, hydrogen is expected to play a crucial role in the island's heaviest vehicle fleets (e.g. buses, construction equipment, trucks) and those with high operational requirements (e.g. taxis, airport ground vehicles). In industry, small-scale dedicated hydrogen plants located at production facilities are viable, but a much larger demand could be realised via blending hydrogen into, or full conversion of the natural gas grid whilst also providing auxiliary benefits into hospitality and residential sectors. Hydrogen DHC solutions, due to the incredible energy demand from hotels and increasing numbers of residential apartment buildings, could be an interesting solution for the archipelago to explore. However, due to the region's temperate climate, and lack of existing deployments, it is the least likely are to see development.

This study concludes with a number of key recommendations to encourage the scale-up of hydrogen demand across these sectors. This includes a suite of cross-cutting targeted measures and timelines for local policy makers to accelerate deployment, as well as real-life lessons learned from two European-leading hydrogen regions – Northern Netherlands and Cologne provided by New Energy Coalition and HyCologne respectively.

3 Introduction

The goal of greenhouse gas neutrality cannot be achieved with green electricity alone. Hydrogen is seen as one of the *key energy carriers* to unlocking the next stage of renewables deployment in international economies – enabling further clean energy penetration to reduce emissions in sectors and locations where electrification is not a viable option. One particular location that this is of interest to is islands, which feature a particular set of unique energy challenges due to their specific geographic and climatic conditions, often featuring strained electrical grids and high energy dependencies on imported fossil fuels.

Nevertheless, European hydrogen policy, such as the continent's hydrogen strategy released in 2020, featured little with regards to island-specific policies and strategies – with the world 'island' being mentioned just one time throughout the entire document. The strategy, and actions since its release on a European and national level, however, have placed a strong emphasis on the role of Hydrogen Valleys - areas where hydrogen applications and production are developed simultaneously within a localised ecosystem. Islands, with their novel and isolated markets, are ideal locations to carry out innovation testbeds including hydrogen technologies, as exemplified by the SEAFUEL project. Recognising this, and building on the momentum provided by the EU Clean Energy Islands Initiative, the EU announced its first island-based hydrogen valley, Green Hysland, based on Mallorca, to investigate the potential of hydrogen to help decarbonise remote areas energy systems.

The aim of GREEN HYSLAND is to deploy a Hydrogen ecosystem on the island of Mallorca, by producing green hydrogen from solar energy and delivering it to the end users, such as the island's tourism, transport, industry and energy sectors, including gas grid injection for green heat and power local end-use. The initiative is receiving €10m of funding from the European Commission through the Clean Hydrogen Partnership, with an aim to reduce the CO_2 emissions of Mallorca up to 20,700t per year by the end of the project. The work also extends to providing results and analyses that will assist the development of a European hydrogen market with a blueprint for decarbonisation of island economies, and an operational example of the contribution of H_2 towards the energy transition and the 2050 net zero targets.

The consortium is formed by 30 partners from 11 countries, 9 from the European Union, as well as Chile and Morocco. The project will develop a fully functioning hydrogen (H_2) ecosystem, from the production to the distribution and consumption of, at least, 330 tonnes per year of green H_2. This hydrogen will be used in six different applications, as follows:

- Blended into a portion of the island's natural gas network via an injection point located in Lloseta operated by Redexis.
- A fuel cell that will supply electricity to the maritime station of the Balearic Port.
- Two hydrogen powered CHPs systems to be located in the Iberostar Bahía de Palma hotel, demand and at the Municipal Sports Centre in Lloseta to cover a portion of the respective sites energy demand.
- The integration of 5 hydrogen buses to the EMT city bus fleet of Palma de Mallorca.
- The integration of H_2 vans in the Alfill Logistics vehicle fleet as well as the search for rental car companies to incorporate H_2 vehicles in their rental car fleets.

This purpose of this study is to understand the role that hydrogen is expected to play in the long-term strategy of Mallorca and the wider Balearic Islands. It involves the analysis of three end-uses that are critical to the creation of a hydrogen economy in the Island of Mallorca, predefined by the initial analysis conducted during development of the project:

- Industrial use of hydrogen in areas such as high-temperature heat, particularly with respect to ceramics
- Potential green hydrogen use District Heating and Cooling (DHC) systems – hotels, residential buildings… etc.
- FC-based road transport applications and the relevant infrastructure (including rental fleets, buses, light- and heavy-duty transport)

This study has chosen to undertake a bottom-up approach which involves data acquisition from first hand contact with the relevant stakeholders research developed by third parties. Data has been collected on in collaboration with local partners *(Universitat de les Illes Balears (UIB) and Instituto Balear de la Energía (IBE))* and sourced from publicly available literature – which has been extrapolated and used as the base for simulations in other parts of this work where appropriate. In addition to this, and to develop a quadruple helix understanding of the energy challenges affecting the islands, key demographic indicators have also been utilised.

The final section of this report brings assumptions and estimations over possible future scenarios for the development of hydrogen fuel-cell based applications across 2030, and 2050. These scenarios, are defined by the energy consumption of the island, taking into account population increases[1], in line with recent local energy transition estimates. The forecasts and projections assumed use data from the Spanish National Climate Plan (PNIEC), and Spanish National Hydrogen Strategy, complemented with a large proportion of local data taken from leading authors such as IBESTAT. Although the deployment location of future renewables has not been considered, within this study, the project's upcoming study investigating the scale-up of green hydrogen supply in Mallorca and the Balearic islands (D6.1) will cover this area in detail. Therefore, to realise the 2030 and 2050 scenarios suggested within this report, the continued integration of further renewables within both the local and mainland energy systems will be an important consideration for local policy makers and stakeholders. However, as of yet, hydrogen has not been included within calculations.[2]

[1] The projection of the population (2030) has been made based on data from the Spanish National Institute of Statistics (INE)

[2] When planning the technologies, and the best transport option and route, both the current and the future producers and consumers of hydrogen in the region were taken into account.

4 Hydrogen Overview

The following section is designed to provide an overview of hydrogen production pathways, end-use sectors and critical regional, national, and European energy & hydrogen policy that has been used to develop the assumptions and scenarios used within this report's scale-up analysis.

Production pathways

The most common method of hydrogen production is Steam Methane Reformation otherwise known as 'grey hydrogen'. In this process, natural gas molecules are reacted with oxygen to provide hydrogen, which is captured, and by-product CO_2 which is released directly into the atmosphere. It is a mature, low-cost, and large-scale production method which has historically produced the lowest cost hydrogen – at typically €1-1.50 /kg_{H2}.

Actions are being taken to mitigate the emissions produced from grey hydrogen production pathways by introducing Carbon Capture Utilisation and Storage (CCUS) technologies – transitioning today's SMR based systems to a 'blue' hydrogen production pathway. Blue hydrogen production technologies have received substantial financial and policy support, particularly from countries with access to underground CO_2 storage sites such as those that border the North Sea. This production pathway has long been thought of an ideal transitionary technology to enable low-cost, low-carbon hydrogen with emissions savings of 80-95% (depending on capture and leakage rates). However, the Russian invasion of Ukraine has caused some uncertainty regarding the pathway's long-term market share. Some regions have chosen to completely abandon blue hydrogen plans in an attempt to reduce reliance on Russian natural gas, whilst others with their own natural gas reserves have bolstered plans to increase energy security. As exemplified by recently announced plans by Germany to import up to 10GW of blue hydrogen Norway to increase overall European energy resilience[3].

COLOUR	SOURCE	PRODUCTION TECHNOLOGY	DIRECT CO_2 IMPACT
H_2 Green	Renewable Electricity and Water	Electrolysis	No
H_2 Grey	Natural Gas	Methane reforming	Yes
H_2 Black	Black Coal	Gasification	Yes
H_2 Brown	Brown Coal	Gasification	Yes
H_2 Pink	Nuclear Electricity and Aater	Electrolysis	No
H_2 Blue	Natural Gas or Coal	Methane reforming	No *captured and stored
H_2 Turquoise	Natural Gas	Pyrolysis	Yes
H_2 Yellow	Solar Power and Water	Electrolysis	No
H_2 Orange	Solar Irradiance and Water	Photolysis	No
H_2 Red	Nuclear Heat and Water	Thermolysis	No
H_2 Purple	Nuclear Electricity, Heat and Water	Thermolysis and Electrolysis	No

Source: Own elaboration

FIGURE 1: *THE RAINBOW OF HYDROGEN PRODUCTION GROWS CONSTANTLY. FOR THE PURPOSES OF THIS REPORT, ONLY GREY, BLUE, AND GREEN HYDROGEN WILL BE DISCUSSED.*

[3] Gas Pathways. Germany sets out plainer role for blue hydrogen in transition plan. (2023) Accessed at: https://gaspathways.com/germany-sets-out-plainer-role-for-blue-hydrogen-in-transition-plan-2185#:~:text=Under%20an%20agreement%20reached%20in,hydrogen%2C%20according%20to%20the%20plan.

Whilst blue hydrogen is facing a critical development juncture, green hydrogen – hydrogen produced from renewable sources - is going from strength to strength, particularly regarding electrolysis. Electrolysis technologies, which split water into its constituent atoms (oxygen and hydrogen) by means of an electric current), can produce completely (process) emission-free hydrogen. Innovation in this area has been a key focus of the European hydrogen sector for some time, simultaneously driving increases in efficiency and size to achieve large-scale emission saving across the continent. This has cemented the positions of the two premier electrolysis technologies – alkaline and proton electrolyte membrane (PEM) - each with their own unique advantages and disadvantages. Alkaline electrolysis is the most mature technology type, having been used for well over 100 years and has, until recently, been the go-to option due to its reliability and scale. PEM, due to increased efficiencies and improved response times when powered by intermittent renewables has gained significant momentum. As of 2022, the majority of installed projects feature PEM electrolysers – a change that has materialised in just three years from 2019 when alkaline systems overwhelmingly dominated the market. For more details on hydrogen production pathways, please see the Green Hysland's upcoming deliverable titled 'Study for scaling-up green H2 supply in Mallorca and the Balearic Islands'.

Application pathways

The European hydrogen market is set to be dominated by three hard-to-abate sectors:

Industry

Fossil-based hydrogen has been used as an industrial feedstock globally for decades. Hydrogen production facilities are typically co-located to these applications and feature direct connections via pipeline systems to enable delivery of large volumes that these processes require. Current processes involving hydrogen include:

Ammonia Production – hydrogen reacts with nitrogen via a Haber Bosch process to produce ammonia which is commonly used as a chemical feedstock for fertiliser. Ammonia production is responsible for 36% of global hydrogen demand.

Methanol production – methanol, like ammonia, is primarily used in the production of other products such as plastics, paints, and other chemicals (acetic acid and formaldehyde). It is formed by hydrogenating carbon monoxide and dioxide is responsible for 15% of global hydrogen demand.

FIGURE 2*: AMMONIA PRODUCTION ROAD TANKER (TOP – MGT GLOBAL), AND METHANOL PRODUCTION FACILITY (BOTTOM - LINDE ENGINEERING)*

FIGURE 3*: OIL DISTILLATION TOWER (NES FIRCROFT)*

Refining – Hydrogen is used during the hydrodesulphurisation process to strip sulphur from crude oil - preventing products from releasing harmful sulphur oxides when burned. Hydrogen demand from refineries has consistently increased in line with growing demand for diesel and greater sulphur content regulations, making refineries the largest single hydrogen consumer (42% of global demand).

Iron and Steel Production - Raw iron ore is reacted within the presence of a reducing gas, frequently a blend of natural gas and hydrogen, to create Direct Reduced Iron, or sponge iron, which can then be processed into more refined materials such as wrought iron and steel. This process, as well as minor demand from other activities such as annealing and finishing, make the Iron and steel industry responsible for 6% of global demand.

FIGURE 4*: STEEL BLAST FURNACE (AMERICAN IRON AND STEEL INSTITUTE)*

Other – There are a number of niche applications that make up just 1% of total hydrogen demand currently. This includes hydrogenation of fats and edible oils in the food industry, providing moisture free atmospheres and cooling to produce semi-conductors, and trace element reduction and atmospheric regulation within float glass manufacturing.

In the future, low-carbon hydrogen is also expected to be a crucial feedstock for energy-intensive industrial processes that require high temperature heat. These processes, which include existing areas that already utilise hydrogen as a feedstock such as chemical manufacturing, oil refining, and iron & steel, as well as pulp & paper and cement production, require temperatures in excess of 600 °C which is extremely difficult to achieve via electrification. Therefore, replacement of existing natural gas-dominated feedstocks with an easily combustible low-carbon commodity, such as blue & green hydrogen, is expected to play a significant role – particularly in locations with constrained grids.

Heating

Heating, due to its high energetic demand, reliance on fossil fuel feedstocks, and need for large-scale purpose-built infrastructure, is seen as one of the most difficult sectors to decarbonise. Low-carbon hydrogen, due to its operational similarity to natural gas, can be a key technology to enable the transition of this hard-to-abate sector.

Trial projects piloting concepts and technologies have already shown promise across Europe. The HyDeploy project, based at Keele University's campus in the UK, has successfully trialled blends of up to 20% hydrogen within a natural gas network to heat a total of 130 buildings. These activities have proven the viability of gas grid blending locally, leading the UK's Energy Networks Association to announce that the country's NG grid will be ready for blends of 20% hydrogen by the end of 2023. Whilst in the Netherlands, where new homes have been banned from being connected to the domestic natural gas network, 100% hydrogen heating trials are taking place as part of the HEAVENN project. HEAVENN will deploy a dedicated localised hydrogen grid for a new housing development within the community of Hoogeveen. The hydrogen will be delivered by road initially, before being connected to larger pipeline networks.

Recognising the opportunity that transitioning to a hydrogen heating system possesses, European gas Transmission System Operators (TSOs) have developed a vision document to deploy dedicated, continent-wide hydrogen transmission and distribution infrastructure – the European Hydrogen Backbone (EHB). The strategy sets out how hydrogen can enable a reduction in emissions across sectors by offsetting the use of natural gas whilst maintaining a similar operational framework.

The EHB will utilise a mixture of refurbished natural gas infrastructure and new dedicated pipelines to initially link production hubs to key demand centres (e.g. industrial hubs) before geographically broadening access for heating systems and other end-uses. The plan has seen frequent updates following the release of further climate legislation such as Fit-for-55 and REPowerEU and now features a total of 28 countries and ambitions to deploy a potential 53,000 km of pipelines to meet an annual demand of >1,640 TWh.

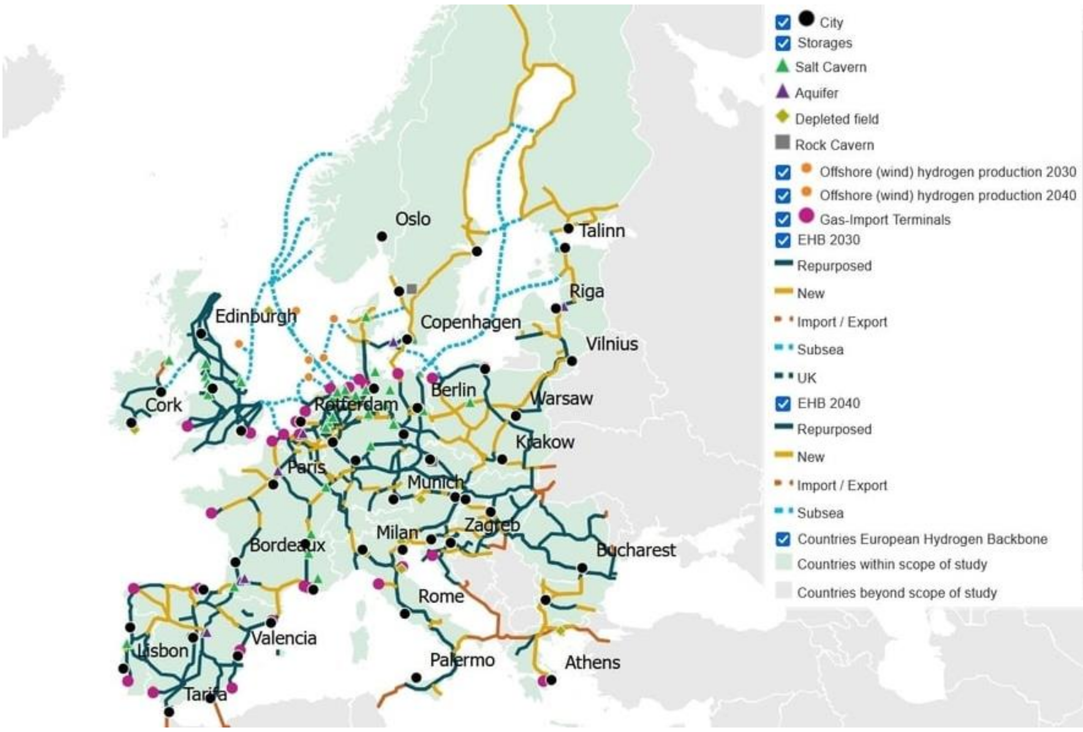

FIGURE 5: *EUROPEAN HYDROGEN BACKBONE (EHB) MAP*

It should be noted, however, that recent reviews of hydrogen-for-heating literature have called into question the viability of these technologies. Rosenow's comparison of 32 studies stated that hydrogen is overwhelmingly predicted to be "less economic, less efficient, and more resource intensive ... with larger environmental impacts" than other low-carbon heating alternatives such as heat pumps. Therefore, it is likely that a hybrid approach, utilising both electrical-based solutions alongside hydrogen heating solutions will be realised in the long-term as electrical grids will struggle to manage with increasing demand from transport (EVs) and heating simultaneously.

