Report

Mapping hydrogen supply chains in Poland and the UK

Commissioned by the The British Embasy in Poland
Warsaw, March 2023

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REA THE ASSOCIATION FOR RENEWABLE ENERGY & CLEAN TECHNOLOGY

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Introductory remarks

Often referred to as 'fuel of the future,' hydrogen is increasingly on everyone's minds. We can see it especially in this part of Europe, where countries are pursuing ways to increase their energy security and give up imports of Russian hydrocarbons.

Hydrogen from fossil fuels has been used safely for many decades in a wide range of applications, including in the food, metal, glass and chemical industries. But as economies strive to achieve carbon neutrality, it's the low carbon hydrogen that presents itself as a true alternative to natural gas.

The UK's goal is to maximise energy decarbonisation in an affordable and secure way and we believe that green and blue hydrogen could be essential in helping us meet our 2050 net zero target, playing a vital role in levelling up the economy, supporting the low carbon economic transformation of our industrial regions, and creating new high value jobs.

Decarbonisation of power, heat and transport sectors will be the key to achieve this. I am confident that UK companies with their world class skills and expertise will have a significant role to play in that process.

The UK's geography, geology, infrastructure, innovation and expertise make it well suited to rapidly developing a low-carbon hydrogen economy. Our Hydrogen Strategy focuses on driving progress to scale up the hydrogen economy in the 2020s, to deliver our 5GW production ambition by 2030.

UK companies are already at the forefront of global hydrogen technology development and they are keen to develop mutually beneficial initiatives with foreign partners. We have a strong history of collaboration between government, industry and innovators to tackle climate change and grow the economy.

I encourage consultancies, policymakers, manufacturers, technology providers and all stakeholders interested in the hydrogen economy to read this report. For UK stakeholders it is an excellent source of information about Poland's emerging hydrogen economy and related business opportunities in this sector. For our Polish partners, it should help identify capable UK hydrogen supply chain companies ready to offer relevant technologies and solutions. There is much at stake, and we're better off pursuing this exciting opportunity together.

Anna Clunes
British Ambassador to Poland

1. Introduction

1.1. Summary of the Polish hydrogen strategy

Poland is the third largest producer of hydrogen in Europe (approx. 1.3 million tons per year). However, almost all the hydrogen currently produced in Poland is fossil-based Polish hydrogen is produced and used mainly in refineries, fertilizer, and chemical industries. The largest producers of hydrogen in Poland are Grupa Azoty (420,000 tons per year), JSW Koksownie (149,000 tons), PKN Orlen (140,000 tons) and Lotos (59,000 tons), with the remaining 41% produced by other companies. The significant volume of production was identified as a potential opportunity for further development of low- and zero-emission hydrogen technologies.

Following the hydrogen strategy for a climate-neutral Europe adopted in July 2020., In November 2020 Polish government presented the „Polish Hydrogen Strategy until 2030 with a perspective until 2040". In October 2021, the government and 138 stakeholders signed the multi-sector agreement for the development of hydrogen economy. Finally, in October 2022, the government presented a draft amendment to the Energy Law, which refers to the hydrogen. Below is a brief overview of these documents.

Polish hydrogen strategy

„Polish Hydrogen Strategy until 2030 with a perspective until 2040" was adopted in November 2020 as an official government paper. The document defines the main objectives of the development of the hydrogen economy in Poland and the directions of action necessary to achieve them. According to the Ministry of Climate and Environment, the overriding goal of the Strategy is „to create a Polish branch of the hydrogen economy and its development to achieve climate neutrality and maintain the competitiveness of the Polish economy".

To achieve this, the document identifies 6 specific objectives:

Objective 1 - implementation of hydrogen technologies in power and heating.
Objective 2 - using hydrogen as an alternative fuel for transport.
Objective 3 - supporting the decarbonisation of industry.
Objective 4 - production of hydrogen in new installations.
Objective 5 - efficient and safe transmission, distribution, and storage of hydrogen.
Objective 6 - creating a stable regulatory environment.

The document reflects the challenges facing the Polish economy – the high dependence of the energy sector on coal and the high level, but based on fossil fuels, production of hydrogen. According to the Strategy, these actions will l help achieve climate and energy goals. Decarbonisation of hydrogen production will minimise the negative socio-economic effects of moving away from coal-based energy. As low- and zero-emission hydrogen production ramps up, the share of RES in the Polish energy mix will increase and regulatory barriers to the development of the hydrogen market will be concurrently removed.

The strategy sets out a total of 44 actions, which include e.g. the creation of hydrogen valleys, which will develop hydrogen economy value chain such as production, transport, storage, and final use of hydrogen in industry. Valleys will act as research and development and investment hubs and will contribute to cooperation between local, national, and foreign stakeholders.

The strategy supports all methods of production of low- and zero-emission hydrogen with an indication of: water electrolysis process, biomass gasification, fermentation or pyrolysis technology, steam reforming of biogas, steam reforming of biomethane, gasification, thermal treatment or pyrolysis of waste, waste gases, steam reforming of hydrocarbons using CO2 capture and storage technology (CCS/CCU), coal gasification using CCS/CCU technology, IGCC technology (gasification in gas-steam cycle integrated with gasification of solid fuels) and IGFC (using part of the captured emissions of combustion gases for energy production).

The indicators of achievement of the objectives adopted in the Strategy assume:

- installation of low-emission hydrogen production installations with a capacity of 50 MW by 2025 and 2GW by 2030
- at least 5 hydrogen valleys are to be formed
- introduction of hydrogen buses: up to 250 units by 2025 and between 800-1000 units by 2030
- at least 32 H2 refuelling stations operational by 2025
- establishment of the Centre for Hydrogen Technologies.

According to the Strategy, the cost of capital expenditures necessary for its implementation will amount to approx. PLN 11 billion, of which the most, about PLN 9 billion, will be attributed to hydrogen production installations. However, the strategy assumes that the cost of hydrogen production from RES would be profitable at a level below EUR 40-50 / MWh at an exchange rate of PLN 4.50 for EUR 1. However, after the outbreak of the war in Ukraine, the currency exchange and energy prices have changed several times. The final ratio is therefore difficult to predict until energy prices stabilize.

The Strategy focuses on the development of infrastructure in the cluster model, postponing the analysis of hydrogen storage and transmission for the future. The cost of adapting or building the transmission infrastructure was estimated at PLN 1.8 million/km for adapting the existing gas pipeline, PLN 1.6 million/1 km of compression systems and PLN 9.4 million/km for the construction of a new pipeline.

1.2. Multi-sector agreement for the development of the hydrogen economy in Poland

The next stage of the government's work was the adoption of the Multi-sector Agreement for the Development of Hydrogen Technologies in October 2021. According to the declaration of the Ministry of Climate and Environment: *The basic and most important objective of the Agreement, in addition to creating conditions and cooperation for the development of hydrogen technologies and their application, is to maximi-*

ze the level of local content – Polish contribution.