Mobility

As the EU's second largest emitter of CO2 – 945.8 Mt_{CO2e} (2018) - transport has been a key focus of decarbonisation policy for decades. During this time, there has been a constant battle between the two-leading low-carbon options - Battery Electric Vehicles (BEV) and Fuel Cell Electric Vehicles (FCEVs) – which has only in the last few years started to unfurl. For the most part, BEVs have and will continue to dominate the passenger vehicle and light duty-market, despite Toyota, Hyundai, and Honda all offering purchasable FC passenger cars. FCEVs, however, have shown more potential within heavy-duty applications due to a number of advantages over BEVS:

- **Advantageous refuelling profiles** that are similar to that of fossil fuel vehicles. Hydrogen trucks and buses can refuel in just 15 minutes, allowing greater operational flexibility.
- **Greater power-weight ratio.** FCEVs offer better performance in more intensive situations such as hilly terrains or when operating with extra amenities such as air conditioning.
- **Greater range** than battery electric vehicles, due to this ratio.
- **Less invasive and costly refuelling infrastructure.** Large scale fleet replacements with BEVs can incur expensive grid connections and cabling upgrades, whereas hydrogen vehicles can be refuelled in conventional forecourt environments.

For these reasons, hydrogen has long been seen as the best option for long-distance heavy-duty trucking. Long charging times and heavy, payload affecting batteries, make BEVs less suited to this application and can severely impact operational business models. Currently, hydrogen heavy-duty vehicles, such as trucks, buses, and other more specialist vehicle types, are only available in small numbers due to small-scale production. However, there are several manufacturers starting to enlarge their production lines ranging from established automobile names like Hyundai and Toyota, to respected hydrogen sector companies such as Cummins, to new players like Hyzon and Nikola. These production lines are predicted to supply Europe with thousands of trucks through to 2030, with the EU's transport commissioner, Adina Vălean, estimating 17% of new trucks in 2030 will be run on hydrogen, equating roughly 60,000 hydrogen lorries[4].

FIGURE 6: *HYUNDAI XCIENT TRUCK (HYUNDAI)*

The need of public authorities to lead by example and decarbonise their transport fleets has also led to an increased interest in hydrogen buses. Fleet operators now frequently recognise the need for a hybrid approach – deploying both batter and hydrogen models simultaneously – to maximise fleet and route efficiencies. In Europe, hydrogen buses have already achieved mainstream success through projects such as JIVE/JIVE2 and H2BUS EUROPE which will roll out hundreds of hydrogen buses over the next decade featuring both single-deck and double-deck models.

Hydrogen, and its various derivative fuels such as methanol and Sustainable Aviation Fuel (SAFs), are also being strongly considered for maritime and aviation applications. Their superior power density and emissions profile, when compared to alternatives such as LNG and other fossil fuel blends, means that hydrogen-based fuels are a suitable long-term, net-zero option for these sectors. Maritime vessels from passenger and car ferries to large methanol-based tankers are already starting to be realised and trialled in standard operational conditions. Whilst, regional hydrogen-electric powered aircraft test-flights have also taken place, such as Zeroavia's 19-seat prototype. Both maritime and aviation will require widespread legislation and standards & code changes to enable large-scale deployment of these technologies, but that so far hasn't put off companies such as Maersk and Airbus deploying considerable resources in these areas. For instance, Maersk, which ordered its first methanol powered vessel in 2021, now has a total of 25 vessels on order with the first being unveiled in September 2023[5], whilst Airbus is hoping to bring a commercial hydrogen-powered aircraft to the market by 2035 as part of its ZEROe development portfolio.

[4] Euractiv. 17% of new trucks in 2030 will run on hydrogen, EU believes. (2021). Accessed at: https://www.euractiv.com/section/energy/news/17-of-new-trucks-in-2030-will-run-on-hydrogen-eu-believes/
[5] CNBC. Shipping giant Maersk unveils world's first vessel using green methanol. (2023). Accessed at: https://www.cnbc.com/2023/09/14/shipping-giant-maersk-unveils-first-vessel-operating-on-green-methanol.html

Hydrogen and energy policy

International and European landscape

The EU has achieved substantial progress decarbonising its electricity grid with renewable energy sources since the introduction of the 'Energy for the future' action plan in 1997 – now accounting for 37.5% of gross electricity consumption across the EU-27 (2021). However, the pace with which economy-wide decarbonisation is being questioned by independent bodies as current strategies will not obtain the 1.5 °C 2050 target set within the Paris Agreement. Electricity only accounts for 23.2%[6] of final energy consumption in the EU, making the total renewable energy consumption across all sectors just 22.2%. Thus, there is a clear need for alternative energy solutions to help enable the penetration of renewables into hard-to-abate sectors such as industry, heating, and mobility, which continue to rely on oil, petroleum, and natural gas to satisfy their energetic demand.

Hydrogen first entered the European Union's energy policy in 2009 as part of the influential Renewable Energy Directive (RED). Since this introduction, hydrogen has slowly gained more traction amongst the European Commission (EC), member states, and energy community resulting in the release of the EU's 'Hydrogen strategy for a climate-neutral Europe' in July 2020. The plan, which focuses largely on scaling up green hydrogen production, employs a phased approach to scaling up domestic electrolysis capacity in which 6GW of electrolysis capacity was targeted by 2024, rising to 40GW by 2030. The document severely lacked policy measures for isolated areas, with the word 'island' only being once mentioned within the whole document. Although, with recent pressure from geopolitical events the need to further accelerate decarbonisation whilst simultaneously addressing energy independency issues, often exhibited by remote communities, has been highlighted.

Acknowledging this, the EU adopted increased climate ambitions in both 2021 and 2023 as part of the Fit-for-55 and REPowerEU packages respectively, which both expanded the role of hydrogen in Europe's future energy system. The Fit-for-55 package – legislation designed to reduce EU emissions by at least 55% by 2030 – introduced an obligation that 35% of industrially used hydrogen across the EU must be renewable by 2030 (since increased as part of RED III) rising to 50% by 2035. To meet these targets, however, large volumes of low-carbon hydrogen will need to be imported, especially into northwest Europe and the industrial hydrogen belt across Belgium, Netherlands, and Germany. Thus, Fit-for-55 also included plans to import 1 Mt of hydrogen to achieve this target, on top of the EU's initial 40GW domestic electrolysis capacity targets. REPowerEU, released after the Russian invasion of Ukraine, built on these targets further. The package, which includes widespread goals for energy efficiency, diversification of energy supplies, and accelerated roll out of renewable energy, also included plans to grow the import of low-carbon hydrogen to 10 Mt over the same time period. This additional supply of hydrogen will also be used to power Europe's transport fleets. The Alternative Fuels Infrastructure (AFI) regulation, published in 2022, necessitates the deployment of hydrogen refueling stations in major cities and at regular intervals along the TEN-T Core Network - a designated network of Europe's most important multimodal transport corridors and nodes that is expected to be fully linked by 2030. This will provide fleet operators with the confidence to invest in hydrogen vehicles knowing that large-scale (refuelling capacity of $1t_{H2}/d$) refuelling infrastructure will be in place by the

[6] Eurostat. Energy statistics – an overview. Accessed at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview#Final_energy_consumption (2022).

end of the decade and help to decarbonise Europe's transport sector – responsible for almost 25% of the GHG emissions.

Meanwhile, across the Atlantic, the US have made a statement of intent to support domestic green hydrogen activities. Following the US Department of Energy's announcement of the 'Hydrogen Shot' – a concerted effort to support production technologies and realise clean hydrogen costs of $1/kg by 2030 – the US released the Inflation Reduction Act (IRA). Included within the IRA are intentions to offer a generous subsidy of $3/kg to green hydrogen producers in an effort to attract equipment suppliers and supply chain companies to stimulate growth in the US as a result of improved business models. Recognising the threat that this posed to the EU electrolysis goals, the EC have announced that they will offer renewable hydrogen producers a fixed premium of up to €4.5/kg_{H2} in order to 'level the playing field' with the US. As part of this announcement the commission also released their renewable hydrogen Delegated Act which defines the conditions for hydrogen, and its derivates, to be classified as Renewable Fuels of Biological Origin, and therefore eligible for subsidy support. This eligibility focuses on three key areas:

Additionality - Concerns regarding the use of renewable electricity to produce hydrogen that could have been used to directly decarbonise the electrical grid, otherwise known as the 'additionality' principle, has been a long-term issue for the hydrogen sector. European energy stakeholders, as a whole, understand the need for renewable energy connected to hydrogen production to be new, and not subverting existing grid renewable electricity. The EC has recognised this requirement and stated, under its new act, that 'a period of 36 months' between new renewable energy installations and the installation infrastructure to produce 'renewable liquid and gaseous transport fuel of non-biological origin' (i.e. hydrogen and other hydrogen-derived fuels) will be applied.

Geography - As part of the act Europe will be split into "bidding zones" which will largely follow national borders. Green hydrogen projects must source renewable energy from the zone they are based in order to be compliant. This can occur via direct linking to renewable sites or Power-Purchase Agreements (PPAs), but projects will also be able to use grid electricity should it meet certain standards. Any bidding zone which has provided >90% of its electricity from renewable energy in the last calendar year, or has an average power production carbon intensity of <64.8 CO_{2eq}/kWh, will be able to class grid-powered hydrogen production as renewable whilst also being considered exempt from additionality requirements. This will enable high load factors in a short timescale to be achieved, lowering the levelized cost of hydrogen produced and instigating a more competitive European hydrogen product.

Time – Following backlash from initial plans to utilise an hourly renewable energy correlation for any renewable hydrogen projects in September 2021, the EC have chosen to apply a middle-ground approach as part of this act. Projects will be required to implement a monthly correlation up until 2030, at which point an hourly approach will takeover, following a successful review in the year previous. The decision has been criticised by organisations such as Global Witness as dirty grid electricity will be used to supplement renewables when the sun doesn't shine, or the wind doesn't blow and has even been referred to as 'a gold standard for greenwashing'.

The long-awaited delegate act is a much-needed step in the right direction for the European hydrogen sector. Despite the rigidity of requirements to become 'renewable' certified, the EU will have successfully eased investors anxiety and unlocked the next phase of renewable hydrogen deployment across the continent by setting intent clearly across these three key areas. This, coupled with recent along with the incoming fixed premium, will help grow European competitiveness against lucrative foreign markets. Further delegated legislation regarding the definition of ‘low-carbon’ hydrogen is expected by the end of 2024, including blue and pink – hydrogen nuclear sources – production pathways. Whilst this has provided hydrogen producers with much needed certainty and financial support, the development of hydrogen demand is now a key area of focus, which the third iteration of the RED, RED III, and ReFuelEU hopes to address. These directives feature increased renewable hydrogen obligations for end-use sectors to drive demand growth, including: 42% of hydrogen in industry by 2030 (now increasing to 60% in 2035), 1% of all transport fuels must be met by RFNBOs by 2030, 1.2% of aviation fuel must be synthetic fuel derived from green hydrogen – equating to 4 million tonnes of hydrogen demand.

As well as dedicated renewables and hydrogen policies, carbon abatement measures have also played an instrumental role in the success of low-carbon technologies. The EU Emissions trading System (ETS) is one of the key economy-wide tools for achieving decarbonisation in a cost-effective manner. The system sets an allowed CO_2 emissions cap that power stations, energy-intensive industries, and civil aviation can emit each calendar year. Depending on a company’s emissions in relation to the cap, which decreases each year, then they will buy or receive allowances – making CO_2 emitting processes more expensive, and low-carbon operations more competitive. This process, however, can harm European competitiveness on a global level by increasing the production prices. To tackle this, the EU Reached Provisional Agreement on Carbon Import Charge, which updated the rules over the development of the Carbon Border Adjustment Mechanism (CBAM) in December 2022. The CBAM will require importers to the EU of covered carbon-intensive products to pay a charge for the carbon embedded in such products identical to the charge imposed on EU producers under the EU ETS. CBAM entered operation from October 1, 2023, and is subject to a transition period of nine years starting in 2026. This “carbon tariff” aims to protect European companies from being weakened by cheaper, more polluting products from elsewhere, and these CBAM certificates will mirror the price of EU ETS allowances and must be compatible with the EU’s World Trade Organization (WTO). It is worth noting that the ETS and other carbon tax schemes can also disproportionately affect products and residents from remote communities, such as the Baleares, that overwhelmingly rely on imported fossil fuel feedstocks to meet their energy demands. The lack of an alternative energy source in these areas can be detrimental if these processes then fail to receive subsidies to cover these extra costs.

Spanish and Regional context

Spain's overarching, legally binding climate target is to achieve net-zero Greenhouse Gas (GHG) emissions by 2050. Currently, however, Spain's final energy mix still features a high reliance on fossil fuels – 25% and 33% met by oil and natural gas respectively (2021), with 69% of their energy demand being imported (2021). As such, the introduction of recent climate legislation on a European level is expected to have a significant effect on the Spanish energy landscape, particularly RePowerEU, as Spain's dependence on Russian oil and gas sat at 10% and 2% respectively[7,8].

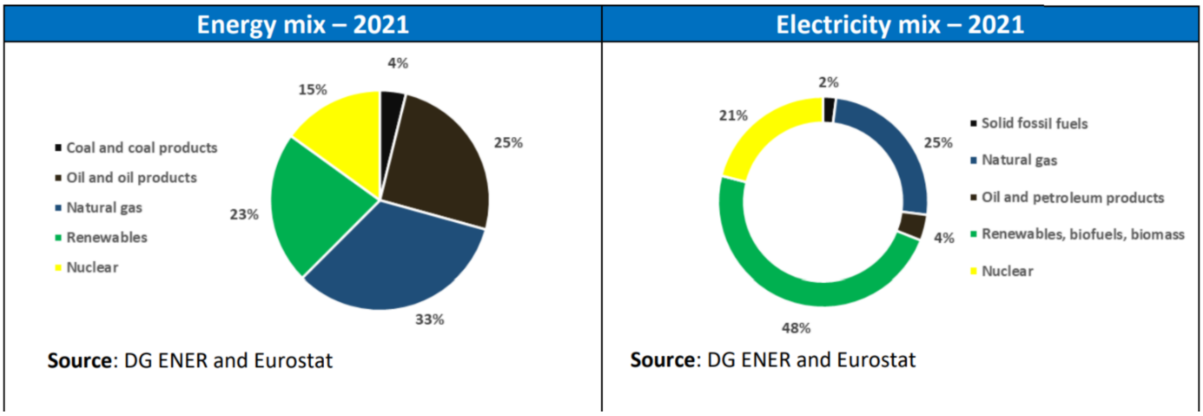

FIGURE 7: *SPAIN'S FINAL ENERGY AND ELECTRICITY MIX 2021*

Following EU law, the Spanish government were required to develop their National Energy and Climate plan (NECP), which outlines national climate and energy targets from 2021-2050, with suite of goals to be achieved by 2030. Many of these 2030 targets were more ambitious than those outlined by the EU at the time, prior to the revision of the European Green Deal in September 2020[8], including:

- 23% reduction in greenhouse gas (GHG) emissions compared to 1990 (since increased to 32% in June 2023)
- 42% share of renewables in energy end-use (Since increased to 48% in June 2023)
- 39.5% improvement in energy efficiency
- 74% share of renewable energy in electricity generation - 100% by 2050, and 97% renewable energy in total energy mix (2030 target has since been increased to 81% in June 2023).

However, despite Spain's ambitious targets, the rate of decarbonisation required to achieve its 2030 GHG emission reduction targets are four times faster than its current rate, and required even greater acceleration to achieve net-zero by 2050. To achieve these goals, it will require massive development of renewable energy and hydrogen alongside energy efficiency, electrification[9]. Measures to optimise the use of Spain's impressive renewable resources, particularly solar and wind. In 2022, Spain had an installed renewable energy capacity of >69GW, with wind power accounting for 40% and solar photovoltaic accounting for 27% of this total. Within the NECP, Spain targets to increase wind power

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[7] European Commission. SPAIN Energy Snapshot. Available at: https://energy.ec.europa.eu/system/files/2022-12/ES%202022%20Energy%20Snapshot_rev.pdf (2022)
[8] Climate Scorecard. As Part of the EU, Spain Has Climate Target by 2030. Available at: https://www.climatescorecard.org/2021/07/south-africa-aspires-to-be-carbon-neutral-by-2050-2/ (2021)
[9] International Energy Agency. Spain 2021. Available at: https://www.iea.org/reports/spain-2021 (2021)

to 50GW, solar to 39GW and hydropower to 14GW by 2030. This will take the installed renewable energy capacity to over 120GW, double what it was in 2020[10].

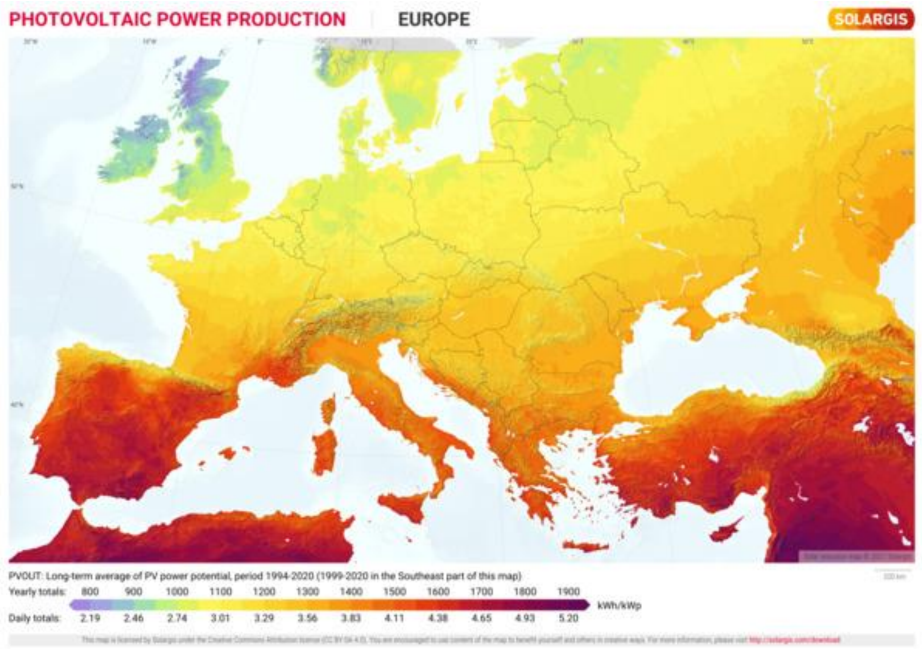

FIGURE 8: *PHOTOVOLTAIC POWER POTENTIAL ACROSS EUROPE*[11]

Expansion of renewable resources to this scale will give Spain excess capacity that is not able to be captured and store in the grid, thus leading to curtailment and constraint. This phenomenon is already occurring in readily Spain, last May renewable energy generation exceeded 100% if the country's demand for nine hours during May 2023[11]. Therefore, to ensure capture and storage of this curtailed energy, it will need converting to an energy vector such as hydrogen. Spain has recognised the role that hydrogen will play its net-zero objectives and hopes to utilise its well-established gas storage and transport system, to propel its production into a major domestic industry with the potential to even exporting to cross-boarders.