The structure of the agreement and the working groups established to prepare it, corresponds to the objectives of the Polish Hydrogen Strategy, except for the sixth Objective (Creating a stable regulatory environment), which was replaced by „Development
of the national hydrogen economy value chain" and „Education and promotion".

The agreement assumes the share of the Polish contribution to the national hydrogen economy up to at least 50% of the value in 2030. According to the document, Polish contribution is understood as the participation of entrepreneurs with their registered offices in Poland, foreign entrepreneurs with a branch or operating in Polish, as well as solutions of the Polish scientific and research sector as well as Polish implementations and patents. It can be assumed that the main tool enabling the implementation of this goal will be achieved using grants, primarily through the National Centre for Research and Development (NCBR) (see the next subsection).

Other objectives of the agreement, in contrast to the „industry" approach of the Strategy, focus on issues such as Research and Development (R+D), Investment, People and Cooperation. In individual areas, the necessary actions, deadlines and entities and administrative units assigned to them have been defined.

The document was signed by representatives of the government, state institutions, research and scientific centres, companies and non-governmental organizations operating or interested in acting in the field of hydrogen – a total of 138 stakeholders.

To coordinate the implementation of the Agreement, the Minister of Climate and Environment appointed a Coordination Council, which consists of 45 members representing public administration, entrepreneurs, science faculties and institutions, as well as business environment units. The Chairman of the Council is Ireneusz Zyska. Mr Zyska is the Secretary of State in the Ministry of Climate and Environment, responsible for Renewable Energy Sources. He is a lawyer by education, a member of the Law and Justice party and previously worked in a legal adviser's office and held local government functions.

Ireneusz Zyska

Secretary of State,
Government Plenipotentiary for Renewable Energy Sources

1.3. Draft amendments to key laws

The draft amendment to the Energy Law and certain other acts published in October 2022 (paper no. UD382) is the first element of the so-called Constitution for hydrogen. First, the amendment introduces the necessary definition of hydrogen in the Energy Law, which, as the legislator explains, will allow to consider „broad applications of hydrogen as a raw material, carrier and energy storage".

The draft amendment also includes definitions concerning, electrolysis, storage, transmission, and distribution of hydrogen. According to the project, it will be necessary to obtain a concession for the storage of hydrogen above 5,000 Nm3, hydrogen trade (only above EUR 100,000 per year), as well as the transmission of hydrogen by pipeline. The hydrogen market is to be supervised by the Energy Regulatory Office.

It is worth noting that the implementing regulations - the conditions for connection to the hydrogen network, technical requirements, the method of hydrogen trade, as well as the conditions for transmission, storage, and operation of the hydrogen network – will only be specified in the Ordinance, which will be announced by the relevant Minister.

The draft amendment also introduces changes to several other acts such as:

- construction law (infrastructure for hydrogen transmission will be subject to the special transmission act, which will facilitate the implementation of such investments. Also, hydrogen purification installations with a capacity of up to 250 kg per day will not require a building permit),

- the Act on the National Centre for Research and Development (NCBR), in which a special place will be occupied by a new hydrogen committee created i.e. by representatives of the Ministries of Finance, Economic Development and Technology, Climate and Environment and Science and Higher education. The Committee will be responsible i.e. for setting research and development strategies and conducting competitions in this area.

The proposed amendment introduces the obligation to obtain a license for hydrogen storage installations above 5,000 Nm3, hydrogen transmission, hydrogen trading (excluding trading below EUR 100,000) and hydrogen supply via direct hydrogen pipelines. **The production of hydrogen is exempt from the concession obligation, but the storage of hydrogen in quantities exceeding 440 kg is subject to such requirements, as well as the transmission and trading. The facilitations will also apply to purification installations with a capacity of up to 250 kg of hydrogen per day.** Although the conditions for issuing the concession by ERO have not yet been determined, a certain barrier for larger installations can be expected.

Although the system of incentives and support for the implementation of hydrogen technologies is not an element of the current amendment, it can be assumed that it will be included in the next part of the „Constitution for hydrogen".

1.4. Building the hydrogen technology value chain (based on the Constitution for hydrogen and the multi-sector agreement):

The main source of energy in Poland is coal and lignite. In 2021, the share of coal in electricity production was almost 76%. Coal also dominates in the heating and individual heating sectors. **The share of RES in electricity production was only 13.6%. The target presented by the Polish government for 2030 is the share of RES at the level of at least 21%.** One of the solutions that will facilitate the development of renewable energy and enable the storage of surplus energy, especially during periodic production peaks – is hydrogen.

Regardless of the adopted documents and the ongoing regulation changes concerning hydrogen the pace and scope of its implementation will be influenced by events that in 2022 affected – to varying degrees – all European countries. Russia's invasion of Ukraine, which has led to a change in the direction of fossil fuel imports, an increase in energy prices, as well as an increase in inflation and a deterioration in the economic outlook, may provide an impulse for investment in renewable energy sources, including hydrogen. In this context, the RES industry, e.g. the Polish Wind Energy Association, appeals to the government to introduce facilitations in the process of investing in new wind farms. According to the organization, unlocking wind energy will increase the energy security of Polish and reduce electricity prices. This could also be an opportunity for suppliers of hydrogen technologies to store excess wind power.