Approved in early October 2020, the Spanish National Hydrogen plan (NHP) aims to imminently boost the country's clean hydrogen production with an investment which totals €8.9bn through to 2030, to which Spain have recently announced an additional €1.6bn of support. To realise this production boost, the hydrogen roadmap includes targets to deploy 300-600 MW of electrolysis capacity by 2024, growing exponentially to 4GW by 2030, with a long-term view to build enough infrastructure to become a major European hydrogen player. However, Spain is considering increasing this 4GW target to 11GW by 2030[12] as it already has an infrastructure pipeline to support a green hydrogen capacity of 15.5GW in 2023[13]. The NHP features a total of 60 measures to be undertaken, split into four main

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[10] ECEE. INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN 2021-2030. Available at: https://energy.ec.europa.eu/system/files/2020-06/es_final_necp_main_en_0.pdf (2020)

[11] Renew Economy. Spanish renewable production exceeds 100 pct of country's demand for 9 hours. Available at: https://reneweconomy.com.au/spanish-renewable-production-exceeds-100-pct-of-demand-for-9-hours/ (2023)

[12] HydrogenInsight. Spain could almost triple its 2030 green hydrogen goal to 11GW in new climate strategy. (2023). Accessed at: https://www.hydrogeninsight.com/production/spain-could-almost-triple-its-2030-green-hydrogen-goal-to-11gw-in-new-climate-strategy/2-1-1476351

[13] Renewable Energy World. Spain plans to lead Europe's green hydrogen push. Here's how. Available at: https://www.renewableenergyworld.com/solar/spain-plans-to-lead-europes-green-hydrogen-push-heres-how/#gref (2023)

categories: Regulatory Instruments; Sectorial Instruments; Cross-Cutting Instruments and Boosting R&D.

Spain has also recognised the role that hydrogen will have to realising greater penetration of renewables into its own hard-to-abate sectors. In the transport sector, the government is focused on deploying hydrogen technologies where electrification is not deemed to be the most efficient solution, such as on public transport, construction, maritime and aviation, rather than smaller passenger vehicles. Therefore, the hydrogen roadmap includes targets for the deployment of at least 150 hydrogen buses; 5,000 FCEVs and two train lines (operating on the peripheries of the country) all operational by 2030[14]. To support use of hydrogen as a vehicle fuel, Spain will implement a network with a minimum of 100 renewable hydrogen stations and green hydrogen-powered handling machinery at the main five ports and airports.

Alongside mobility, Spain has positioned green hydrogen for industry as its principal end-use focus. This can be seen through the NHP's commitment to replace 25% of industrially consumed hydrogen (e.g., oil refineries, fertilisers, chemical etc.) with its zero-carbon alternative. Whilst one of the most ambition national end-use targets when it was announced in 2020, these ambitions will have to increase significantly to match new European legislation, as outlined above. By focusing on the industrial sector, Spain is hoping to create a secure and reliable baseload demand for their renewable hydrogen activity. To aid this development, Spain is taking an active role in the development of its domestic hydrogen sector, already having part-funded three hydrogen valley deployments in various stages of their lifecycle development, including Green Hysland, Basque Hydrogen Corridor (BH2C), and Green Crane. These hydrogen valleys will boost the hydrogen value and supply chains by creating an integrated ecosystem of hydrogen applications to ensure supply, distribution and use of green hydrogen in multiple different sectors. Data and key learnings from pilot projects like these are already being used to help guide and shape the direction of future hydrogen deployments internationally, as can be seen through plans such as H2MED. H2MED is a large-scale infrastructure plan to deploy 700km of dedicated hydrogen pipelines to transport 2 million metric tons of low-cost hydrogen produced in Spain and Portugal to industrial end-users primarily in France and Germany by 2030[15]. This just one of Spain's headline-catching activities the country is undertaking to solidify themselves as Europe's hydrogen production hub, with other activities such as pipeline connections with Italy and Morocco[16] and hydrogen shipping to Rotterdam[17], Netherlands, also being investigated.

[14] INTERNATIONAL TRADE ADMINISTRATION. SPAIN RENEWABLE HYDROGEN ROADMAP. Available at: https://www.trade.gov/market-intelligence/spain-renewable-hydrogen-roadmap (2020)

[15] En:former. H2MED pipelines to supply Europe with hydrogen. (2023). Accessed at: https://www.en-former.com/en/h2med-pipelines-to-supply-europe-with-hydrogen/

[16] FuelCellWorks. Spain will connect with Italy and Morocco to export green hydrogen, but it will not do so with Algeria. (2023). Accessed at: https://fuelcellsworks.com/news/spain-will-connect-with-italy-and-morocco-to-export-green-hydrogen-but-it-will-not-do-so-with-algeria/

[17] Reuters. Spain's Cepsa signs green hydorgen shipping deal with Rotterdam port. (2022). Accessed at: https://www.reuters.com/business/energy/spains-cepsa-signs-green-hydrogen-shipping-deal-with-rotterdam-port-ft-2022-10-11/

FIGURE 9*: FIGURE 9: H2MED PIPELINE PLANS AND HOW THEY INTERLINK WITH EARMARKED SPANISH TRANSMISSION AND STORAGE INFRASTRUCTURE (EN:FORMER)*

However, whilst the NECP, NHP, and Spain's overarching hydrogen activities feature influential policies and clarity for the sectoral development of mainland Spain, they provide little in terms of the role of island-based regions. These locations often exhibit low amounts of industry and rely heavily on tourism to drive their economies. Additionally, they have higher carbon intensities and import dependencies relating to both electricity and heat producing fuels compared to mainland regions and are therefore at risk of being left behind by mainland-focused energy policy. Despite this, these regions (Baleares, Canaries, etc.) are well positioned to deploy innovative energy transition solutions[18]. Their strong renewable resources, both onshore and offshore, and isolatable energy infrastructure can provide an ideal testbed for hydrogen and other technologies, whilst initial deployments will lead to greater emissions savings in these currently carbon rich locations.

[18] Farras, Machado, Flynn, Williamson. 2023. Policy supports for the deployment of solar fuels: islands as test-beds for a rapid green transition.

Balearic level

Global warming-derived effects disproportionately affect island-based communities due to their fragile ecosystems; this is particularly true for islands based within the Mediterranean insular regions which are seen as 'Climate Change Hotspots'. Rises in temperature and sea level, and the knock-on effects of these phenomena, such as an increase in droughts brought on by a reduction of average precipitation, or an overall reduction in the environmental quality of the archipelago (Enríquez & Bujosa Bestard, 2020), put Mallorca's tourism-focused economy at extreme risk (C. Torres et al., 2021). However, despite this risk status, the Balearics, based roughly 200km off the west cost of the Spanish peninsular, import the majority of their energy consumption in the form of polluting fossil fuels, exacerbating climate issues whilst simultaneously raising questions regarding the islands' long-term energy security. Therefore, recognising this, the local Balearic government has placed an emphasis on the introduction of policies that have a positive environmental and economic impact for the islands, backed up by commitments to wider international decarbonisation strategies, such as UNEP Mediterranean Strategy for Sustainable Development 2016-2025.

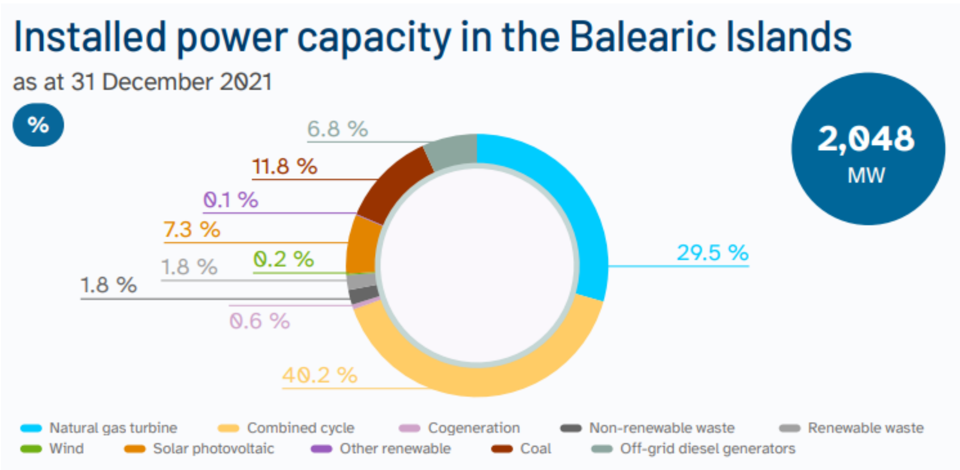

FIGURE 10: *POWER GENERATION INFRASTRUCTURE BY SOURCE IN THE BALEARIC ISLANDS – 2021 (RED ÉLECTRICA)*

In terms of electricity generation, the Balearics, and more specifically Mallorca, has already undertaken somewhat of a transition in their energy habits to reduce their GHG emission. First decreasing their reliance on coal-fired power plants[19] in favour of combined cycle power plants and natural gas turbines from 2019-2020 whilst simultaneously increasing renewable deployments, particularly solar photovoltaics (PV). Installed PV capacity has now reached 220 MW across the Balearics, with 86% being based on the island of Mallorca. However, due to a lack of available land-space across Mallorca in combination with difficulties harmonising intermittent renewables with the local grid, an ever-increasing proportion of PV deployments are dedicated for self-consumption - 54.9MW as of 2022 (SolarInfo). This matches an increasing upwards trend in self-consumption seen across Spain as annual deployments grew by >2.5GW in the country according to Spanish Solar Photovoltaic Association (APPA).

[19] Red Eléctrica de Espana (REE). Electricity production on the Balearic Islands with coal fell by 90% while renewable energy reached its highest share in the Islands' generation mix. Accessed at: https://www.ree.es/sites/default/files/07_SALA_PRENSA/Documentos/2021/20210312_PR_BalearicIslands_ENGW.pdf (2021).

Despite increases in local deployment, renewables were responsible for just 6.7% of the electricity generated across the Baleares in 2020, despite a nearly 20% drop in energy demand caused by the COVID-19 pandemic. The same can be seen on an island-level in Mallorca where, in spite of increased renewables deployment across the past two years, renewables were responsible for just 7.25% of electricity generated in 2022 due to struggles to match increasing and seasonal energy demands. This also has a knock-on effect for the cost of electricity produced on the islands – the additional processes associated with import, processing, storing, and transformation of island-based electricity production from fossil sources are significant.

In 2011, for instance, the cost of generating 1MWh$_e$ on the peninsular in comparison to the Baleares was €51 to €141, and whilst recently this cost gap has narrowed, it still remains roughly 50% more costly to produce electricity on the islands (June 2021). This cost difference, however, is not felt by the consumer, and is instead assumed by the state (nationally).

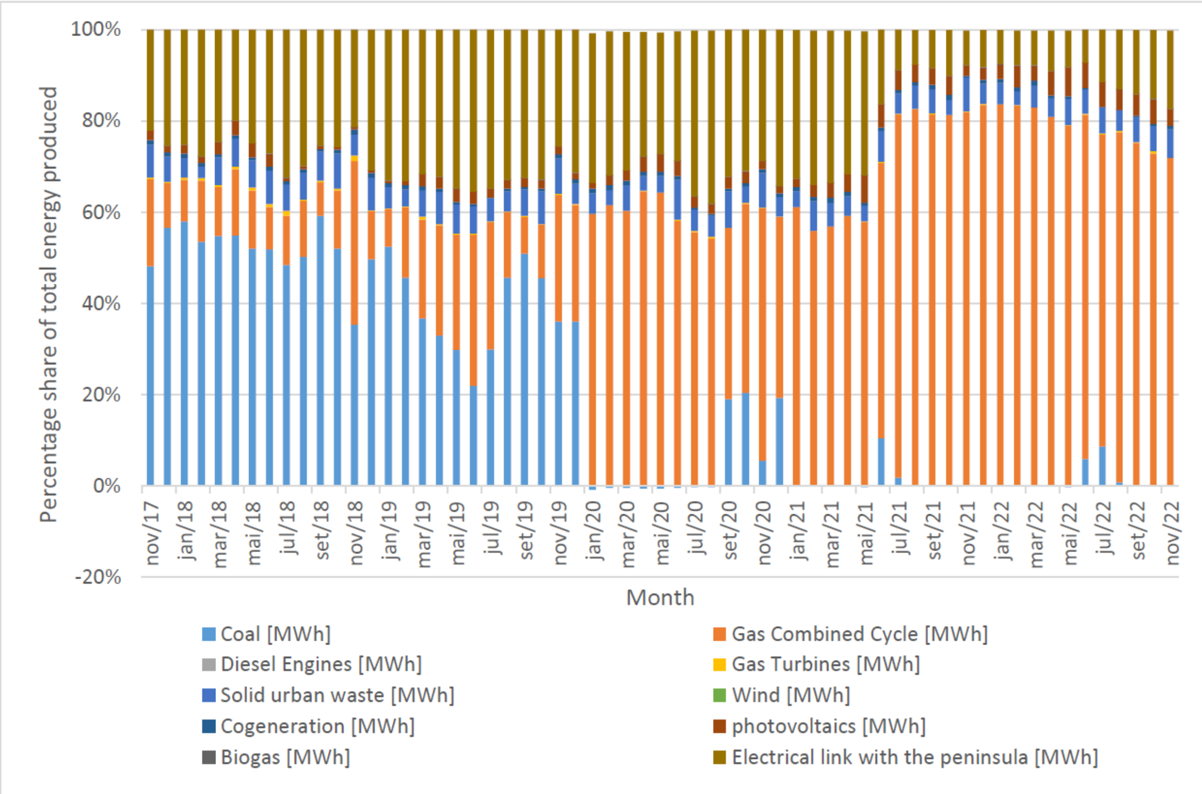

FIGURE 9 - PERCENTAGES OF TOTAL ENERGY PRODUCED IN MALLORCA IN EACH MONTH. (SOURCE: UIB ELABORATION BASED ON DATA FROM INSTITUT D'ESTADÍSTICA DE LES ILLES BALEARS, 2022)

One way the Balearics and Spanish government have found to reduce this cost deficit, whilst simultaneously improving the emissions profile of the local Balearic grid, is through greater interconnective infrastructure between the peninsular and the islands. For instance, the Rómulo project developed the first electrical interconnection between the Spanish peninsula and Baleares – a €420m investment which has been fully operational since 2012 and now provides roughly 30% of all energy consumption across the islands.

This significantly reduced the islands demand for fossil fuels from the electricity sector and reduced emissions by 285,000t_{CO2} in its first year. Recognising the success of this project, the Spanish government approved a second link between the islands and the peninsular in June 2022 as part of a

wider plan to increase the robustness of the Balearic's grids with a total investment of over €1bn due to be completed by 2026. This is expected to raise the contribution of mainland energy production to 65% of the islands' consumption. This cost could also be decreased by finding ways to utilise curtailed and constrained electricity, such as energy vectors like hydrogen, but there is currently no strategy to deal with this on a local level.

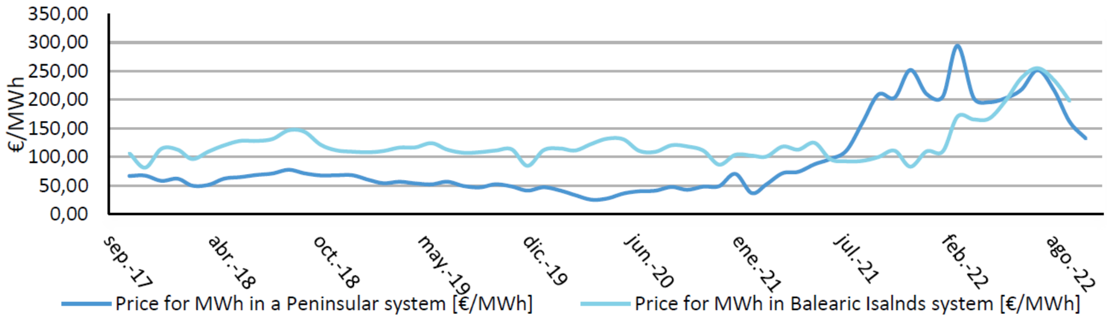

FIGURE 11: *PRICE FOR MWH IN PENINSULAR SYSTEM VS. BALEARIC ISLANDS SYSTEM INCLUDING COST EQUALISATION. SOURCE: (OWN ELABORATION BASED ON: INSTITUT D'ESTADÍSTICA DE LES ILLES BALEARS (GOIB), 2022),(RED ELÉCTRICA, 2023),(COMISIÓN NACIONAL DE LOS MERCADOS Y LA COMPETENCIA)*

As well as greater interconnectivity with the peninsular, the Baleares has defined quantitative local decarbonisation targets within Law 10/2019 to reduce emissions. The 'Climate change and Energy Transition' law establishes economy-wide goals in four key areas – emission reduction, energy efficiency, penetration of renewable energy, and energy dependency – with sub-targets for key sectors such as energy generation and transport, which generate >80% of local emissions. This includes objectives for 30% of the archipelago's rental fleets to be made up by zero-emission vehicles by 2035, 1,000 free access recharging points to be installed by 2025, no new coal or diesel power generation from 2025 and no fossil fuels by 2040, and all newly constructed buildings to have near-zero energy consumption (Govers de les Illes Balears, 2019 n.d.). These plans currently do not feature any targets relating to the production or use of low-carbon hydrogen.