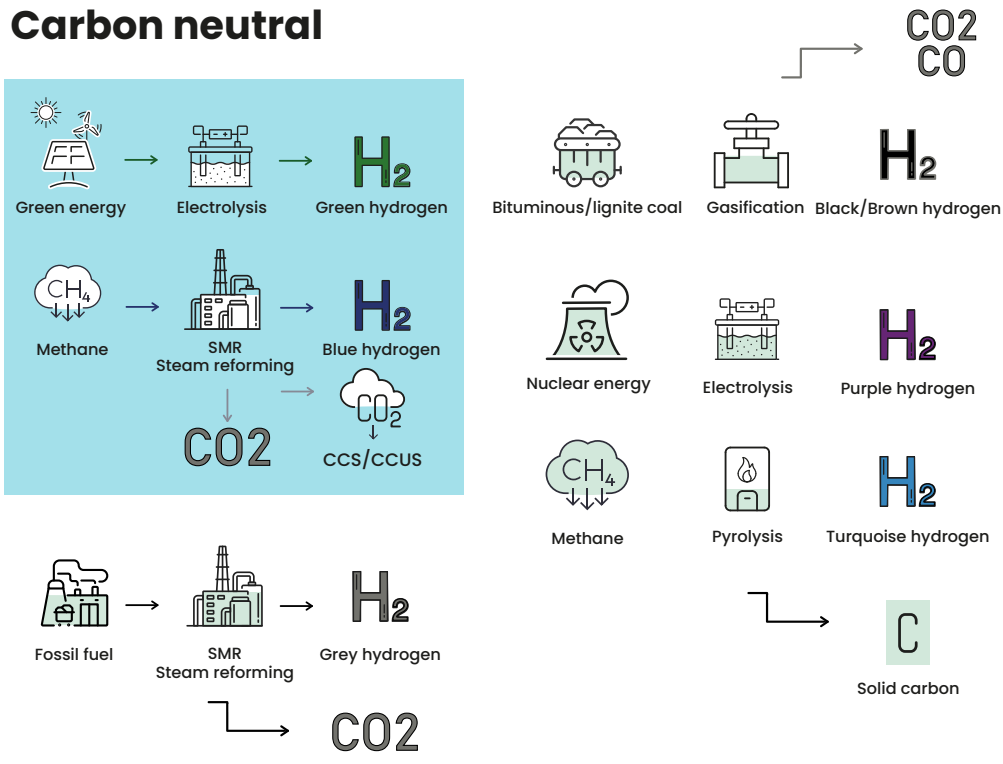
The outbreak of war also led to the announcement of the acceleration of work related to the construction of a nuclear power plant. Poland has received offers from the American Westinghouse, the French EDF and the Korean KHNP. Prime Minister Mateusz Morawiecki announced the selection of the American offer, although the media also reported that two bidders, including the Korean one, would be selected in the parallel. At the same time, statements appeared in the press regarding work on the use of atomic energy to produce hydrogen. Such a possibility is also provided for by the Polish hydrogen strategy.

Despite the economic and geopolitical challenges, the level of resources involved, and the ongoing legislative work testify to the determination of the authorities and stakeholders to create a hydrogen economy.

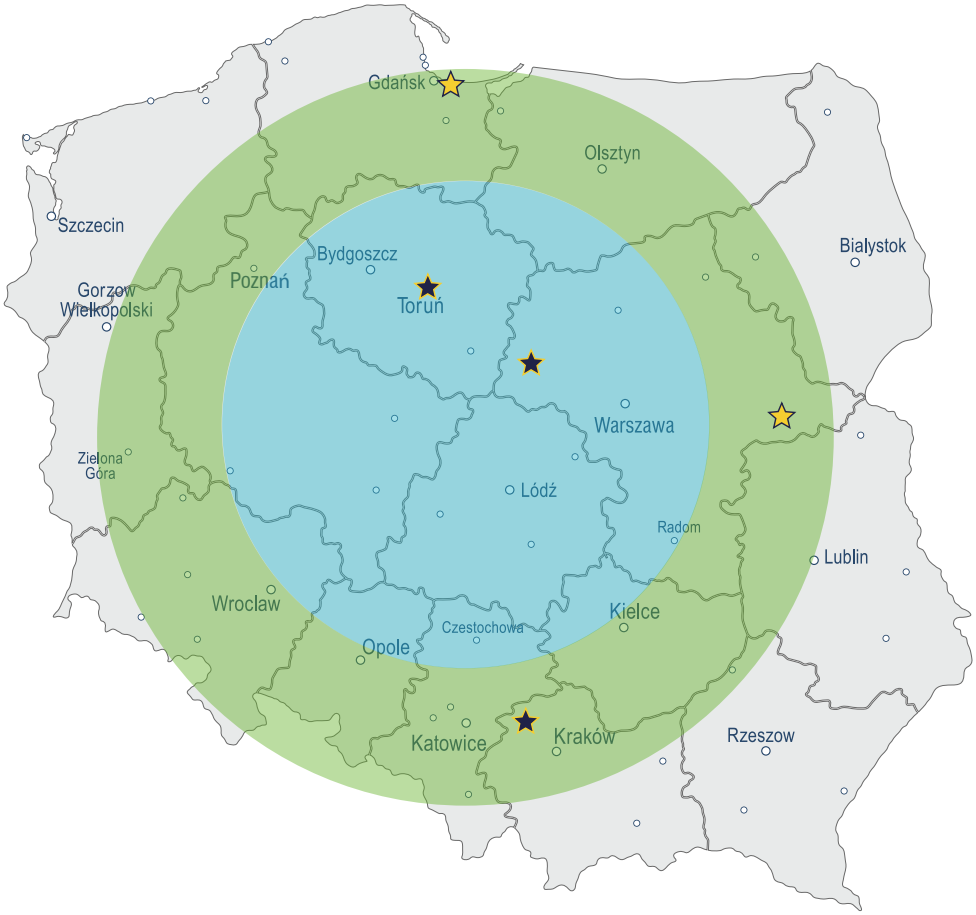
1.5. Green, blue or turquoise? What do the hydrogen "colours" mean

Although hydrogen is an invisible gas, to simplify its categorization several colours are used to describe them. It must be underlined that the following is not a scientific division:

- ***"Green hydrogen"*** is produced through water electrolysis process by employing electricity from renewable sources such as wind, sun, or sea tides. A renewable alternative is the gasification of biomass, provided it is powered by renewable energy. Those methods are called "green" or "renewable" because there is no CO2 emission during the production process.
- ***"Blue hydrogen"*** is sourced from methane. Some of greenhouse gas created in the process of reforming (steam reforming – SMR or thermic reforming - ATR) might be captured and stored (CCS) or captured and used (CCSU). However, this method is not considered carbon neutral by the European Commission.
- ***"Grey hydrogen"*** is produced from fossil fuel and uses steam methane reforming (SMR) method in most cases. During this process, CO2 is produced and released to the atmosphere.
- ***"Black"*** or "brown hydrogen" is produced from coal (bituminous or lignite). The coal is gasified to produce hydrogen. However, it is a very polluting process, and CO2 and CO are produced in the process and then released to the atmosphere.
- ***"Purple hydrogen"*** is made thanks to nuclear power and heat through electrolysis of water.
- ***"Turquoise hydrogen"*** is produced from methane via pyrolysis process in which hydrogen and solid carbon are created.



Profitability of hydrogen distribution



Source: PKN Orlen

- Hydrogen production sites

- Road transport

- Hybrid solutions

According to PKN Orlen, hydrogen distribution is economically viable, in the compressed form (300 bar) in the range of approximately 250 km (155 miles) from the production site. If the distance is higher, hybrid solutions can be used (such as local production of some part of the hydrogen in demand).

2. Review of the ongoing hydrogen projects (top 5)

2.1. Port Gdynia

The Port of Gdynia in the hydrogen economy will create a hydrogen hub in a seaport ranked among the largest ports in the Baltic Sea region and being a node in the TEN-T (Trans-European Transport Network) core network. Ultimately, the launch of renewable hydrogen production is planned for the needs of Gdynia Port stakeholders.