Objectives	2030	2050
Emission reductions	40%	90%
Reduction of primary energy consumption	26%	40%
Penetration of renewable energies	35%	100%*

*: 70 % of produced in the territory.

TABLE 1: *OBJECTIVES OF THE BALEARIC ISLANDS IN THE FIGHT AGAINST CLIMATE CHANGE AND PROMOTE THE ENERGY TRANSITION WITHIN THE FRAMEWORK OF LAW 10/2019*

Mallorca as an island heavily reliant on tourism due to its outstanding natural beauty and climate temperament, is dedicated to realising an accelerated deployment of low-carbon technologies to ensure the longevity of this sector whilst improving the quality of life of its residents. Hydrogen, as one of these low-carbon technologies, has the opportunity to provide benefits to tourists and residents alike, by enhancing the sustainability of both local and tourism activities, whilst improving air quality, noise pollution and having a knock-on effect in other areas such as water quality and health. Furthermore, local hydrogen production and use provides an opportunity to reverse the high energy dependency trends seen across the Balearic Islands by replacing demand for imported natural gas, an issue which culminated in the implementation of a nation-wide energy savings plan in the winter of 2022[20].

Mallorca, however, unlike the majority of Europe's islands, possesses a considerable strategic advantage that can help to accelerate the introduction of hydrogen locally – a natural gas grid. This grid, provides 13 of Mallorca's municipalities and 125,000 users (Economía de Mallorca, 2020) (Miquela Valls, 2020) with access to natural gas and, like the region's electricity system, is connected to the mainland via Eivissa (single directionality from peninsular to Baleares), with a planned connection to Menorca to be completed shortly. This network is made from a mixture of carbon steel and polyethylene materials, and features pipelines ranging up to 16 inches wide, running at pressures of typically around 80 bar and achieving natural gas flow rates up to 390,000 Nm^3/h depending on the route. Currently this network does not allow for the injection of hydrogen, but a desire to increase hydrogen blending limits within Spain, as has been discussed by the HyDeal project, and the local authority's acceptance of a trial on Mallorca within Green Hysland to investigate hydrogen/natural gas blending shows this could be a viable long-term end-user for hydrogen.

Currently, the island's experience with hydrogen is low due to a lack of 'conventional' hydrogen industries and applications, but through the Green Hysland project and its activities, Mallorca is increasing its local hydrogen knowhow exponentially. Production and demand of hydrogen, due to its local suitability and potential benefits, are expected to significantly increase in the short-to-medium-term due to increasing interest from stakeholders across crucial sectors as well as policy and decision makers.

The following section of this study has therefore undertaken a sectoral mapping of the potential to scale-up hydrogen end-use activities on Mallorca, with a particular focus on fuel cells, to illustrate the opportunity for hydrogen technologies across the value chain. This will be a vital contribution to the knowledge base for the development and expansion of a local hydrogen economy built around reliable and cost-effective infrastructure.

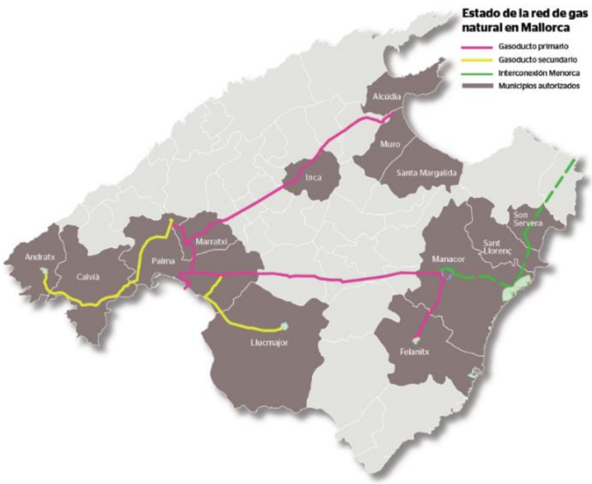

FIGURE 12: *MALLORCA'S NATURAL GAS NETWORK – ULTIMA HORA*

[20] https://www.mallorcadiario.com/acuerdo-consejo-ministros-limitacion-temperatura-aire-acondicionado-calefaccion

5 Scale up Scenarios

Following the Green Hysland project's deployment activities, hydrogen demand is expected to continue to grow across the island of Mallorca and wider Baleares. The three end-use areas discussed within this report – industry, DHC, and road-based transport – will be critical to ensuring this increase in demand. In this section, the level of this anticipated growth will be hypothesised across these three different areas. It is assumed that:

- **By 2025** - no applications external to the Green Hysland's activities will yet be realised on the island of Mallorca due to the fledgling nature of the island's hydrogen sector.
- **By 2030** – the project's learnings will have suitably disseminated across the island of Mallorca and the first activities external to Green Hysland will be starting to be realised.
- **By 2050** – the local hydrogen sector will have reached maturity, allowing widespread deployment of hydrogen technologies where appropriate.

The most applicable deployment opportunity for each area in 2030 will be assessed in the following section, as well as the potential market share hydrogen could achieve in their respective sectors by mid-century. The ambition of these opportunities has been developed based on an understanding of the local, national, and European policy, as well as lessons learned from other hydrogen projects and regions, such as those discussed from Cologne and the Northern Netherlands (pg. 43).

Study Area: Industrial Opportunity

Conventionally, industrial off-takers are seen as the primary driver to initialise low-carbon hydrogen development across Europe – due to the opportunity to replace existing feedstocks and high-temperature heat fuels with less emitting variants. However, as a region that is heavily reliant on tourism – responsible for 30% of the islands' GDP in 2012 (L. Alomar y M. del M. Ribas, 2013) – the region exhibits very little conventional industry. On an energy-basis, transport is the most energy intensive sector, accounting for 58% of total demand, followed by the domestic and service sectors which are collectively responsible for 33% of demand. Whereas the primary and industrial sectors account for less than 5% of final energy consumption, compared to 29% on a national level (2019[21]). Although the industrial sector of the Balearics is small on a national-scale, largely due to additional costs of exporting making products uncompetitive on the peninsular, these activities still play an influential role on a local level, particularly within Menorca, the most industrialised of the islands.

[21] IEA. Spain 2021 Energy Policy Review. Available at: https://iea.blob.core.windows.net/assets/2f405ae0-4617-4e16-884c-7956d1945f64/Spain2021.pdf (2021).

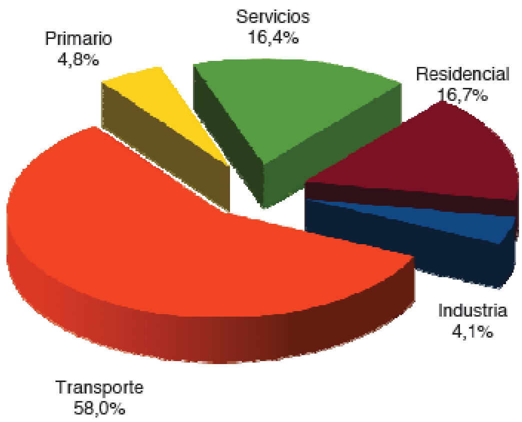

FIGURE 13: *FINAL ENERGY CONSUMPTION BY SECTOR. SOURCE:(GOIB, 2015; 2010 DATA)*

Mallorca has seen a gradual de-industrialisation of its economy since the 1950s, largely in favour of tourism with only a few applications remaining locally. Nevertheless, the industrial applications that are present on the island, ceramics and potentially cement production, dependent on CEMEX's ambitions to reestablish full operation at their Lloseta facility, are well-suited to hydrogen.

Ceramics is an industry of national importance in Spain, with a total turnover of over €5.5bn in Spain in 2022 – 16.2% higher than previous year-on-year figures despite a fall in sales volumes caused by the energy crisis[22]. Decarbonisation of ceramic production, therefore, is critical to maintaining the country's competitiveness in the global marketplace. A number of high-profile stakeholders are already investigating the efficacy of utilising green hydrogen to supply high-temperature heat for these processes. For example, British petroleum is working alongside the Spanish Manufacturing Associations of both Ceramics, Tiles and Pavements (ASCER), and Frits, Enamels, and Ceramic Colours (ANFFECC)[23], to transform the Castellón ceramic cluster into a clean energy hub by deploying renewables in combination with electrolysis to meet the location's high thermal requirements. These activities will be key to understanding the efficacy of hydrogen in non-conventional high-temperature heat processes such as ceramic production, and particularly its effect on the chemical processes responsible for ceramic rigidity and coloration.

Mallorca's ceramic sector primarily focuses on the production of bricks, tiles, and other building materials which are currently overwhelmingly supplied energy by natural gas. These sites, which have only recently switched from oil and solid fuel fired heat production due to energy security and emissions concerns, are likely to be interested to switch to alternative solutions due to rises in natural gas costs and further emissions anxiety. Local stakeholders, who are over ten times smaller than the leading ceramics producer in Spain, are already transitioning away from standardised products to locally specialised analogues (e.g. for listed and unique buildings), due to a lack of ability to compete with cheaper, imported, mass-produced alternatives. For example, in 2014, 7 factories were present on Mallorca in the regions of Vilafranca, Manacor, Felanitx and Campos, or Llevant and Migjorn but

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[22] Ceramic World-Web. Soaring gas prices hold back the Spanish tile industry. Accessed at: https://ceramicworldweb.com/en/news/soaring-gas-prices-hold-back-spanish-tile-industry (2023).

[23] Hydrogen Central. bp Promotes The Decarbonization of The Ceramic Sector in Spain with The Help of Hydrogen Along with ASCER and ANFFECC. Accessed at: https://hydrogen-central.com/bp-decarbonization-ceramic-sector-spain-hydrogen-ascer-anffecc/ (2022).

due to price stagnation locally compared to national decreases – €0.32-€0.33 compared in €0.26-€0.27 in 2018 – just four tile factories remained at full capacity as of 2020. Therefore, with premiums already expected on these local products, the potential short-term cost-increase of deploying hydrogen technologies will not impact the competitiveness of these products in the same way.

Mallorca thus represents an ideal replication location for these sorts of activities due to its highly regionalised industrial sector. However, a lack of total industry on Mallorca at scale, however, limits the number of initial hydrogen deployments to a distinct number of geographically disparate locations. These off-takers would require electrolysis deployments in the region of 1–10 MW individually, unlike the potentially GW-scale deployments seen in other industrial regions across mainland Europe. Whilst the integration of these technologies within Mallorca's less modernised processes are also likely to cause difficulties.

Name	Web	Address	Combustible
Tejar Castor Balear	tejarbalear.net	carretera Palma-Manacor KM 41 - Petra (07520)	Non available
Tejar Bandris	tejarbandris.com	Camino Bandrís s/n | 07500 Manacor – Mallorca – España	Wood
Teulera Can Benito	canbenito.com	Carrer des Palmer 07630 Campos, Islas Baleares	Wood
Huguet Rajoles Hidràuliques S.L.	huguetmallorca.com	Cami Vell de Ciutat,33 07630 Campos Illes Balears	Non available
Ladrillerías Malloquinas	ladrillerias.es	Carretera Felanitx-Petra km 1, 07200- Felanitx- Mallorca.	Natural gas (Ladrillerías mallorquinas, 2022)
Tejar Miquel	tejarmiquel.com	Plaça de Primo de Rivera, 1, 07500 Manacor, Illes Balears	Non available

TABLE 2 : *NON-EXHAUSTIVE LIST OF CERAMIC FACTORIES OPERATIONAL WITHIN MALLORCA (DATA COMPILED VIA DIRECT UIB RESEARCH)*

As well as Ceramics, Mallorca has historically been home to cement production via CEMEX's production site in Lloseta. The plant, which had formally shutdown in January 2019, has continued to be maintained by CEMEX in order to preserve operability should a viable business case allow the re-establishment of production and prevent decommissioning. In March 2021, CEMEX formally announced it had informed the Environmental Commission of the Balearic Islands (CMAIB) of their intention to resume production at the facility which began in May[24] of the same year, although it is unclear at what scale. Similar to the ceramics industry, this plant will now be supplying specialised products designed for the local market, particularly focused on low-carbon production methods. Notably, in 2019 at its Alicante Cement Plant, CEMEX successfully trialled the use of hydrogen injection technologies as a way to improve the efficiency of their existing cement kiln fuel mix by behaving as a combustion catalyst. The technology significantly reduced CO_2 emissions within CEMEX's overall processes and was installed at all its European sites in 2020[25]. Whilst it is unclear whether this technology has already been installed in Llosetta when the plant was shutdown, it is highly likely that the production site could make use of hydrogen in a similar way in the future.

[24] GlobalCement. Cemex Espana reopens Lloseta cement plant. Accessed at: https://www.globalcement.com/news/item/12350-cemex-espana-reopens-lloseta-cement-plant (2021).
[25] CEMEX. CEMEX successfully deploys hydrogen-based ground-breaking technology. Accessed at: https://www.cemex.com/w/cemex-successfully-deploys-hydrogen-based-ground-breaking-technology#:~:text=The%20company%20leads%20the%20cement,technology%20throughout%20its%20global%20operations. (2021).

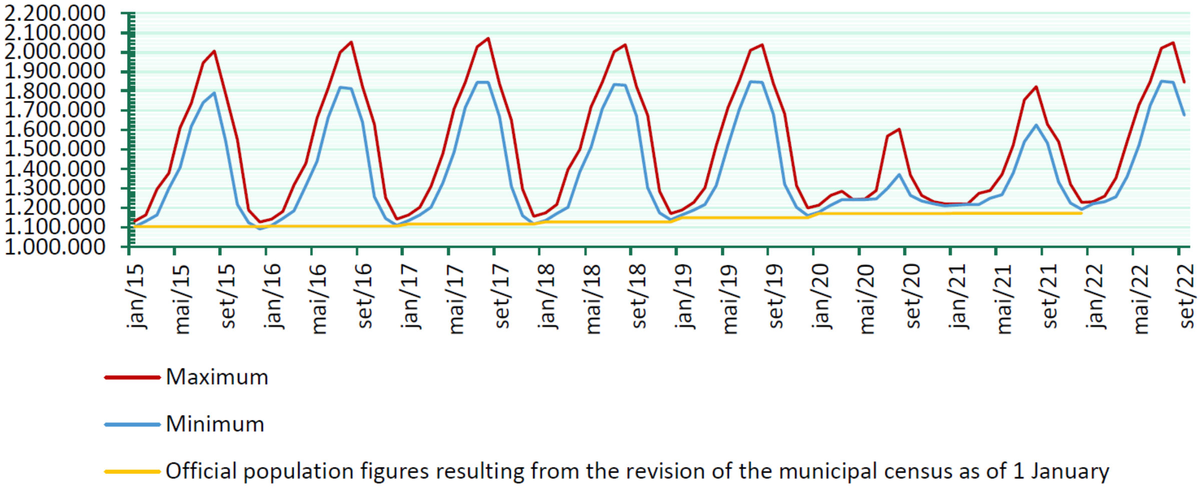

FIGURE 14*: MINIMUM AND MAXIMUM VALUES OF THE MONTHLY HUMAN PRESSURE INDICATOR, AND OFFICIAL FIGURES OF THE MUNICIPAL CENSUS ON 1 JANUARY OF EACH YEAR FOR THE BALEARIC ISLANDS. (INE, 2022; INSTITUT D'ESTADÍSTICA DE LES ILLES BALEARS, 2022)*

Aside from conventional industrial areas, Mallorca, due to the scale of its tourism sector, also operates services on an industrial scale. The hospitality sector requires a nearly constant supply of energy throughout the peak season to deal the influx of visitors present on the island – 14.6 million per year (avg. 2016-2019 figures), 2.09 million tourists per month. This has a substantial seasonal effect on the energy landscape of Mallorca as the population of the island swells during this period by an average 50.62% (2015-2019) but can achieve rates as high as 75.14%. Whilst this increased population is typically based around cities and tourist districts, a larger proportion of visitors are choosing to stay in geographically disparate locations, putting an increased strain on the energy landscape of the island – as is exemplified by Ibestat's Human Pressure Index (HPI), a parameter which details the demographic burden of a number of factors, including tourism, on the residential population of the Balearics.

As well as tourist accommodation, the region's hospitals require considerable amounts of energy too - constant air conditioning to keep patients comfortable, large hot water requirements for laundry purposes and sterilisation, and considerable fuel supply to run their vehicle fleets (ambulances etc.). Of Mallorca's four hospitals, three have already taken considerable steps to reduce the emissions of their facilities. The Regional Hospital of Inca, and the Hospital of Manacor have PV arrays on their premises, whilst Hospital Universitario Son Llàtzer has gone a step further and deployed a trigeneration system alongside renewables to supply 50% of its hot energy demand, and 40% of its cold energy demand on-site, whilst reducing overall electricity consumption by 55%. These energy-intensive facilities could be further decarbonised directly via the use of district heating systems (as described in section 0), or indirectly via decarbonisation of the natural gas grid, as is being investigated for the first time locally within Green Hysland's activities. Further blends of hydrogen into the grid, past the project's initial 2% trial, could mitigate natural gas usage and lead to a reduction on the mainland for imported natural gas, helping the Balearics to achieve two of their major energy transition targets.