Project start date: May 2022.

Planned date of introduction of hydrogen into operation: 2024.

Main objectives: (1) reduce pollutant emissions from means of transport, handling equipment and transhipment equipment both in the Port of Gdynia and in the port region; (2) implement projects related to fuel and energy transformation, which concern alternative fuels (ensuring bunkering of ships with LNG fuel), renewable energy sources (installation of photovoltaic panels on the roofs of buildings in the port), electromobility (providing electricity supply to ships from land during their stay in the port) and broadly understanding digitization of investment implementation processes and property management.

Furthermore, the possibilities of using hydrogen at the Port of Gdynia regarding fuel and energy transformation are analysed.

The scope of the analysis encompasses using hydrogen as a fuel dedicated to ships, port transhipment facilities and equipment, means of road and rail transport, but also for other purposes. The aim of these analyses is to determine whether it is worth developing technologies for the production and distribution of hydrogen as a zero-emission fuel for consumers in the port area and/or its surroundings.

Company leading the project: Port of Gdynia Authority SA (PGA SA). The company is responsible for the management of infrastructure and port areas, while operational activities such as cargo, passengers and means of transport within the administrative boundaries of the port are carried out by service companies. All these entities form the Port of Gdynia. In 2021, a total of 26.7 million tonnes of goods were handled at the port, or 8% more than in 2020. The Port of Gdynia is also the largest port for agriculture products in the Baltic Sea. It ranks third in terms of container transshipment - nearly 1 million TEU (twenty-foot equivalent unit) in 2021.

Investment plans: depending on the volume of demand, the facility will be equipped with fixed storage and distribution facilities, possibly hydrogen production (e.g. electrolysers, fixed storages, local hydrogen refueling stations) and/or mobile devices (mobile storage and refueling stations). The initiative will enable the production, distribution and use of zero-emission hydrogen. The company estimates the demand for hydrogen fuel reported by its potential buyers, but also examines the interest of investors in the production and distribution of this fuel at the port. Such studies are necessary to justify or exclude the decision to involve PGA SA in projects related to hydrogen economy.

Risks: lack of access to sufficient hydrogen for consumers of this fuel and energy carrier (in Poland, hydrogen is generally produced to meet its own needs and is not traded). The future price of hydrogen is also unknown, which is important for stakeholders in connection with the need to conduct long-term calculations regarding investments in equipment, hydrogen production and distribution installations and hydrogen-powered vehicles. Currently, a very serious barrier to making decisions regarding the implementation of innovations related to the use of hydrogen is the fact that necessary regulations are being drafted, which may delay the implementation of investment projects in this area. Another risk factor seems to be the lack of staff properly prepared to operate equipment for the production, storage and distribution of hydrogen. The relatively high cost of purchasing hydrogen-powered means of transport and handling equipment compared to traditional solutions also remains a problem. Port terminals (i.e. potential stakeholders of the hydrogen hub in the port) are commercial enterprises (often subsidiaries of large international corporations), and therefore it is difficult to expect them to make very risky decisions regarding the implementation of hydrogen innovations in a situation of uncertainty caused by the above-mentioned factors. The creation of an attractive mechanism for their financing also seems to be an indispensable condition for the implementation of hydrogen technologies.

Activities for the implementation of hydrogen technologies at the Port of Gdynia:

- Signing of the Sectoral Agreement for the construction of a hydrogen economy in Poland (previously participation in government working groups for the development of this agreement) and participation of a representative of PGA SA in the work of the Coordination Council for hydrogen economy operating in the Ministry of Climate and Environment.

- Active participation in the work of the Cluster of Hydrogen Technologies and the Pomeranian Hydrogen Valley (which are local cooperation platforms that can facilitate the preparation and course of fuel and energy transformation in the port).
- Joining the Green Corridor project on green maritime transport corridors.
- Preparation of initial conceptual assumptions regarding the production and use of hydrogen fuel at the Port of Gdynia in the form of developing the concept of a hydrogen hub in this port. Establishing the principles of cooperation with potential stakeholders, including hydrogen producers, its distributors, suppliers of resources necessary to create infrastructure for supplying means of transport with hydrogen fuel and consumers of hydrogen.
- Participation of the company's employees in national and international conferences, seminars, study visits on hydrogen issues to acquire knowledge about the possibilities of developing the hydrogen economy at the Port of Gdynia.
- Exploring the possibilities of participation in hydrogen projects with domestic and foreign partners.
- Animation of activities aimed at the development of the hydrogen economy at the Port of Gdynia, including those related to the introduction of means of transport, devices, equipment, and machines with hydrogen cells (including the commencement of cooperation with potential partners within the port market and road, rail and maritime transport).
- Activities aimed at the development of hydrogen fuel refuelling and bunkering points at the Port of Gdynia.
- Starting cooperation with suppliers of hydrogen-powered means of transport, handling equipment, machinery, but also producers of fuel, hydrogen cells, energy storage solutions, electrolysers, etc. and local fuel companies supplying hydrogen.
- Using the concept of fuel and energy transformation, including hydrogen solutions, in the process of preparing a partial strategy (which is part of the port development strategy) regarding the implementation of this transformation.

Expected benefits of creating a hydrogen hub:

- Reducing the carbon footprint of the Port of Gdynia and its stakeholders.
- Implementation of climate goals as set out by the European Union.
- In the long run - reducing environmental costs generated by PGA SA and port operating companies by providing the necessary and legally required infrastructure related to the production and distribution of hydrogen for seaport stakeholders.
- Participation in the creation of logistic supply chains of a new zero-emission fuel.
- Increasing the competitiveness of the port through activity on the hydrogen market already at the initial stage of its development.
- Enhancing image as "the green" port.
- Reducing the potential risk associated with non-compliance with the obligations related to the Port of Gdynia's membership in the TEN-T core network.

PGA team:

- ***Dr Hanna Klimek*** - economist and academic teacher. Scientific interests: transport economics, operation and development of seaports, port services markets, competitiveness of seaports, port policy, logistics.

- ***Dr Beata Barbara Szymanowska*** - Plenipotentiary of the Company's Management Board for the implementation of the hydrogen program, Head of the Research and Technology Development Department, Port of Gdynia Authority S.A., Member of the Coordination Council for Hydrogen Economy at the Ministry of Culture and Culture.

- ***Michał Daczuk*** - Project Manager, Research and Technology Development Department.

2.2. Techplast

Techplast Sp.z o.o. – production of innovative composite hydrogen tanks.

Project start date: 2021

Main goals: The company intends to expand its operations and implement new technologies. For this purpose, a new 4,500 sqm production and research facility is being built. As part of the investment, a hall with a new production line, an office building, a laboratory, and service workshops will be built. Currently, Techplast employs over 50 people, but after the construction of the plant in the zone, the planned employment may reach up to 150 workers.

The company running the project:

Techplast is a manufacturer of fourth generation high-pressure composite tanks. Currently, Techplast produces specialized, lightweight gas tanks, e.g. for oxygen, used by divers and rescue services. The innovation of the SAFER® cylinder consists in reducing the weight of the tank by 65% compared to a steel cylinder. The effect of lightness was achieved thanks to the use of PET liner and high-quality carbon and aramid fibers.
The PET liner is characterized by high barrier properties and does not react with the stored gases, preventing corrosion, thanks to which the gases stored inside the tank retain their purity and are completely safe for the user of the cylinder.

As part of the development the company is planning to produce composite hydrogen tanks in Andrychów. The construction cost is estimated at about PLN 20 million. Financing will be partly from EU funds and a bank loan.

Within a NCBR project Techplast received PLN 10 million from EU funds. The aim of the project is to develop and increase Techplast's competitiveness on the industry market. The main goal will be achieved by developing a technology for manufacturing of ultra-light composite hydrogen storage tanks for distributed energy systems. According to the company, this will allow it to achieve a significant competitive advantage.

In 2022, Techplast opened a procedure for the purchase of elements of a technological line to produce hydrogen tanks. The next stage is the construction of a R&D center that will develop hydrogen high pressure storage technologies.

Techplast team:

- ***Adam Saferna*** – founder and owner of Techplast
- ***Dawid Saferna*** – managing director of Techplast

2.3. ZE PAK

ZE PAK is a complex of three thermal power plants using lignite and biomass in the Wielkopolskie Voivodeship. The company is the largest private energy producer in Poland. The annual electricity production of ZE PAK is 4 TWh, which is about 3% of the total energy production in Poland. Currently, 87% of energy in ZE PAK is produced from lignite coal, and the remaining 13% is provided by biomass and renewable sources. Employment in ZE PAK is approx. 3,200 persons. The company invests and conducts numerous projects in the field of renewable energy – biomass, photovoltaics, on-shore and off--shore wind, as well as thermal waste treatment, nuclear energy and hydrogen. ZE PAK's activities focus on the transformation towards clean, zero-emission energy and investments in renewable hydrogen. For this purpose, a nationwide, full supply and value chain of renewable hydrogen is being built.

Net – Zero Energy	Green hydrogen production	Storage and transport	Green hydrogen distribution	Customer goods
Solar Wind Biomass	Goal – electrolyser 100 MW Production – 40t green hydrogen/day	Goal - storage and transport using batteries and gas cylinders 40t hydrogen/day	Goal – building a green hydrogen fuelling stations network 30 stations	Production of polish hydrogen busses Over 100 busses/ year
Operational	First electrolyser in Q2 2022	Testing first storage facilities	First station in the process of gaining building permissions	Bus prototype ready Factory in preparation

Pic. 1 Supply chain and value of renewable hydrogen ZE PAK.

ZE PAK wants to become a leading producer of renewable hydrogen in Poland and use the already existing capacities from zero-emission sources, i.e. energy from the sun, wind and biomass. In October 2021, a 70 MW photovoltaic installation was launched, the largest facility of this type in Poland. Another installation with a capacity of up to 180 MW is in the preparation phase. The production of renewable hydrogen is to reach 40 tones per day. For this purpose, the company will install electrolysers with a total capacity of 100 MW. The company installs the first modular electrolyser with a capacity of 2.5 MW of Polish production. The renewable hydrogen produced by ZE PAK will be distributed through a network of over 40 refueling stations.

The company also intends to mass-produce a hydrogen bus, which is currently i n the finished prototype phase. For this purpose, a factory with a production capacity of up to 200 buses per year is currently being built in Świdnik.The plant is to be ready

in the third quarter of 2023. The company is also investing in fuel cell company cars. Currently, ZE PAK has 100 FCEVs in the company's fleet and has ordered 50 more. It is the largest fleet of this type currently used in Poland. In addition, ZE PAK uses 3 mobile hydrogen storage facilities with IV generation cylinders, a mobile hydrogen bus refueling station and builds its own stationary hydrogen refueling station in Warsaw. The facility is to be delivered in 2023.

Pic. 2 Polish hydrogen bus, which is one of the links in the hydrogen value chain ZE PAK – Nesobus.

Source: https://www.youtube.com/watch?v=E72li33HMME

2.4. Hydrogen Eagle – project by PKN Orlen S.A.

Project start date: 14 June 2021

Main objectives: construction of 102 hydrogen refuelling stations for individual, public and cargo, road, and rail transport (there will be approx. 57 such stations in Poland, 28 in Czech Republic, and 26 in Slovakia). The stations are to be supplied by hydrogen from a network of hubs powered by renewable energy sources and installations converting municipal waste into zero- and low-emission hydrogen. The Hydrogen Eagle project main goal is to enable the construction of a comprehensive infrastructure in Poland for the production and distribution of low- and zero-emission hydrogen. The total capacity of RES-powered electrolysis will be approx. 250 MW. In addition, it is planned to launch installations producing hydrogen from municipal waste in two sites in Poland (Płock, Ostrołęka) and the Czech Republic. Stations included in the project will provide hydrogen refuelling in the North-South and East-West corridors. It is also one of the key elements in the implementation of PKN ORLEN's strategy to achieve carbon neutrality by 2050. The first PKN Orlen hub supplying hydrogen fuel quality suitable for transport with a capacity of approx. 50 kg/hour was established in 2021 in Trzebinia and currently produces hydrogen from natural gas. Ultimately, it will produce low-emission hydrogen derived from biomethane.

The company running the project: State Treasury controls over 31% of PKN ORLEN S.A. share capital. ORLEN is the largest company in Central and Eastern Europe and its revenues in 2021 amounted to PLN 131.3 billion. In 2021 the company achieved the highest net profit in its history amounting to PLN 11.2 billion. In 2022 PKN Orlen completed, in accordance with the announcements of the Polish government, a merger with other energy companies controlled by the State Treasury: Lotos and PGNiG. After the merger, PKN Orlen's capitalization increased from PLN 31 billion to PLN 78 billion (according to the WSE quotations of 10 October 2022). More than 50% of PKN Orlen's shares are held by the State Treasury or the companies it controls. Since 2018, the President of the Management Board of PKN Orlen has been Daniel Obajtek, previously a local politician and a member of the ruling *Prawo i Sprawiedliwość* party.