Name	Address	Postal Code	Town	Island	Sector of the Island	Annual consumption electricity	Annual photovoltaic energy
Hospital Comarcal de Inca	Carretera Carretera Vieja de Llubí, s/n	7300	Inca	Mallorca	Tramuntana	6.100 MWh/year(Pep Córcoles, 2017)	311,1 MWh/year (Consejería de Salud y Consumo, 2020). Instalated Photovoltaic Power: 225kW
Hospital de Manacor	Carretera Carretera Manacor Alcudia, s/n	7500	Manacor	Mallorca	Llevant	5.145 MWh/year("El Hospital de Manacor Ahorrará 100.000 Euros Con Las Placas Solares Del Parking," 2022)	1.029 MWh("El Hospital de Manacor Ahorrará 100.000 Euros Con Las Placas Solares Del Parking," 2022)
Hospital Universitario Son Espases	Carretera Carretera de Valldemossa, 79	7210	Palma (Ponent)	Mallorca	Ponent		
Hospital Universitario Son Llàtzer	Carretera Carretera de Manacor, Km 4	7198	Palma (Migjorn)	Mallorca	Migjorn	11.878,8 MWh(Sala de prensa, 2018)	712,7 MWh/year(Sala de prensa, 2018)
Centre Penitenciari de Mallorca	Carretera de Sóller, 1	07009	Palma (Ponent)	Mallorca	Ponent	638 MWh/year (lighting)(Almoguera Bermejo, 2022)	

TABLE 3: *LIST AND CHARACTERISTICS OF HOSPITALS AND PRISONS IN MALLORCA (DATA COMPILED VIA DIRECT UIB RESEARCH)*

2030 deployment opportunities: Industrial Offtake - Of the stakeholders based locally, CEMEX is the most optimal initial off taker in this sector. CEMEX, who have already deployed hydrogen technologies as part of its high-temperature processes across Europe, are based <1km from Green Hysland's hydrogen production site in Lloseta. This site has been initially sized to the project's activities but does have the potential to scale from 2.5MW to 7.5MW of electrolysis capacity to service increasing demand locally. CEMEX's recently re-opened cement facility, if full commercial operation is re-established, represents the perfect opportunity to scale production alongside – a proximally located offtaker that requires regular hydrogen supplies of considerable size. This link could install a direct pipeline between the two sites which is likely to be preferable due to the minimal distance. Alternative industrial offtakers, such as ceramic tile manufacturers, would likely require road-based tube trailer delivery mechanisms, or to install their own electrolysis systems. Stakeholders exploring the opportunity to install electrolysers purely for industrial use are able to make use of higher efficiency high-temperature units. This includes technologies such as Bloom Energy's Solid Oxide Electrolyser (SOE) which can produce hydrogen at just 37.7kWh/kg$_{H2}$ of energy – a 30% increase in efficiency compared to PEM technologies.

Co-location opportunity - Whilst the majority of Medium-/Heavy-Goods Vehicles that drive around the Balearic's roads refuel on the Spanish mainland, some of the few fleets of these vehicles that do refuel locally carry out distribution for the island's industrial processes. As such, these vehicles are some of the most polluting on the island and will require transitioning to zero-emission alternatives if Mallorca is to meet its net-zero objectives. By co-locating hydrogen production and end-uses around critical industrial sites across the island, the opportunity arises to also use hydrogen to power the distribution fleets of these industrial stakeholders. Although the Green Hysland project hasn't directly demonstrated the use of hydrogen within these vehicle classes locally, the knowledge gained from the introduction of FC buses into EMT's fleet and other hydrogen valleys with more specific experience with these technologies, can enable Mallorca's first steps in this area. This not only provides considerable emissions savings, but also can realise fuel security benefits too – enabling stakeholders to have greater control of their fuel supplies, enabling a greater penetration of local renewables into the energy system.

Gas Grid - Many of the island's industrial stakeholders also receive their energy directly via connection to the local gas grid – therefore, decarbonisation of the island's grid also decarbonises the local industrial base. Dedicated and blended hydrogen gas grids, due to the scale and regularity of demand present from this network across industrial and residential sectors, constitute one of the most reliable off-takers areas across all of Europe.

The opportunity to blend 2% hydrogen into Mallorca's natural gas grid will be proven as part of the Green Hysland project's activities, which, if plausible, could represent an instant hydrogen demand of over 91,100 MWh. In other areas of Europe, such as the UK, much larger blending percentages of 20% have already been realised as part of demonstration projects utilising existing natural gas infrastructure. Spain currently allows up to 5% hydrogen blended across its national network, and whilst that proportion is likely to be increased, as it has in other areas of Europe, Mallorca's opportunity for gas grid blending by 2030 is more likely reach a maximum of 10%. This is due to the high calorific requirement of the applications attached to the local gas network, making a 20% blend less likely, but still representing a considerable hydrogen opportunity of 415,991 MWh per year in 2030, accounting for decreases in gas demand in-line with local estimates. Gas grid demand, whilst considerable, is likely to be used as a 'baseload' off-taker – an offtaker which is used to enable the scale-up of production until other, more efficient and lucrative offtakers such as mobility and DHC are online.

Therefore, the long-term opportunity of gas grid injection is still uncertain, particularly with the increasing momentum of electrical-based heating solutions, such as heat-pumps, to drive emissions reductions within this sector. A more conservative estimate of a 2% hydrogen blend within the natural gas system would still represent a demand of over 70,000 MWh_{H2} in 2030, roughly seven times the current production capacity of the Green Hysland project.

2030			
	Blending Percentage	*Pot. Hydrogen Demand (MWh)*	*Pot. Hydrogen Demand (kg)*
Low	*2%*	*69,993*	*2,100,000*
Medium	3.5%	123,321	3,700,000
High	10%	416,625	12,500,000

TABLE 4: *2030 GAS GRID LOW, MEDIUM, AND HIGH DEPLOYMENT OPPORTUNITIES - POT. HYDROGEN DEMAND ROUNDED TO NEAREST 100,000KG*

2050 Opportunity – There are primarily three approaches to realise long-term industrial hydrogen demand within the Balearic Islands, which follow the scenarios described previously – dedicated industrial hydrogen production plants, co-location opportunities, and gas-grid blending.

Industrial hydrogen production plants will be limited by the size of the Balearic's industrial high-temperature heat demand base, although with a growing population, and greater greening of existing construction products (ceramic and cement) market demand will have increased in comparison to 2030 figures. Co-location opportunities, due to the ability to combine demand from industry and mobility, improve the viability and scale of this approach. This approach could offer the most cost-effective decarbonisation option for private stakeholders by enabling optimal deployment configurations for electrolysis and end-use applications whilst minimising needs for storage and distribution. This could also provide meaningful opportunities to realise emissions savings across sectors with a single deployment of hydrogen technologies. These opportunities will most likely focus around the archipelago's heaviest vehicle fleets due to their applicability to hydrogen and their locality to existing industrial locations.

Similarly, decarbonisation of the gas-grid will also be limited, not this time by a lack of demand, but by the stance of local policy makers relating to the long-term use the region's legacy infrastructure. With the hydrogen sector's expected retrofitting capabilities, the Balearics could retain existing levels of gas-based energy demand but via replacement of natural gas with hydrogen. Desires to improve the energy efficiency, and reduce the use of fossil fuels, will see overall gas demand drop in the short-to-medium term by an expected minimum of 40% by 2050 in-line with local climate change policy. It is likely, due to advancements in electric-based heating and industrial solutions, and further deployment of renewables to replace gas-based electricity generation, a 75-80% reduction could be achieved. In both cases, the only option to replace the remaining demand with a zero-emission alternative that is locally producible, to help meet other regional energy targets, is hydrogen.

The largest natural gas reduction estimation would still result in the gas grid being one of the largest hydrogen demand applications on the island, comparable to that of the most ambitious hydrogen mobility scenarios. Whilst a 40% gas demand reduction would comfortably make this the leading hydrogen end-user.

2050				
	Total gas-grid demand reduction	*Blending percentage*	*Pot. Hydrogen Demand (MWh)*	*Pot. Hydrogen Demand (kg)*
Low	*40%*	*50%*	*1,333,200*	40,000,000
Low	*40%*	*100%*	*2,666,400*	80,000,000
Medium	60%	50%	889,911	26,700,000
Medium	60%	100%	1,779,822	53,400,000
High	80%	50%	443,289	13,300,000
High	80%	100%	886,578	26,600,000

TABLE 5: *2050 GAS GRID LOW, MEDIUM, AND HIGH DEPLOYMENT OPPORTUNITIES – POT. HYDROGEN DEMAND ROUNDED TO NEAREST 100,000KG*

Study Area: District Heating Opportunity

According to the International Energy Agency (IEA), keeping buildings warm produces one tenth of global energy-related CO_2 emissions. Energy efficiency measures, for homes and technologies alike, as well as improvement in grid emission intensities are expected to reduce the built environment's carbon profile. Likewise, the deployment of heat pumps is expected to cut emissions significantly, by up to 40% by 2030 (IEA), but deployment of these measures in Mallorca's increasingly apartment and hotel-oriented settings[26] is more difficult than in conventional housing developments. Thus, alternative solutions, such as the deployment of District Heating and Cooling (DHC) plants, which can service the heat, power, and electricity requirements of multiple buildings/dwellings from a single system could prove to be viable and efficient. These systems, via cogeneration or trigeneration, can provide these utilities more efficiently than individual boilers or heat pumps per capita, and with a reduced overall footprint.

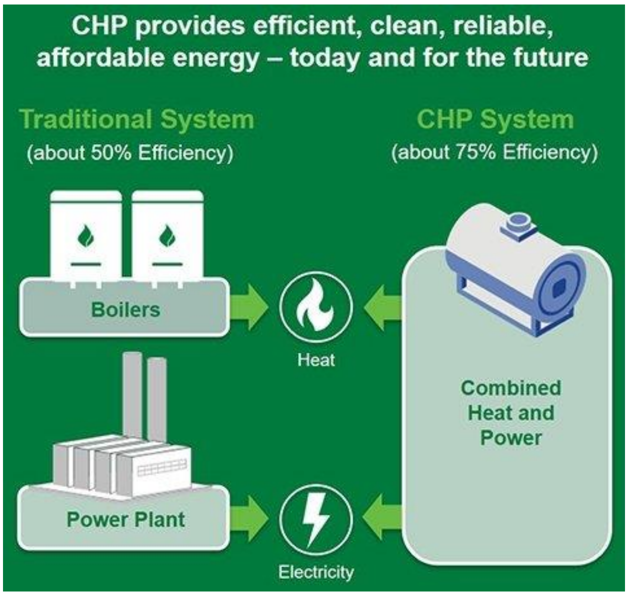

FIGURE 15: *EFFICIENCY COMPARISON OF CHP APPLICATIONS [DOE[27]]*

The concept of cogeneration is not a new principle to the Balearics, where these technologies already make up a considerable proportion of electricity generation infrastructure via the use of Combined Cycle Gas Turbines (CCGT) Combined Heat and Power (CHP) plants. CCGT and CHP plants operate in a similar way to conventional power plants, burning fuels to turn generators but with added heat recovery processes to increase efficiency. Yet this familiarity doesn't translate into widespread deployment of local DHC systems – with just one based in the archipelago at the ParcBit power plant providing 2.9MW of electricity, 6.2MW of heat, and 7.8MW of cooling to the University of the Balearic Islands' (UIB) campus. As of yet, however, local authorities and developers have been reticent to deploy DHC technologies for new tourist buildings in the centre of Palma due to the complexity of

[26] "de principios generales y directrices para la coordinación en turismo; de regulación de órganos consultivos, coordinación y cooperación del Gobierno de las Islas Baleares, y regulación y clasificación de empresas y establecimientos turísticos".

[27] Office of Energy Efficiency & Renewable Energy. Combined Heat and Power Basics. Accessed at: https://www.energy.gov/eere/amo/combined-heat-and-power-basics (2023).

installing or retrofitting these systems in densely populated areas. This is despite the positive assessment of DHC systems in Palma beachfront hotels detailed within studies carried out by UIB.

For large-hotel complexes with >1,000 rooms and multiple buildings, a centralised heating and cooling system using DHC that utilises waste-heat can make sense. However, to make these systems cost- and technically effective, different companies across the hotel sector must co-operate and share infrastructure has not yet been achieved. Current lack of DHC deployment represents a major challenge for the introduction of FC-based DHC systems due to three reasons (1) lack of local momentum to introduce these technologies due to a preference for alternative solutions, (2) lack of technical knowhow regarding DHC systems in general as well as more innovative FC-based versions, and (3) legislature immaturity with respect to DHC technologies.

The prevalence of this practice in other areas of Europe, however, alongside the pioneering work being carried out by Green Hysland - deploying two 50 kW, and one 100 kW Combined Heat and Power fuel cell systems within hotel and port areas – showcases the potential benefit of that these technologies could have on local economy.

Fuel cell integration with CHP technologies has been shown to be capable of producing the highest electrical efficiency of all CHP technologies[28]. Whilst the inclusion of fuel cells drives up capital cost of these systems, some geographies have chosen to deploy these units in large quantities. For example, in Korea, where a large proportion of the world's fuel cell expertise is based, Kopso have developed a 78 MW fuel cell power plant capable of providing electricity for 250,000 households and hot water for 44,000 households simultaneously, with further deployments expected soon.

FIGURE 16: *THE WORLD'S LARGEST FUEL CELL POWER PLANT WAS BUILT IN KOREA IN 2021 (KOPSO)*

Tri-Generation Systems (TGS) – which combine cooling, heating, and power (electricity) production - seem to be the most optimal application for fuel cells on the island due to overwhelming requirements of the island's tourism sector. This will allow stakeholders to simultaneously obtain heating for laundry, central heating, and sanitation requirements; cooling for air conditioning; and electricity for a variety of uses. It is expected that Proton Electrolyte Membrane (PEM) fuel cells will be the best fuel cell type to couple to these applications. Their relatively low operational temperature (60-80^{o}C) and short response times make them well suited to operation in residential locations under variable loads as is necessitated by Mallorca's seasonal, tourist-driven economy.

Alongside fuel cells, there is also considerable momentum surrounding the conversion of natural gas turbines, like those seen in Mallorca's CHP plants, to run on alternatives such as low-carbon hydrogen. Trials demonstrating the efficacy of these technologies with hydrogen and natural gas have already occurred – the Hyflexpower consortium successfully piloted 30% hydrogen blends during tests of a

[28] Comparison between the five predominant prime mover technologies used for CHP systems: Reciprocating Engine, Gas Turbine, Microturbine, Fuel Cell, and Steam Turbine [DOE] https://www.energy.gov/sites/default/files/2017/12/f46/CHP%20Overview-120817_compliant_0.pdf

conventional NG turbine at its Sillat-sur-Vienne facility in France in 2022[29] as well as a 100% hydrogen conversion in October 2023[30]. However, these tests were carried out utilising a 1MW gas turbine and thus the technology will need to be scaled to play a significant role within Mallorca's power production portfolio which currently features >1.2GW of turbine-based assets (CCGT and dedicated natural gas turbines).

2030 Deployment Opportunities: New greenfield developments – Residential housing in Mallorca, due to lack of land space around local hotspots, such as Palma, is becoming increasingly apartment oriented. This trend improves the viability of DHC systems, which can become much more efficient than individual boilers when servicing multiple proximally located end-users. DHC, by generating heat centrally, which is often provided by low-grade or waste heat sources, can eliminate the energy losses associated with the use of individual boilers.

With some of the Baleares' premier decarbonisation targets focused around the reduction of primary energy demand and increasing domestic energy production, the use of DHC combined with fuel cells and locally produced hydrogen can play a critical role in addressing the energy challenges seen across the Baleares. These solutions are seen as commonplace in other locations across Europe, particularly in areas such as UK which has over 17,000 systems providing 2% of the country's total heat demand. Therese areas have found that DHC not only provides emissions and demand benefits, but they also have a knock-on effect for consumers too – reducing fuelling bills by up to 30%[31]. Thus, it makes sense for Mallorca to increasingly look to deploy these systems in new building developments, learning from the hydrogen CHP activities within the project, combining that with Europe's leading expertise in integrating renewables in these systems.

However, it should be noted that the Balearic Islands has no historical tradition of deploying centralised heating or cooling systems due to the location's mild temperament. This, therefore, not only represents a technical challenge to transfer knowhow of DHC technologies into the region, but also a policy and planning challenge to implement these technologies due to a lack of maturity of local regulations, codes and standards with relation to these technologies.

Retrofit Opportunity – There is an opportunity to retrofit DHC systems on the island of Mallorca amongst key energy-intensive amenities. These amenities, often based around high population areas, such as just north of Palma where the local university hospital (Son Espases), prison, and Carrefour shopping centre are all proximally situated, will draw massive amounts of power from the already strained local grid if decarbonisation via electrification is pursued, making an alternative solution desirable.

Previously, this site has been discussed as an ideal location to extend the use of Mallorca's only existing DHC system, the cogeneration plant at Parc Bit Technology Park, which already services the university buildings. The location's opportunity to connect multiple applications and end-users across this area significantly increases the viability of deploying a DHC solution. However, now with secondary drivers such as local targets to accelerate decarbonisation, reducing local energy demand, and increasing local

[29] CompressorTech2. First power-to-hydrogen-to-power demonstrator completed. Available at: https://www.compressortech2.com/news/first-power-to-hydrogen-to-power-demonstrator-completed/8025609.article (2022).
[30] HydrogenInsight. World first as Siemens Energy burns 100% hydrogen in industrial gas turbine. (2023). Accessed at: https://www.hydrogeninsight.com/power/world-first-as-siemens-energy-burns-100-hydrogen-in-industrial-gas-turbine/2-1-1535850
[31] EnergySavingsTrust. District Heating. Accessed at: https://energysavingtrust.org.uk/service/district-heating/ (2023).

energy content, the feasibility of a DHC system, particularly one that is hydrogen-based, further improves again. This could provide services such as:

- Conventional central heating and air conditioning across the network.
- Conventional electricity demand across the network if a TGS is deployed.
- Hot water requirements across the network, including laundries for both the hospital and prison as well as sterilisation.