Hydrogen Eagle project budget: approx. PLN 7.4 billion by 2030

Key facts:

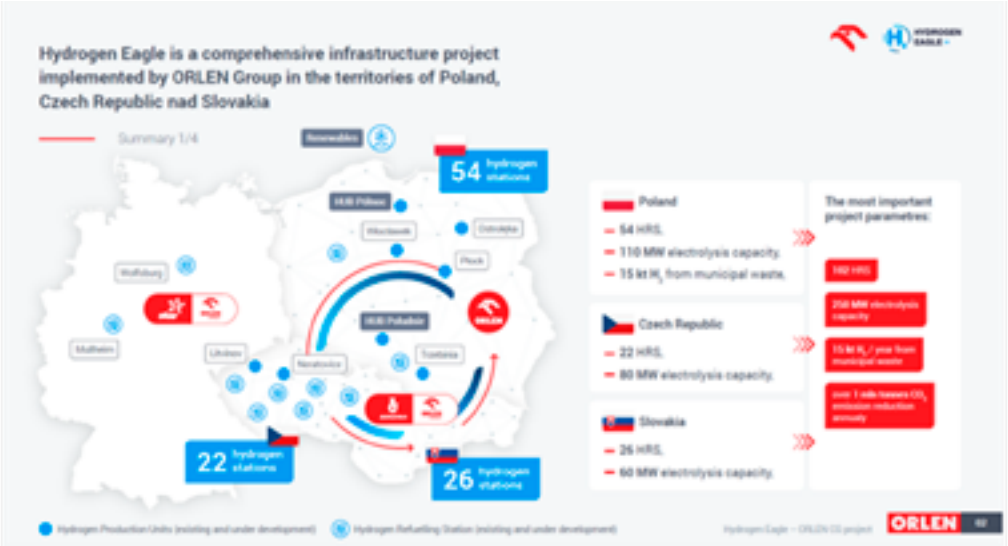
- the program obtained non-refundable co-financing in the amount of approx. PLN 60 million from the EU CEF Transport Alternative Fuels Infrastructure Facility program, for the construction of public hydrogen refuelling stations in Bielsko-Biała, Gorzów Wielkopolski, Kraków, Warsaw and Piła (as of September 2022, public stations are to be commissioned in mid-2025).
- the program obtained positive decision from the European Commission under the IPCEI - Hy2Use program, it is the only Polish project among 35 projects from 13 European countries (as of October 2022).
- PKN ORLEN has signed the agreement with NFOŚiGW (National Fund for Environmental Protection and Water Management) for the construction of 3 hydrogen stations in Wałbrzych, Poznań and Katowice. The mobile stations in Katowice and Poznań are planned to be mobile in the second half of 2023, and in Wałbrzych at the beginning of 2025. The location of hydrogen stations results from the signing of letters of intent regarding the purchase of hydrogen buses for public transport by these cities.

Lider of the project:

Grzegorz Jóźwiak

Director of the Alternative Fuels Implementation Office at PKN Orlen

The implementation of Hydrogen Eagle will allow us to join the international hydrogen refuelling network. This is to happen thanks to the construction of 102 hydrogen refuelling stations, both for road transport and railways. By 2030 the project will be able to achieve zero-emission hydrogen generation capacity of approx. 50,000 tons per year
– Source: „**Hydrogen without secrets**" Magazine.



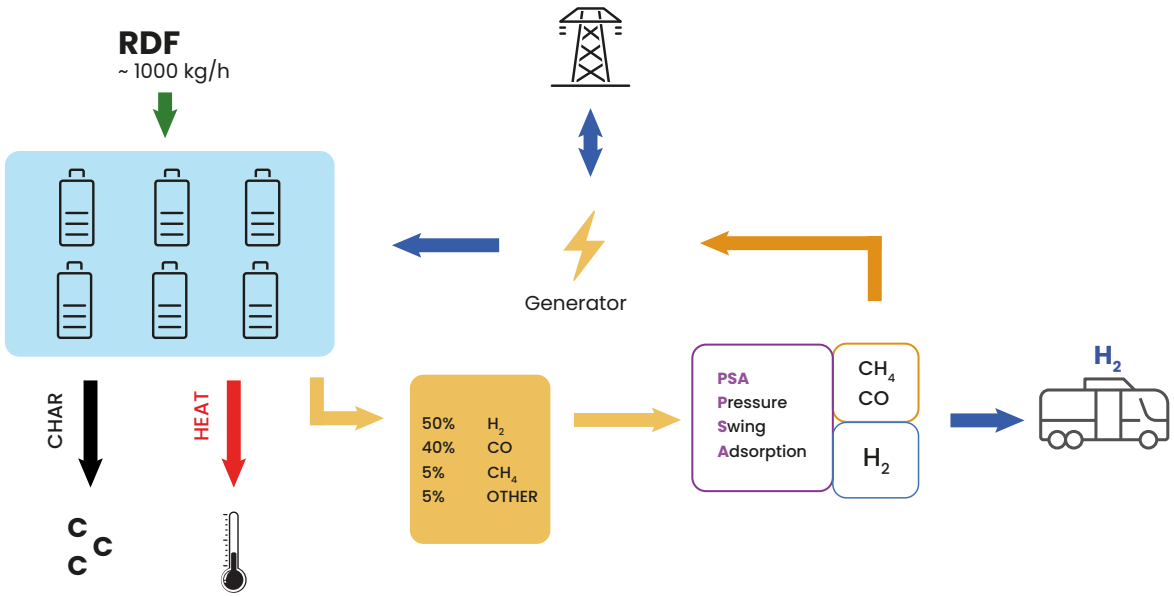
2.5.W2H2 - production of clean hydrogen as part of the circular economy

Project implemented in cooperation with: Gdańsk University of Technology, GSC Sp. z o.o.

Project start date: June 2022

Main objectives: construction of a set of innovative pyrolysis reactors in which non-segregated municipal and industrial waste (RDF - Refuse-derived fuel) will be processed. Pyrolysis will produce pure syngas consisting of a mixture of simple hydrocarbon compounds (with high concentration of hydrogen), and high-calorific char, which can be used in other processes.

Company leading the project: W2H2 sp. z o.o. is a company registered in June 2022 by people from the scientific and business environment. The pyrolysis technology (thermal decay, which is not a combustion process) was developed by Prof. Bogusław Kusz from the Gdańsk University of Technology and was patented in Poland, with a plan to obtain international patents. One of the partners is Marek Łupina, the founder of the company GSC, which since 2002 has been operating on the market to produce pressure and capacity control elements in industrial natural gas installations. GSC, which built the reactor for testing in 2021, had PLN 27 million in revenue.



Value of the installation: approx. PLN 40 million (7 480 000 £)

The W2H2 model farm consisting of 6 reactors will be able to process 8,000 tons of RDF per year and produce 320 tons of hydrogen. The estimated annual energy demand of the W2H2 farm will be approx. 3,200 MWh.

Key facts:

- The annual amount of RDF produced in Poland is 2 million tons, and in the EU, it is 60 million tons and is constantly growing.
- The market for the treatment of non-segregated RDF waste in the EU is estimated at around EUR 6 billion per year.
- Hydrogen contained in non-segregated RDF waste in Poland is approx. 2.4 million tons worth approx. EUR 12 billion.

W2H2 Team:

- R&D + science - Prof. Bogusław Kusz and Bartosz Trawiński, both working scientifically at the Faculty of Technical Physics of the Gdańsk University of Technology.
- Engineering side - Łukasz Łupina, Karol Wołczyk and Włodzimierz Mikucki specializing in industrial gas installations and Bartłomiej Kusz specializing in automation and power engineering.
- President of the Management Board - Wojciech Białecki, experienced manager previously working in new technologies, renewable sources, and sustainable energy.

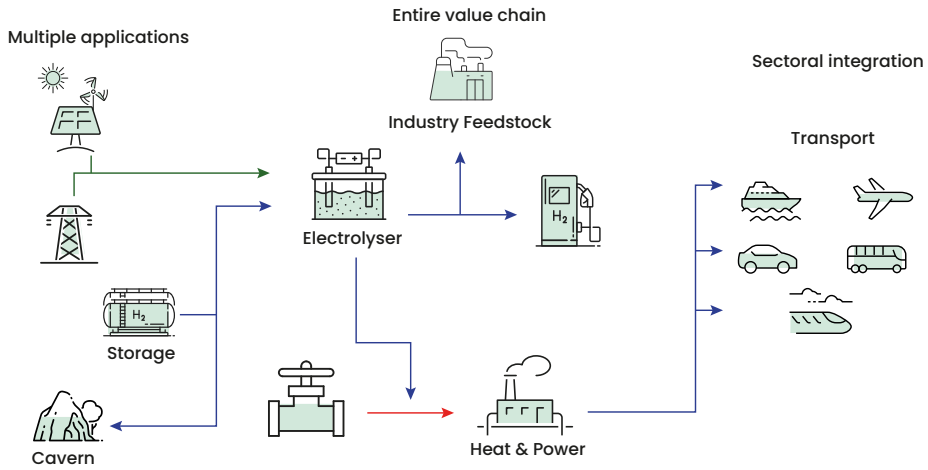
Cooperation with external partners:

- Research partner - Gdańsk University of Technology
- Economic organizations - Pomeranian Hydrogen Valley
- Government organizations - Sectoral Agreement for the Hydrogen Economy
- Financial institutions – Bank Gospodarstwa Krajowego, Bank Ochrony Środowiska
- Other: Stena Recycling, Eneris, Elwoz

3. Review of the Hydrogen Valleys

As mentioned in the introduction the creation of hydrogen valleys forms part of the National Hydrogen Strategy. Valleys are to act as research, development, and investment hubs and contribute to cooperation between local, national, and foreign stakeholders. Until now seven different valleys have been created. Some of them are more advanced than other. In general, their goals and objectives are similar, therefore we present them in common and abbreviated form although each Valley is a different entity.

Hydrogen valleys scheme (by ARP*)



* ARP- Agencja Rozwoju Przemysłu- main hydrogen valleys integrator/operator

Objectives:

- To develop renewable energy sources and promote their use.
- To stimulate the emergence of local manufacturing competences across hydrogen value chain.
- To create a platform for cooperation between local small and medium-sized enterprises, local government units, scientists, and hydrogen market participants.
- To support and implement research and development projects.
- To educate and train specialized staff.

Tools and activities:

- Access to knowledge about hydrogen technologies.
- Support of regional self-government bodies.
- Organization of meetings, seminars, and networking opportunities.
- Cooperation with entities on the regional and international hydrogen economy market.
- Consultation, information activities and exchange of experience.
- Assessing business needs and identifying investment opportunities.

3.1. Mazovian Hydrogen Valley

Date of constitution: 8 April 2022

Address: Płock (office of PKN ORLEN S.A.)

Leader/Founder: PKN ORLEN S.A.

Website: N/A

Planned and ongoing projects:

- More than 120 projects within 7 consortia, of which the most advanced are five research projects and two implementation projects. These are i.e. projects in the field of certification of hydrogen and synthetic fuels, use of carbonate technology and the use of fuel cells.

- In the conducted technological cycles, it is allowed to use CCSU technology, i.e. the capture and later use of carbon dioxide. The resulting carbon monoxide and carbon dioxide will be used in the production of synthetic fuel.

- One of the signatories of the Mazovian Hydrogen Valley (KAPE) has received permission to run an important project. National Integrator of local government initiatives for the development of zero-emission public transport powered by hydrogen and will provide comprehensive advice. It is co-financed by the European Investment Bank as part of the implementation of the guidelines of the Directive „On the development of alternative fuels infrastructure", the European Green Deal, the Hydrogen Strategy for Eu-

rope climate neutral and the Strategy for Sustainable and Smart Mobility.

- The signing of the founding act of the Mazovian Hydrogen Valley is in line with the assumptions of the „3W: water-hydrogen-coal" initiative initiated by BGK, a state-owned development bank supports the sustainable socio-economic development of the country. As part of it, Bank Gospodarstwa Krajowego has an impact on strengthening cooperation between scientists, administration and entrepreneurs who implement projects in responsible management of water resources, hydrogen technologies and innovative carbon materials.

Members of the Mazovian Hydrogen Valley:

1. PKN ORLEN
2. Bank Gospodarstwa Krajowego
3. Agencja Rozwoju Przemysłu
4. Centralny Port Komunikacyjny
5. Instytut Maszyn Przepływowych im. Roberta Szewalskiego
6. Instytut Ochrony Środowiska - Państwowy Instytut Badawczy
7. Instytut Energetyki Instytut Badawczy
8. Politechnika Warszawska
9. Akademia Górniczo-Hutnicza im. Stanisława Staszica
10. Krajowa Agencja Poszanowania Energii
11. PERN
12. Instytut Chemicznej Przeróbki Węgla
13. Instytut Techniczny Wojsk Lotniczych
14. TOYOTA Motor Poland Company Limited
15. Pojazdy Szynowe PESA Bydgoszcz
16. ALSTOM KONSTAL
17. SIEMENS ENERGY
18. Solaris Bus & Coach
19. Komunikacja Miejska Płock
20. Izba Gospodarcza Energetyki i Ochrony Środowiska
21. Polska Izba Przemysłu Chemicznego
22. Polska Agencja Inwestycji i Handlu
23. UNIQATE
24. Stomil Bydgoszcz
25. „NanoSpaceLab"
26. Instytut Informatyki i Optoelektroniki
27. Politechnika Łódzka
28. Urząd Dozoru Technicznego
29. Krajowa Spółka Cukrowa
30. OMIS S.A.
31. Microsoft Sp. z o.o.
32. AC Spółka Akcyjna
33. Centrum Łukasiewicz
34. Polska Spółka Gazownictwa sp. z o.o.
35. Fundacja KEZO
36. Instytut Badań Edukacyjnych

Date of constitution: 1 October 2019

37. HORUS-ENERGIA Spółka z o.o.
38. Soltec Sp. z o.o. Sp.k.

3.2. Pomeranian Hydrogen Valley

Address: Al. Grunwaldzka 82, 80-244 Gdańsk

Leader/Founder: Pomeranian Regional Chamber of Commerce

Website: https://klasterwodorowy.pl/pomeranian-hydrogen-valley,53,en

Planned and ongoing projects:

- Building offshore wind farms: Nepthyne project - hydrogen production on offshore platforms.