However, the real advantage to this opportunity comes when co-locating hydrogen production capacity on this network as well – the likes of which would not be possible in a residential setting due to the safety considerations of storing hydrogen. Co-locating production not only then provides greater energy supply security to these critical facilities by providing them the potential to make their own fuel, but can provide a number of secondary benefits:

- Hydrogen production on-site can couple to fuel-cell road transport applications.
  - This can include passenger transport systems.
  - Or help to decarbonise the hospital's other fleets such as ambulances which require high levels of operability and so would benefit from the improved recharging time from hydrogen in comparison to batteries.
- Oxygen that is also produced during the electrolysis process can be captured and utilised within medical processes on-site.
- Waste-heat from the electrolyser, which is often left unutilised, can be integrated back into the DHC process in order to raise the operating efficiencies of both systems.
- Wastewater, once purified, can be re-integrated into the amenities' water systems.

Therefore, it is recommended that this deployment case should be explored as a critical next juncture to continue the development of Mallorca's hydrogen economy and realise cross-sector emissions savings.

2050 opportunity – the 2050 deployment opportunity for fuel-cell based DHC systems is almost certainly dependent on the realisation of a successful local demonstration system in the coming decade. This vital step is necessary in order to break the regulatory and social hurdles to deploying greater number of these systems locally.

Nevertheless, the continued deployment of solitary heating solutions will likely continue as standard, decarbonised via the combination of electric-based heating systems alongside increased renewable deployment. Further increases in population and apartment-oriented living arrangements in the coming decades could result in greater DHC opportunities compared to present-day. However, with a lack of current deployments as well as available data on the current fuel consumption of residential heating and cooling applications locally, it is difficult to suggest the potential scale of local deployments. Therefore, a local system trialling this technology in the next 10 years is required to build the evidence base for future deployments going forward.

Study Area: Fuel Cell Road-Based Transport Opportunity

Decarbonising road-based transport, as one of the archipelago's most polluting sectors responsible for 56% of local emissions (Mallorca Strategy 2030), is a leading goal of Mallorca's net-zero strategy. The Balearics, which feature more vehicles per inhabitant than any other Spanish region, has so far prioritised restricting the use of fossil fuel vehicles (e.g. low-emission zones) and the implementation of EVs and their enabling infrastructure – including the deployment of 1,000 EV charging points in the Balearics by 2030. This has already resulted in an increase in BEV sales locally, making up 4.7% of vehicle sales in 2022, compared to less than 2% in 2019[32]. Whilst BEVs are expected to dominate passenger vehicle sales in Mallorca, there could be a considerable market opportunity for FCEVs due to the island's climate and route gradient requirements. Within Green Hysland, five hydrogen buses will be added to the fleet of local transport operator EMT, and OK Mobility will deploy ten light-to-medium duty FCEVs on a rental model to provide a variety of stakeholders the opportunity to gain experience with hydrogen technologies. The opportunity to expand this initial deployment of hydrogen-powered vehicles locally by 2030 is considerable particularly in the following key areas:

2030 Deployment Opportunities: Public and Private Buses – With >100 natural gas-powered units in their fleet, local bus operator, EMT, possesses considerable expertise of large-scale gas-based bus fleets. Green Hysland leveraged this existing knowledge of gaseous operating procedures, refuelling, and safety considerations, to seamlessly introduce five hydrogen-powered units into full operation in 2023. Thus, with the acceleration of zero-emission bus legislation on an EU-level, it is expected that the deployment of zero-emission technologies locally will also be expedited.

A significant proportion of newly ordered vehicles are expected to be hydrogen due to the experience EMT have built up with these vehicles within this project, as well as the required range, gradient, and HVAC loads of local routes making deployment of hydrogen technologies preferential in certain areas. Although with both EMT and TIB, the other major public bus operator on the island, having both recently carried out fleet regeneration – introducing 165 and 223 units respectively in the past four years - this limits the number of hydrogen powered buses that can enter service by 2030 to roughly twenty.

Composició de flota (juny 2014)							
Und	Marca	Model	Motor	Euro	Any	Pot.(CV)	Pass
80	MERCEDES	CITARO 12m	Diesel (12L)	II	2001 2002	292	101
8	MERCEDES	CITARO 12m	Diesel (12L)	III	2006	292	100
14	MERCEDES	CITARO G 18m	Diesel (12L)	II	2001 2002	292	137
12	MERCEDES	CITARO G 18m	Diesel (12L)	III	2005 2006	345	124
11	MERCEDES	CITARO K 10,5m	Diesel (6L)	IV	2008	279	80
22	IVECO	CITELIS 12m	Diesel (8L)	V	2009	283	100
18	IVECO	CITELIS 18m	Diesel (8L)	V	2009	372	150
10	IVECO	CITELIS GNC 12m	Gas natural (8L)	EEV	2010	266	100
2	IVECO	CITELIS GNC 18m	Gas natural (8L)	EEV	2010	311	142
2	IVECO	DAILY MICRO	Diesel (3L)	IV	2008	142	16

FIGURE 17: *TECHNICAL CHARACTERISTICS OF THE EMT BUS FLEET, IN 2014.*

Alongside the public bus fleet, it may also be appropriate to target the Balearic's private bus fleet. These buses are primarily used by tour companies to transport tourists around the islands as well as for private hire. Fleets are often comprised of smaller minibus style vehicles and whilst these vehicles will use a smaller amount of hydrogen per unit – somewhere 7-9kg per vehicle in comparison to 20kg - the overwhelming local fleet size of over 1,000 vehicles on Mallorca represents a considerable

[32] International Council on Clean Transportation. Spain's electric vehicle infrastructure challenge: How many chargers will be required in 2030? Accessed at: https://theicct.org/sites/default/files/publications/Spain-EV-charging%20infra-jan2021.pdf (2021)

demand opportunity. In fact, with 2,411 of these vehicles based across the Balearics (2022), this could also be an ideal opportunity to broaden hydrogen vehicle knowhow from Mallorca to other islands.

Hydrogen-powered minibuses are still at an early-stage within their development life cycle and whilst this may cause issues obtaining considerable number of units in the short-term, they are expected to be widely available by 2030 – with units from Slovakia's Mobility & Innovation, or France's Hyvia already launched. At this early-stage stakeholders could also leverage national and European funding to work alongside manufacturers and optimise technology and business models for deployment across European islands.

High operation capacity fleets – Within other hydrogen valley projects, fleets which require round-the-clock operation in order to maximise revenue streams, such as logistics, have been found to be ideal hydrogen deployment opportunities. These applications cannot afford to take vehicles out of service to charge for long periods of time and are, therefore, increasingly investigating the potential of hydrogen vehicles.

On an island like Mallorca, with comparatively little hydrogen expertise, local stakeholders will be hesitant to completely replace fleets with hydrogen vehicles at this stage. Therefore, it's likely a gradual replacement will be preferred to allow stakeholders to obtain experience with these vehicles before entering widespread replacement. This could be enabled by a hydrogen vehicle aggregator who rent vehicles to local companies to take purchase risk away from fleet operators curious about hydrogen vehicles. Similar approaches have been shown to obtain greater inclusion of stakeholders through activities included within Green Hysland, as well as HEAVENN, and private entities such as HyLane in Cologne too. On Mallorca, it's expected that this aggregator fleet would comprise of primarily medium-duty vehicles, with other public authority units, such as refuse vehicles, potentially included as well. The aggregator position is expected to be time sensitive, and will only be viable up until 2030-2035, after which vehicles will be sufficiently mature to enter commercial operation without significant cost risk to local stakeholders.

Taxis - Another area that could be worthwhile targeting is local taxis. The 2,942-strong fleet across the Balearic Islands, requires constant operation and will regularly exceed the daily range of currently available BEV alternatives when considering required HVAC loads and the gradients of local roads, thus making units well suited to conversion to hydrogen.

Pioneering sector stakeholders such as *Hype* has already shown the efficacy of using hydrogen to power taxis across Europe. The company, based in Paris, have deployed 600 FC taxis and 6 hydrogen refuelling stations and plans to extend this portfolio to 1,000 zero-emission taxis by the end of 2024 and 26 stations by the end of 2025[33].

Taking lessons from these leaders in this area, alongside mobility activities in the Green Hysland project, can help to initialise deployments of these vehicles, and with such a large fleet, a partial fleet replacement would still represent a considerable demand opportunity. Larger replacement of this fleet, or any other fleet located within the island's capital of Palma, could be enabled via coupling to hydrogen refuelling infrastructure necessitated by Alternative Fuels Infrastructure regulation.

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[33] Hype. Integrated hydrogen mobility platform. Available at: https://hype.taxi/en/accueil-en/ (2023).

Medium-duty, Heavy-duty and other – There is a total of 2,145 tractor trailers, and 7,789 other vehicles (ranging from construction equipment and forklifts to snowploughs and quarry dump trucks) currently powered by diesel across the Balearic Islands[34]. These vehicles are some of the most polluting road-based vehicles based across the archipelago and, due to their high-power requirements will almost certainly prefer decarbonisation via hydrogen powertrains in comparison to battery electric.

Some of these vehicles, such as refuse trucks, concrete mixers, and large-scale construction equipment, can require as much as 25kg of hydrogen per day for normal operating procedures. Therefore, only a small number of vehicles are required to realise considerable volumes of hydrogen demand. For instance, under 50 vehicles requiring 25kg of hydrogen per day for 273 days per year would utilise the entirety of Green Hysland's current production capacity. Medium duty vehicles, primarily trucks and vans may require less hydrogen per vehicle but represent a much larger potential market with a total of 124,291 diesel-powered units currently registered within the Balearics.

These vehicles - defined as "motor vehicles with four or more wheels designed and constructed for the transport of goods, with a cabin that is not integrated into the rest of the body and a maximum of nine seats, including the driver" by the Spanish Dirección General de Tráfico - will likely be decarbonised via a mixed battery and hydrogen approach, whilst the default will likely be to replace vehicles with battery analogues, heavier variants or those carrying out payload dependent activities will likely prefer hydrogen. Airport ground vehicles will also be a critical vehicle category to convert within this size range to also to grow knowhow within the aviation sector before hydrogen is necessitated for aircraft in the period from 2030-2035.

Rental Fleets – Other island-based hydrogen projects, such as the SEAFUEL project in Tenerife, have shown notable potential of deploying hydrogen-powered rental units for tourists. Surveys carried out within the project found that not only could these technologies eliminate range anxiety, but that they could also command a premium due to their sustainable credentials. The Balearic's rental vehicle fleet currently swell by tens of thousands of units in the summer, to deal with tourist demand reaching a peak of approximately 100,000 vehicles in the summer of 2023. It is expected that the majority of these vehicles, like privately owned passenger cars, will be converted to battery-electric alternatives as the primary way to decarbonise due to their overwhelming market share amongst new vehicles in vehicle size range. However, leading on from Green Hysland's initial activities a small proportion of this large rental fleet could be FCEV-based.

This proportion is expected to be <1% for passenger vehicles, partly due to BEVs superiority, and also due to a reduced focus of vehicle manufacturers on hydrogen-powered passenger vehicles in European geographies, but could increase for larger vehicle types such as vans and trucks which could better utilise the increased power output of hydrogen-based solutions.

Alternative Fuels Infrastructure Regulation (AFIR) – The recently approved AFIR regulation will necessitate the installation of 1 tonne per day hydrogen refuelling stations every 200 km along TEN-T corridors *and* in urban nodes – 424 major EU cities featuring port, airport, and rail infrastructure – by 2030. As one of these nodes, Palma be required to install hydrogen refuelling infrastructure, most likely based around the port or airport due to the number of applicable end-uses situated in these locations. With public European funding available for refuelling stations available from bodies such as the

[34] Spanish Ministry of Public Works and Transport for the year 2021.

Connecting Europe Facility, Mallorca can utilise this enabling infrastructure to couple to initial FC vehicle deployment and incentivise hydrogen technology uptake locally.

2030 - Low									
Vehicle Type	*City Buses*	*Alt. Buses*	*Trucks and Vans*	*Airport (Ground)*	*Cars*	*Taxis*	*Other*	*Ind. Tractors*	*Energy Demand (MWh)*
Total Number of Vehicle	5	0	0	0	5	5	0	0	1,388
2030 – Medium									
Vehicle Type	*City Buses*	*Alt. Buses*	*Trucks and Vans*	*Airport (Ground)*	*Cars*	*Taxis*	*Other*	*Ind. Tractors*	Energy Demand (MWh)
Total Number of Vehicle	10	10	25	10	5	29	0	5	7,293
2030 – High									
Vehicle Type	*City Buses*	*Alt. Buses*	*Trucks and Vans*	*Airport (Ground)*	*Cars*	*Taxis*	*Other*	*Ind. Tractors*	Energy Demand (MWh)
Total Number of Vehicle	20	50	50	50	20	145	0	30	30,663

TABLE 6: *2030 LOW, MEDIUM, AND HIGH VEHICLE DEPLOYMENT PROJECTIONS*

2050 Deployment opportunity – The potential uptake of fuel-cell based transport is dependent on many factors. Some of these factors, namely the deployment of policy measures like subsidies and obligations to incentivise the uptake of hydrogen, are within the Balearic's control, whilst others, such as the scaling of large-scale FCEV manufacturing to gain increased access to vehicles, are not. Therefore, the extent to which hydrogen fuel cell-based transport will play a role in the Balearic's long-term mobility landscape is uncertain.

To understand this opportunity better, this report has combined local context and hydrogen sector-standard predictions to suggest the potential breadth of hydrogen required for mobility applications locally through the production of three high, medium, and low scenarios. These scenarios, which predict varying levels of hydrogen penetration into road-based vehicle fleets, provide a clear indication that, even in the lowest forecasts, hydrogen is likely to provide a significant proportion of the archipelago's future vehicle energy demand.

Across the scenarios produced, it is assumed that hydrogen vehicles will be far outnumbered by Battery Electric analogues across light-duty vehicle types (e.g. passenger cars and vans). The exception to this rule, the archipelago's taxi fleet, could see the introduction of FCEVs to their fleet, as currently hydrogen-based solutions represent an advantage to BEV alternatives such as increased range and operational availability. However, improvements in BEV range and recharging still expected in the coming years, could be negated, or limit this opportunity – as represented in the projections below.

Penetration into heavier vehicle types is expected to be much larger. Amongst these vehicle types, four in particular stand-out as ideal FCEV deployment opportunities. This includes:

(1) City buses – following on from the Green Hysland project's initial activities, the archipelago can continue to make use of its head start in this area by deploying further vehicles in this area. Deployment of these units is limited in 2030 due to recent renewals but a greater fleet replacement will be necessitated by 2050 to realise decarbonisation targets, which could feature considerable numbers of hydrogen-powered units.

(2) Airport Ground Vehicles – Airports will require hydrogen long-term to fuel their aviation activities and therefore they could also make use of this fuel to decarbonise their ground fleets. The exact number of airport ground vehicles at Mallorca is unclear and comparison against other airports with available data has provided an inclination for the size. Estimates used within this report have been conservative (Assuming around 3,000 vehicles) but still show considerable demand potential.

(3) Industrial tractors – includes conventional Heavy-Duty Vehicles such as conventional lorry tractors, tractor-trailers, and tractor-trucks. Despite being registered locally, these vehicles for the most part will refuel on the Spanish mainland. However, if a small proportion refuel locally then demand from these vehicles will be sizeable, due to each truck's 20-25 kg_{H2} tank.

(4) Other – these vehicles, which don't automatically fit into another category, features construction equipment, quarry trucks, forklifts, and snowploughs, amongst other units. These vehicles have some of the highest power output requirements and not only will significantly prefer hydrogen, but each vehicle also represents considerable demand similar to that of trucks.

The deployment rates of these vehicles vary between scenarios, but in each instance the indicated rise in hydrogen road-based mobility demand is expected to be equal to between 14 and 115 times the existing hydrogen production capacity of the Green Hysland project, without including demand from aircraft and maritime vessels which are also expected to be significant.

2050 - Low									
Vehicle Type	*City Buses*	*Alt. Buses*	*Trucks and Vans*	*Airport (Ground)*	*Cars*	*Taxis*	*Other*	*Ind. Tractors*	*Energy Demand (MWh)*
Assumed Percentage Penetration	5%	5%	0.5%	5%	0%	0%	20%	0%	134,300
Total Number of Vehicle	25	95	742	156	0	0	981	0	
2050 – Medium									
Vehicle Type	*City Buses*	*Alt. Buses*	*Trucks and Vans*	*Airport (Ground)*	*Cars*	*Taxis*	*Other*	*Ind. Tractors*	Energy Demand (MWh)
Assumed Percentage Penetration	20%	10%	2%	20%	<1%	20%	50%	10%	504,300
Total Number of Vehicle	100	190	2,969	625	40	558	2,451	215	
2050 – High									
Vehicle Type	*City Buses*	*Alt. Buses*	*Trucks and Vans*	*Airport (Ground)*	*Cars*	*Taxis*	*Other*	*Ind. Tractors*	Energy Demand (MWh)
Assumed Percentage Penetration	50%	20%	5%	50%	<1%	50%	80%	25%	1,093,800
Total Number of Vehicle	250	380	7,422	1,563	100	1,462	3,922	536	

TABLE 7: *2050 LOW, MEDIUM AND HIGH VEHICLE DEPLOYMENT PROJECTIONS – ENERGY DEMAND PER MWH ROUNDED TO THE NEAREST 100,000*

6 Lessons from hydrogen-active territories

Within the following section key developments and learnings from projects in the Netherlands and Germany have been offered by partners *New Energy Coalition* and *HyCologne* to detail how low-carbon hydrogen activities have been explored, initialised, and expanded in other areas of Europe. It is hoped that this information provided by these regions can act as an exemplar and provide confidence to local stakeholders to engage in similar activities in the Balearics.

As outlined in the German National Hydrogen Strategy, hydrogen is seen as an indispensable component of the future energy as it has been recognised that the goal of greenhouse gas neutrality cannot be achieved with green electricity alone. In highly industrialised areas of Germany, such as the greater Cologne area, it has been determined that hydrogen will be needed in especially large quantities both as a classic chemical feedstock and as an energy carrier to substitute fossil fuels such as coal, oil and natural gas. The greatest demand is expected for the industry, logistic and transport sectors. Similarly, The Netherlands has also acknowledged hydrogen's potential role. Currently most locally produced hydrogen is from grey pathways but plans a major shift to renewable hydrogen via electrolysis using renewable energy exemplified by the Dutch Climate Agreement, which targets 500 MW of electrolysis capacity in 2025 and 3-4 GW by 2030[35]. However for both countries, balancing electrolysis expansion with renewable energy production, particularly the scaling of offshore wind capabilities, does pose a major challenge in these timescales.

Use of hydrogen in Pipelines to enable end-users – An essential prerequisite for the development and expansion of a hydrogen economy is a reliable and cost-effective distribution infrastructure. For this reason, the HyCologne - Hydrogen Region Rheinland e.V. network is pursuing the HyPipCo (Hydrogen Pipeline Cologne) project with the aim of laying the foundations for the rapid expansion of a pipeline-based infrastructure in the greater Cologne area[36].

The project idea has received considerable buy-in from a number of stakeholders and been promoted by municipalities, infrastructural operators, gas grid operators, industrial partners and research institutions. The feasibility study has concentrated mainly on districts and independent cities around Cologne to access greater amounts of hydrogen as hydrogen demand cannot be met on its own by hydrogen production plants based within the region. Therefore, connection points to a prospective supra-regional hydrogen backbone were also considered. It is conceivable that the conclusions of this study could help to deliver ideas and starting points for a wider integration of hydrogen within Mallorca's gas grid.

The study concludes that the construction of pipeline infrastructure to supply the region of Cologne with hydrogen is technically feasible and offers great opportunities to accelerate expansion of hydrogen technologies for all parties involved. When planning the route, both the current and the future producers and consumers of hydrogen in the region were considered. Depending on the scenario, pipeline lengths of 270 to 300 kilometres were estimated for their connection, with investments in the range of 95 to 110 million euros are required for transformation of a greenfield sites into such an intricate network. However, the investment volume can be significantly reduced if parts of the existing natural gas transport and distribution network are converted to hydrogen, as it

[35] Green Hydrogen Organisation. Netherlands. Accessed at: https://gh2.org/countries/netherlands
[36] HyCologne. Connect. Develop. Make.. Accessed at: https://www.hycologne.de/

could be in the Balearics. Pilot projects of various operators already show that such a conversion is possible with manageable effort, as well as interlinking with existing dedicated hydrogen infrastructure such as Air Liquide's pipeline to the north of Cologne that has been operational since 1938.

During the investigation and subsequent stakeholder interviews, further research and development topics were identified which could not be addressed in the study which could have significance for further design of hydrogen supply networks across Europe, not just locally. This includes:

- Significance of gas purity for transport, network equipment or the consumers and their processes, if applicable purification concepts in distribution networks.
- Pressure increase and throughput increase for cost reduction.
- Works to convert of existing pipelines and other components in the distribution network.
- Transformation pathways for the switchover, including temporary transport and storage options to compensate for bottlenecks, if necessary.
- Local storage of hydrogen, open technology approach.
- CHP in the regional area and conversion of existing options to hydrogen, e.g. gas turbines H_2 -ready.

For all these topics, a cross-border exchange of experience and co-operation are a good way to avoid duplication of effort and to accelerate technical development for hydrogen pipeline grids.

For the Cologne region, with its high energy demands from industry and transport, the rapid implementation of pipeline infrastructure is a crucial prerequisite to improve the feasibility and profitability of the potential utilisation and generation applications with hydrogen. Therefore, the HyCologne network together with many other stakeholders is currently taking further steps to realise the first part of the HyPipCo pipeline grid in the southwest of Cologne. Currently, modelling of the prospective pipeline and potential funding opportunities are being actively explored.

Similar developments and conclusions have been drawn in the Netherlands where pipeline transport is also recognised to be the most efficient means of domestic hydrogen distribution. Plans to implement a national hydrogen transport network were initiated in 2022, with construction of the first 30km stretch of pipelines officially starting in October 2023[37]. The primary demand for transport capacity arises from the country's coastal industrial clusters and ports, where renewable hydrogen production with offshore electricity will occur. The network's initial phase will connect these clusters, while a second phase will address broader regional needs, including the Chemelot industrial cluster in Limburg. Whilst other chemical clusters, such as Emmen, have taken matters into their own hands and started to deploy their own individual pipelines (3.6km in length) with the help of Gasunie.

Additionally, the study of hydrogen storage in salt caverns and underground gas fields is ongoing, with full-scale storage locations anticipated post-2030. The aim is to establish a nationwide hydrogen network to serve various sectors and regions. Whilst geological storage in the Balearics is limited, the initial development of hydrogen pipeline networks around core stakeholders with a phased expansion to include additional end-users is expected to be the most suitable approach for archipelago.

[37] HydrogenInsight. Europe's first national hydrogen pipeline network to start construction this month. (2023). Accessed at: https://www.hydrogeninsight.com/industrial/europe-s-first-national-hydrogen-pipeline-network-to-start-construction-this-month/2-1-1529347

End-uses - In **the industrial sector**, Cologne sees increasing interest in decarbonisation among industry in the region. Hydrogen is principally being considered for the provision of green heat or process gas, including:

- Near Cologne, a major aluminium producer is researching the use of hydrogen for high-temperature kiln-firing applications that cannot be electrified.
- Similarly, a local asphalt production plant, based to the south of Cologne, is investigating the opportunity to replace their existing 2.5 million tonnes of annual natural gas with low-carbon variations
- In the glass industry, a global glass producer plans to use approx. 25 MW of electrolysis to cover the daily demand for process green hydrogen.

Whilst these industries aren't major in the Balearics, there are mutual learnings in the use of hydrogen as an energy carrier for high-temperature processes which can be utilised in Mallorca's production of ceramics and cement. The electrolysis system is part of an overall sustainable energy ecosystem that combines renewable energy production, waste heat utilisation, energy storage and hydrogen for sector coupling. In addition to that Mallorca can take note of these application's co-location ambitions to utilise hydrogen in auxiliary areas such as distribution and refuelling stations. For industrial sites that may produce more hydrogen than they will consume, pipeline connection opportunities will provide these locations with a guaranteed offtaker, the likes of which may also be of interest to Mallorca's industrial base.

Industry in the Netherlands, the second-largest of hydrogen consumer in the European Union, mainly relies on hydrogen from natural gas and industrial waste gas. To enhance industry sustainability, there's a push to transition to renewable and low-carbon hydrogen. Currently, hydrogen serves as a raw material, but the future envisions its role as a CO2-free energy carrier for high-temperature processes, marking a significant shift toward cleaner and more sustainable industrial practices.

- The HEAVENN region contains Delfzijl, a major chemical cluster where hydrogen is already being produced and used by chemical industry and investigated for mobility too. The Emmen region also has a smaller chemical cluster where a 3-5 MW electrolyzer will be realized for industry and mobility with the aim to green both heat and power at the GETEC park.

Away from industry, **mobility** is seen as a critical low-carbon hydrogen user in Europe. The research Centre: Jülich have outlined three demand development scenarios for the local sector which, taking into account the technological and commercial framework conditions, identify low, medium and high market penetration for cars, buses, heavy commercial vehicles (SNF) and trains for the base years 2023, 2030 and 2035. In the short term, buses and trucks in particular show themselves to be a potent technology with significant market shares. Depending on the scenario, passenger cars could achieve a market penetration of up to approx. 7% by 2035, buses 37%, heavy commercial vehicles 24% and trains 54%, the Balearics should similarly focus on end-use areas where direct electrification is much more difficult.

Cologne is a hydrogen mobility pioneer, with the region being home to five publicly available operational 350 bar hydrogen refuelling stations, soon expected to rise to 10 by 2025. The first station, which became operational back in 2010, provided sufficient learning opportunities to public authorities and transport operators to realise a slow and steady introduction of these technologies to local fleets which they now hold a world-leading position in. For instance, the local bus operator RVK, who started with just two hydrogen buses, now operates the largest bus fleet in Europe with a total of

74 FC buses with units from a multitude of suppliers including VanHool, Solaris, and Wrightbus fuelled by a further four privately operated HRSs. This fleet will expand to 180 FC busses by 2025[38].

An important learning point from the introduction of FC buses in Cologne from RVK is to start small and understand how they can be best utilised. Mallorca can take this learning point by expanding hydrogen transport deployments alongside green hydrogen supply across the island. In addition to the operation of the buses, know-how and resources had to be built up for the procurement of hydrogen, the planning and construction of filling stations and the maintenance of the vehicles. For this reason, RVK is planning a training and education centre for climate-neutral and digital mobility.

Other municipalities close to Cologne are exploring the potential of hydrogen within their own fleets too. In the Rhein Erft region, 5-10 buses are already operational, and another operator, Stawag, has launched tenders for 10-20 units in proximal Aachen, with trains and refuse trucks also in the procurement phase from other stakeholders. Secondly, In the district of Düren, 30 km from Cologne, there are currently 5 FC buses in operation that are refuelled by one HRS. The fleet is to be expanded by 35 more buses by 2025. In addition, 17 passenger trains are to be converted to hydrogen propulsion by 2026. The conversion of existing combustion engine vehicles to run on hydrogen could also be of interest to the Balearics to simultaneously reduce emissions and increase lifespan of legacy assets.

At present, it can be observed that fleet operators and logistics companies are still reluctant to invest in the conversion of vehicles to hydrogen propulsion due to a lack of experience and knowledge. The industrial gas company Messer wants to remove this hurdle by offering customers integrated solutions in the sense of a one-stop-shop solution. For this purpose, Messer formed a strategic cooperation with Toyota Tsusho, amongst others, to provide vehicles, together with hydrogen fuelling and maintenance as a service for its customer with a pay-per-use pricing model. The business model of the company Hylane is similar, with a private rental model, including services, repairs, and insurance, for hydrogen trucks. This aggregator position deployed by Messer and Hylane can help to overcome the anxieties experienced of prospective customers through real-world operational experience for a fraction of the cost.

Like Cologne, the Municipality of Groningen in the Netherlands has been very ambitious and a frontrunner of hydrogen mobility. It currently operates several cars, vans, and refuse trucks on hydrogen co-funded by projects such as REVIVE, HyTrEc2, Hector and HEAVENN. This leading role adopted by the municipality has been very important for the region and has enabled local SMEs to develop hydrogen activities. At the province level Groningen and Drenthe have set ambitious goals for sustainable public transportation. In 2017, QBuzz undertook a pilot with 2 hydrogen buses and due to their experience has grown their fleet to units which regularly operate around the Groningen region. Qbuzz will also add a further 10 buses in Emmen, making it one of the largest hydrogen fleets in the Netherlands, enabled by funding from the JIVE and JIVE2 projects[39]. Further vehicles, such as 100 passenger vehicles, several taxis and 8 heavy trucks are also being added to the regional fleet courtesy of activities within the HEAVENN project. These feature a mixed approach between aggregators and private fleet uptake.

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[38] Sustainable BUS. RVK signed its 3rd order for Solaris hydrogen buses: 18 more articulated buses headed to Cologne. Accessed at: https://www.sustainable-bus.com/fuel-cell-bus/rvk-cologne-fuel-cell-buses-solaris-hydrogen-order/ (2023)

[39] hive.mobility. Hydrogen buses and hydrogen filling stations. Accessed at: https://www.hivemobility.nl/en/project/hydrogen-buses-and-hydrogen-filling-stations/

Whilst hydrogen-powered trucks are unlikely to penetrate the Balearic geography in as significant amounts as mainland Europe, due to a lack of local refuelling of this vehicle type, the model of Messer, HyLane and projects in Groningen could be extremely interesting to help introduce hydrogen vehicles to the region. The 'vehicle-as-a-service' model helps to reduce customer's maintenance and expertise anxiety that is frequently encountered when launching these specialised technologies into new areas. This model could be ideal for the introduction of further vehicles to Mallorca, following a similar model to that deployed by OK Mobility within Green Hysland. For this reason, it is recommended for partners in this area to expand their aggregator activities past initial small-to-medium scale vehicles to include heavier duty variants too.

Due to the innovative nature of hydrogen-based **District Heating and Cooling (DHC)** technologies, expertise for these sorts of systems is locked to a few key projects across of Europe, whilst general heating applications are being investigated more widely. In the HEAVENN region several hydrogen heating projects are being developed in both the municipalities of Groningen and Hoogeveen. The municipality of Hoogeveen plans to construct approximately 80 homes in Nijstad-Oost to understand how to build without natural gas. This demonstration project is serving as a catalyst for hydrogen applications in the built environment throughout the Netherlands and is the first step in a multi-year program with the ultimate goal of developing a technology blueprint to provide homes with 100% hydrogen-based heating. The research focuses on heat provision, societal aspects, and business opportunities. Ultimately, this project will provide answers to questions about hydrogen application in homes, energy storage, and hydrogen production in the neighborhood, with attention to technological and societal aspects, legal impact, and scaling[40]. The Cologne region is investigating the opportunity to use hydrogen for heating as part of its HyPipCo project whilst simultaneously also investigating the opportunity to deploy large-scale heat pumps. This includes a 150 MW heat pump unit that will use water from the Rhine River to power 30,000 residential units to be operational by 2027, with another 50MW at a separate site in the north of the city. The results of these activities and the opportunity to deploy 100% hydrogen heating activities, alongside other key energy transition technologies should be monitored by Mallorca to understand the best next steps to realising hydrogen demand uptake in the built environment.

[40] European Union. Hydrogen heating in Hoogeveen: explanatory video. Accessed at: https://northsearegion.eu/stronghouse/news/hydrogen-heating-in-hoogeveen-explanatory-video/#:~:text=As%20part%20of%20the%20Stronghouse,the%20existing%20natural%20gas%20infrastructure. (2023)

7 Further Recommendations

As this study has shown, hydrogen has the potential to play a key role in enabling Mallorca and the wider Baleares' energy transition and security especially within critical hard-to-abate sectors – industry, mobility, and heating. To realise this potential, however, the region must actively encourage the deployment of hydrogen technologies through cross-cutting targeted measures that aid research & innovation, economic incentives, policy & regulation, safety codes & standards, sustainable skills development. By tackling these areas, the uncertainties of stakeholders can be addressed in an accelerated fashion, leading to greater local hydrogen technology deployment with greater emissions savings, energy security, and value added as a result.

Specialised hydrogen strategy – One of the critical requirements to enable development of a local hydrogen sector is clarity. This clarity is present for developments on the Spanish mainland, where activities are focused on replacing industrial grey hydrogen feedstocks, whilst developing the country's position as a continental renewable energy provider. Whereas, on a local level the future development of a hydrogen sector uncertain – the Balearics' varied economic makeup focused upon tourism requires a specialist implementation strategy that varies considerably from the industrially-focused national analogue.

To galvanise the same level of private-sector interest and confidence seen on the mainland, the local Balearic government must adopt a locally optimised hydrogen strategy with legally binding measures and targets. To aid local policy makers in this task, the Green Hysland project is combining local knowhow with that of sector-leading European hydrogen experts to develop a Hydrogen Roadmap for the Balearic Islands. Local government is strongly encouraged to follow in the footsteps of other regional authorities – such as Orkney (BIG HIT), Groningen and Hoogeveen (HEAVENN), and Cologne (HyCologne) – who have used the influence of pioneering stakeholders and outputs from hydrogen valleys to stimulate sector development. As the first island-based hydrogen valley in Europe, Mallorca can act as a lighthouse for other deployments of hydrogen technologies on European islands, but only if it effectively capitalises on successes of the project in a time-efficient manner. If the islands delay for too long, they risk losing their ground-breaking position to other locations, and with it the potential to add significant amounts of value to the local economy through dissemination of knowhow to other islands and regions.

It is expected that the development of the Balearic hydrogen sector will occur in three defined phases, the first of which, occurring up until 2030, is Initial Market Development. Within this phase, there is a requirement to simultaneously grow hydrogen production and end-use applications as well as policy, regulation, and codes & standards, to ensure a beneficial, and symbiotic growth of all hydrogen involved stakeholders. Initial growth will be focused on Mallorca, due to the head start the island has received from Green Hysland, with initialisation of low-carbon hydrogen activities, occurring on other Balearic islands between 2026 – 2028.

Then, from 2030-2040, constant and rapid market development will occur across the archipelago. Optimisation of local hydrogen production alongside the accelerated deployment of large-scale renewables (onshore, offshore, and self-consumption) will significantly increase renewable penetration across all economic sectors. As such, hydrogen applications proliferate, and new supply chains will be created with necessary dependencies on components and services from the mainland identified and incentivised where appropriate. Whilst the number of individual deployments of production and end-use technologies on other Balearic Islands is expected to exceed those on Mallorca in this period, Mallorca is still expected to have the largest hydrogen demand period due to the overwhelming airport fuel requirements (see next section).

The market is then expected to reach a fully established position between 2040-2050 where maturation is achieved through both optimised technologies, and mass deployment across the Baleares. Policy must drive the retention of local economic value and skills to guarantee the local opportunity is not lost to international rationalisation in a widely developing global market.

To ensure this, ambitious key targets should be set to be achieved by 2030. Whilst the examples mentioned within this study are largely centred around Mallorca, due to the presence of Green Hysland, these goals should be designed to disseminate hydrogen knowhow and activities across the entire archipelago. The Baleares must commit to the adoption of a suite of focused policies and actions that provide stakeholders with clarity and confidence to engage and invest in this area for long-term benefit. Alongside the leading 2030 deployment scenarios suggested within the previous section of this report, leading targets should focus on the following areas: (1) Hydrogen production, (2) Storage and distribution, (3) Decarbonisation of transport, (4) Decarbonisation of industry, (5) Decarbonisation of electricity and heat production, (6) Synthetic fuels and other uses, (7) Employment, requalification, and vocational training, (8) Cross-cutting actions. Leading Considerations should include:

Recommended Action	**Implementation period**
(1) Approve the necessary procedures for the licensing of hydrogen production installations and associated renewables infrastructure. This should include a simplified licensing mechanism for hydrogen production facilities when directly associated with an existing renewable electricity production centre.	2023-2025
(2) Regulate hydrogen injection into natural gas networks, including the identification of potential injection points.	2023-2025
(2) Promote hydrogen injection into natural gas networks by establishing mandatory incorporation targets.	2024-2025
(2) Promote the use of hydrogen as an energy storage mechanism that complements existing renewables infrastructure, plans, and targets.	2023-2030
(3) Provide clear and concise regulations regarding the installation of hydrogen refuelling stations, featuring both off-site and on-site hydrogen production	2023-2024
(3) Promote the use of green hydrogen in specific road-based transport fleets (such as those discussed above) by encouraging replacement of existing vehicles with hydrogen alternatives, as well as establishing a minimum hydrogen obligation.	2023-2033
(4) Promote and encourage the replacement of natural gas and fossil fuel-based feedstocks with green hydrogen and raw materials produced using green hydrogen, with the determination of targets for its introduction.	2023-2033
(5) Promoting the use of hydrogen for combined energy production (electricity and heat), using hydrogen in buildings and community energy installations.	2023-2033
(6) Carry out a foresight assessment of synthetic fuel production potential from hydrogen, in addition to other forms of energy, and how they can contribute to the decarbonisation of the economy - particularly in sectors with fewer options such as aviation. Identifying potential demonstration projects to be implemented in the coming years to grow knowhow is critical.	2023-2028
(7) Establish a collaborative vocational training network for the energy transition and renewable energies. Also, consider the establishment of a local centre of excellence in these fields.	2023-2028
(8) Stimulate the conversion of replacement of carbon-intensive activities with, lower emission, hydrogen alternatives in applicable sectors.	2023-2040
(8) Encourage the implementation of 100 % renewable city pilot projects, where hydrogen emerges as a complementary solution for total decarbonisation energy consumption.	2023-2033
(8) Promote studies on public perception, impact on employment, health and safety and regional/local development.	2023-2028
(8) Develop yearly data monitoring procedures of local fuel usage by sector across the Balearics Islands, including reporting on renewable fuel penetration in each sector.	2023-2025
(8) Foster cross-sector hydrogen demonstration projects, as exemplified by Green Hysland, to improve the viability of local projects by directly linking production, storage & distribution, and multiple end-uses (industry, mobility, and heating) together.	2023-2028

TABLE 8: *RECOMMENDED ACTIONS TO BE INCLUDED AS PART OF SPECIALISED LOCAL HYDROGEN STRATEGY TO GALVANISE DEVELOPMENT ACROSS THE WHOLE HYDROGEN VALUE CHAIN*

Aviation potential enabling inter-island collaboration – Transport accounts for over 42% of the Balearic's emissions (2019). On the island of Mallorca, however, due to the presence of Palma de Mallorca (PMI) - Europe's 12th busiest airport by number of passengers - transport is responsible for a much larger proportion of local emissions. In order to match pace with the region's 2050 legislated targets – 100% renewable energy consumption, 70% local content, and 90% emissions reduction – the island must accelerate its transport decarbonisation efforts, particularly with reference to aviation.

Aviation is often seen as one of the most challenging areas of mobility to decarbonise. Direct electrification – the standardised emissions saving route for other areas of transport such as passenger vehicles – is only possible for the smallest types of aircraft. The power-density of aviation grade batteries, 170 watt-hours per kg (wh/kg), is much lower than that of currently used fuels such as Jet A at 12,000 wh/kg[41], which limits their applicability. Therefore, to enable the decarbonisation of other aircraft types, particularly medium-distance, and long-haul aircraft, alternative solutions are required.

Sustainable Aviation Fuels (SAFs) – conventional jet fuels made using sustainable resources - will dominate the long-haul sector. However, in medium-distance aircraft, liquid hydrogen (LHY) is expected to be the most optimal decarbonisation option, enabling zero-emission flight through use of FC technology. Analysis by McKinsey & Company[42], suggests that large European airports, such as PMI, could exhibit hydrogen demand of 40,000 tons per year by 2040 when replacing just 5% their fuel with LHY – over 120 times Green Hysland's production capacity. It should be noted that, whilst external to the scope of this study, the potential hydrogen demand of PMI is expected to far exceed the demand from mobility, industry, and district heating combined.

LHY's penetration into the aviation market, however, is still in its infancy. Component parts such as engines are only just entering testing phases and commercial demonstrations of these technologies will be the crucial next step to realising widespread acceptance. Mallorca represents an ideal location for these demonstrations. With the first hydrogen-powered aircraft units expected to be available from 2030 – 2035, the Balearics can use aviation as an impetus to spread hydrogen knowhow from Green Hysland's initial nucleus to the rest of the archipelago.

For example, PMI can deploy hydrogen ground service vehicles (buses, taxis, tugs, forklifts etc.) to gain confidence in hydrogen technologies and refuelling and safety protocols – taking learnings from Green Hysland's mobility deployments – before scaling to hydrogen aircraft for use on local routes. Demand from a single aircraft is likely to represent an order of magnitude increase from the project's initial activities and therefore constitutes an ideal next step for all stakeholders involved, whilst making meaningful progress towards key decarbonisation targets. A single 1,500km journey – the same distance of Mallorca to London – would need around 1,500 kg of liquid hydrogen per journey, or 546 tonners per year for a single daily flight – over 1.5 times Green Hysland's current production capacity. Overall, PMI consumed 600,476 MT of Kerosene in 2022 across >200,000 flights, making the potential demand for LHY in the airport substantial.

PMI can then use this initial demonstration to enhance its other decarbonisation activities – utilising their leading hydrogen position to launch further collaboration opportunities with other proximal destinations such as mainland Spain and Southern Europe and increase their hydrogen fleet. These

[41] SIEMENS. Hydrogen-powered aircraft design.
[42] McKinsey & Company. Hydrogen-powered aviation. (2020).

follow-up activities could also target the private jet sector to maximise emsisions savings per vehicle which emit, on average, two tons of CO_2 per hour – ten times more than a commercial aircraft – and are responsible for 16,000 movements in Mallorca, and 15,000 movements in Ibiza (2022).

The exploration of use of hydrogen within PMI and other Balearic airports is strongly encouraged to develop a prosperous archipelago-wide hydrogen sector. Similar inter-island collaboration opportunities can be found in the maritime sector through replication of FC-based CHP in other Balearic ports, or the establishment of hydrogen-powered marine transport links as demonstrated within other European projects with both passenger and car ferry vessels.

Recommended actions in this area	Implementation period
Work alongside applicable national bodies to provide a clear and concise regulatory pathway regarding the implementation of hydrogen technologies (production, storage & distribution, and end-uses) within an airport environment.	2023-2025
Foster demonstration projects that replace the use of fossil fuels with hydrogen in ground-based airport vehicle fleets. Specific focus to collaborate with other European airports to share best practices regarding hydrogen fuels in airport environments (supply, distribution, bunkering, refuelling, safety, etc.)	2023-2028
Ensure active participation in policy development groups at a national level to promote the Balearic's opportunity to pioneer in promoting hydrogen technologies in aviation.	2023-2033
Design targeted calls to support the development and implementation of hydrogen-powered aviation projects with an initial focus on linking the Balearic Islands together and other strategic locations across Europe	2028-2035

TABLE 9: *RECOMMENDED ACTIONS TO STIMULATE AND GROW THE USE OF HYDROGEN IN AVIATION ACROSS THE ARCHIPELAGO*

The need for support and regulatory mechanisms – Green Hysland's initialisation of the Balearic hydrogen sector has been enabled by European and National grant funding, but that is just the start of support that is required. Countries who have also deployed hydrogen valleys – such as the Netherlands (HEAVENN) and Germany (Multiple) - have similarly found that, whilst these initiatives are effective at creating the foundations of a local hydrogen sector, more aid is required to realise a widespread hydrogen economy.

A mixture of Capital, Operational, and Regulatory measures are required to effectively broaden hydrogen deployment by preferentially incentivising these systems over carbon-emitting or more mature battery technologies. This includes broad economy-wide actions, such as national carbon taxes or Europe's CBAM, as well as more targeted sector-specific support. Hydrogen production subsidies have so far been the most popular form of financial support so far - with around $170bn of finances available globally and mechanisms in place both on a Spanish and European level. However, hydrogen production projects are not yet progressing to Final Investment Decision (FID) regularly enough due to a lack of certainty around the awarding of these finances, as well as demand certainty once up and running. A report from the Hydrogen Council[43], released in May 2023, suggested from >1,000 clean hydrogen projects worldwide, under 10% had reached FID. Recently released definitions of renewable hydrogen by the European Commission alongside national legislation regarding Guarantee of Origin (GoO) systems, such as Spain's renewable gas scheme that came into force in May 2022, has provided much needed clarification for projects to start to overcome this hurdle, but more must be done, particularly in remote locations.

Current financial support mechanisms are not well suited to remote locations. Production-based subsidies are primarily focused on subsidising large-scale production projects which have considerable

[43] Hydrogen Council, McKinsey & Company. Hydrogen Insights 2023. (2023).

land-space needs and require flexible robust electrical infrastructure to provide power when the wind doesn't blow, or the sun doesn't shine. Whilst end-user subsidies, both on a European and national scale, are suited to replacing grey hydrogen and fossil fuel use amongst the region's industrial bases. Islands, which feature a distinct lack of local industry, constrained land resources, and fraught electrical grids, will therefore struggle to obtain funding in competitive processes against mainland European areas.

Two primary solutions are available to alleviate this issue. The first is ring-fenced national funding for isolated regions to prevent competition with similar activities based on the mainland which, due to its connectivity, will be seen as superior. The second is targeted support towards sectors which are more evenly distributed across all Spanish regions – such as transport rather than industry. Biofuel transport related measures are common within a Spanish context, with ever-increasing obligations for wholesale and retail operators of fuels present since 2009 – now requiring 10.5% penetration (2023[44]). These entities are rewarded certificates for each 1 TOE of these fuels supplied and are penalised if they do not meet the expected quota. However, no such quota for hydrogen exists despite the mobility goals laid out within the national hydrogen strategy. Spain could take note from the systems deployed within the other regions – such as the UK's Renewable Transport Fuel Certificates (RTFCs) or the Netherland's HBEs – which reward hydrogen supplied into transport preferentially over other biofuel options to help develop its position within the marketplace. Although, currently, these systems only apply to certain transport applications, limiting their impact to certain areas. Spain can deploy similar measures whilst utilising their own biofuel experience, to seek wider deployments of a more inclusive certificate-based scheme to progress the hydrogen economy from its developmental stage into a fully-fledged competitive sector. The Balearics, as a location where transport accounts for such an overwhelming proportion of local emissions, would be the ideal deployment location for a trial of this measure before enacting country-wide implementation – enabling an accelerated development of local value chains and leading to more significant per capita emissions reductions.

Recommended actions within this area	**Implementation period**
Develop and publish local sector-specific renewable fuel obligation targets, with specific goals for the use of hydrogen	2023-2025
Ensure active participation in national-level support scheme development activities to ensure they are inclusive of the Balearic's tourism driven economy.	2023-2033
Develop local support schemes to incentivise the deployment of hydrogen technologies across the local economy. Renewable fuel certification schemes and CAPEX grant funding schemes are highly recommended.	2024-2025

TABLE 10: *RECOMMENDED ACTIONS TO DEVELOP AND POSITION LOCAL SUPPORT MECHANISMS TO ACCELERATE HYDROGEN SECTOR DEPLOYMENT.*

[44] Fastmarkets. Spain eyes alternative fuel focus in 2023. Available at: https://www.fastmarkets.com/insights/spain-alternative-fuel-focus-2023#:~:text=Spain's%20mandate%20for%20sales%20or,(RD%201085%2F2015). (2023).

8 Conclusion

Hydrogen, as a locally producible, renewable fuel that can simultaneously realise emissions savings and energy security improvements will play a transformative role within Mallorca and the wider Balearic Island's energy transition. However, as seen across other hydrogen-active regions, the scaling and bankability of hydrogen demand, alongside continual development of enabling infrastructure such as pipeline networks and refuelling stations, will be crucial to increasing local activities across the hydrogen value chain. The Balearics Islands, with the presence of a hydrogen valley, considerable renewables potential, and critical resources such and a natural gas grid are well positioned to continue growing its hydrogen sector but will need considerable policy development to galvanise private sector activities.

As part of this study, a number of deployment scenarios were produced assessing the potential scale-up of hydrogen technologies across 2030 and 2050 timelines for each of the three sectors of interest. The key findings of these modelling activities were: (1) Mallorca's gas grid has the potential to provide a considerable 'baseload' of hydrogen demand that can be used to enable scale-up of production until other offtake areas come online. The demand potential associated with even medium blend percentage predictions of 3.5% in 2030 is likely to far exceed potential production volumes in this time frame. (2) By 2030, there are a number of vehicle fleets which could provide a core baseload of hydrogen demand within the mobility market, mostly associated with heavier vehicle types. These could be principally serviced by an AFIR eligible HRS within Palma. (3) The opportunity for hydrogen DHC across the Balearic Islands is likely to be dependent on an initial trial to gain experience and confidence with relevant technologies. This demonstration is seen as vital to breaking down the regulatory and social hurdles preventing widespread deployment. Therefore, without a local trial in the next decade, hydrogen DHC is unlikely to penetrate the market in the long-term. (4) Despite expected energy demand reductions in line with regional energy transition policy, considerable gas and transport fuel demand will remain come 2050. Even in low sector penetration rates, this still results in considerable demand for hydrogen which will be required to meet net-zero commitments.

This report recommends that (1) green hydrogen should be supported as a route to decarbonise heavy-duty and high operational requirement transport modes, (2) green hydrogen should be supported as a route to decarbonise high-temperature industrial heat and the gas-grid, (3) the opportunity to deploy a hydrogen DHC trial locally should be explored to fully understand the potential impact of the technology, (4) the Balearic Islands requires its own specialised hydrogen strategy that is optimised to the makeup of the local economy rather than the national hydrogen strategy, (5) the Balearic Islands should seriously explore their future requirements of hydrogen-powered aviation with a view to utilise initial developments to expand hydrogen knowhow across the archipelago, (6) the deployment of local support and regulatory mechanisms that preference hydrogen technologies should be prioritised to instigate further development from Green Hysland's initial activities.

9 Appendix

What is a Fuel Cell?

Unlike batteries which store energy, fuel cells convert chemically stored energy into electricity. In the case of hydrogen, this process occurs by stripping the hydrogen molecules of its electrons which then flow through the system to provide an electrical current. The hydrogen ion then reacts with oxygen to form water as its only by-product – essentially the same an electrolyser operating in reverse.

Fuel cells have been used since the 1960s, perhaps most notably by NASA to help power space craft whilst in orbit but have found a new following to provide low-emission energy via the use of low-carbon hydrogen. Fuel Cells, due to their zero-emission, quiet, and efficient power production potential are being positioned to play a crucial role in hard-to-abate sectors such as transport, heating, and industry. They come in a variety of different technologies, each with their own unique set of advantages which make them optimised to certain end-uses, as outlined below.

Fuel Cell	Efficiency	Power	Operating temperature	Startup time	Operational lifespan (stack)	Applications	Advantages	Disadvantages
Proton Exchange Membrane (PEM)	40-60%	0.12-5kW	80-100°C	<1 minute	40,000 hours	HDVs LDVs	Small Light weight Quick startup	Sensitive to low temp. Senstive to salinity Sensitve to humidity Expensive catalysts
Alkaline (AFC)	60-70% (80% CHP)	0.5-200kW	60-70°C	<1 minute	6,500-8,000 hours	Backup power Mobility Aerospace	Low operating temperature Quick startup Cheaper components	Relatively large Senstive to fuel & air impurities
Phosporic Acid (PAFC)	40-50% (80% CHP)	100-400kW	150-200°C	N/A	40,000 hours	Buildings Hotels Hospitals Utilities	Mature technology	Less power output Produces phosphoric acid vapor
Molten Carbonate	50-60% (80% CHP)	10kW-2MW	650°C	10 minutes	40,000 hours	Electrical utilities Industry	Fuel variety High efficiency (with CHP)	Slow startup Highly corrosive
Solid Oxide (SOFC)	60% (90% CHP)	0.01kW-2MW	500-1000°C	60 minutes	40,000-80,000 hours	Power plants Auxiliary power Electrical utilities	High efficiency (with CHP) Fuel variety	Intense heat

FIGURE 13: TYPES OF FUEL CELLS AND THEIR CHARACTERISTICS (HYENERGY)

PEM fuel cells are currently dominating the automotive industry due to their lightweight, small size and quick startup times, with systems already deployed across several vehicle types such as fuel cell electric buses and trucks. Whereas Industry has historically used PAFCs, MCFCs or SOFCs as they can be deployed with larger power outputs and their higher operating temperatures allow them to make better use of waste-heat from the industrial process and therefore increasing the efficiency of the system as a whole. A variety of different fuel cells will be best used in hydrogen-based applications on the island of Mallorca due to the different benefits of each type in respective sectors.

GREEN HYSLAND

www.greenhysland.eu
info@greenhysland.eu

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