- Pure H2 Project (Grupa LOTOS S.A.), which comprises a hydrogen purification unit with distribution and refuelling infrastructure.

- In addition, it is planned to implement a zero-emission public transport system, implement a train connection with a hydrogen-powered locomotive on the Gdynia – Hel route, create a hydrogen hub supplying equipment and transport in the Port of Gdynia, start the production of hydrogen-powered ships and catamarans, produce hydrogen from RES, design, and manufacture hydrogen-powered service vessels to service offshore wind farms (in Trójmiasto shipyards).

- „The four neighbouring cities of Gdańsk, Gdynia, Wejherowo and Tczew (‚4-cities') in northern Poland intend to jointly acquire and deploy 91 fuel cell buses in regional public transport as part of their decarbonisation strategy.
A total of 51 solo buses and 40 articulated buses are planned to reach a share of 8% to 54% of the urban fleet by 2028, reducing greenhouse gas emissions by 2,847 t/year and Nox emissions by 3,892 kg/year. The CAPEX of the project is estimated at EUR 65.83 million.

Members of the Pomeranian Hydrogen Valley:

1. Województwo Pomorskie
2. Klaster Technologii Wodorowych i Czystych Technologii Węglowych
3. Gmina Miasta Gdyni
4. PKP Energetyka S.A.
5. Port Gdynia S.A.
6. Rada Inteligentnej Specjalizacji Pomorza z obszaru Technologie off-shore i portowo-logistyczne (ISP1)
7. Stowarzyszenie Obszar Metropolitalny Gdańsk, Gdynia, Sopot
8. Grupa LOTOS S.A. (PKN ORLEN Group)
9. Energa S.A.
10. Elmal Sp. z o.o.
11. Edoradca sp. z o.o.
12. Takeneka
13. LAB CONTROL Sp zo.o.
14. Enmaro
15. Pietro Fiorentini
16. PEC Sp. z o.o.
17. Exdin Solutions sp. z o.o.
18. Vekamaf Sp. z o.o.
19. Scan 3D
20. Polska Strefa Inwestycji Pomorska Specjalna Strefa Ekonomiczna
21. IWOS Clean Energy (no www adress)
22. MMI Sp. z o.o.
23. h2energy sp. z o.o.
24. SES Hydrogen S.A.
25. Swagelok
26. Westport Fuel Systems
27. Sun Sol
28. STASTO Automation Sp.z o.o.
29. Samson Sp. z o.o. Automatyka i Technika Pomiarowa
30. Miasto Piła
31. Stowarzyszenie Doradców na Rzecz Rozwoju Obszarów Wiejskich AGROPLUS+
32. Polska Agencja Energetyczna Sp. z o.o.
33. CO2 ENERGY STORAGE Sp. z o.o. (brak strony www)
34. Poltraf sensors controls sp. z o.o.
35. Emerson Electric Co
36. Alseva Innowacje S.A.
37. Bibus Menos Sp. z o.o.
38. E-engineer computer simulation
39. Comade successful together

40. Fronius Polska Sp. z o.o.
41. Yokogawa Poland
42. Regionalna Izba Gospodarcza Pomorza
43. Sescom S.A.
44. Sescom Data control (Sescom S.A.)
45. 99rent Sp. z o.o.
46. Automatic Systems Engineering Sp. z o.o.
47. Biproraf Sp. z o.o.
48. NEXUS Consultants Sp. z o.o.
49. Gdańskie Autobusy I Tramwaje Sp. z o.o.
50. Żegluga Gdańska Sp. z o.o.
51. MGS LAW Kancelaria Radców Prawnych
52. KB Pomorze Sp. z o.o.
53. Hydropress Sp. z o.o.
54. Best systemy grzewcze sp. z o.o.
55. Worthington Industries Inc.
56. Toyota Central Europe Sp. z o.o.
57. Miasto Rumia
58. Rumia Invest Park Sp. z o.o.
59. Inwebit Sp. z o.o.
60. Rockfin
61. Jakusz Sp. z o.o.

Date of constitution: 31 January 2022

Address: Mikołowska 100, 40-065 Katowice

3.3. Silesian-Malopolska Hydrogen Valley

Leader/Founder: Industrial Development Agency S.A. (branch in Katowice)

Website: https://h2dolina.eu/

Planned and ongoing projects:

- A specific objective is linked to Silesia's coal-based economy and the plans to revitalize it. Therefore, the valley is undertaking activities aimed at using the scientific and research potential of regions, including the implementation of solutions in the field of thermochemical processing of fossil fuels in combination with CCS, CCU and CCUS technologies, which will be an important source of hydrogen in the transitional period.

- The Tauron company, together with the Sebastineum Silesiacum Research Institute in Kamień Śląski, plans to build a hydrogen installation that will produce electricity and heat for the needs of the palace complex from the Sanctuary of St. Hyacinth. The project involves the production of hydrogen from electrolyser. The device used in the installation, can produce about 30 m cubic of this fuel in one hour. The resulting hydrogen will then go to be stored in two tanks, in which it will be possible to store as much as 360 cubic meters under appropriate pressure.

- The Department of Motor Vehicles of the Cracow University of Technology has developed a system of hydrogen injection in internal combustion engines. This system has been practically verified during the implementation of the project on the use of waste hydrogen and in its current form it is suitable for implementation, for example, in engines of diesel locomotives, power generators, as well as – after making the necessary modifications – for hydrogen supply in internal combustion bus engines. According to the creators, the ecological parameters of internal combustion engines powered by hydrogen are significantly more favourable in relation to the supply of other fuels.

- Metacon AB in cooperation with The State Forests Directorate in Katowice is planning an investment in a photovoltaic farm, which is to power electrolysers producing hydrogen for public transport.

- Experts from PGNiG and the Silesian University of Technology are working on an innovative sensor for hydrogen detection as part of the HydroSens project. The project received funding from the NCBR. The funding granted by NCBR concerns the program „Low temperature hydrogen sensors based on polycarbazole and its derivatives". The project focuses on the development of sensors to detect hydrogen in gas mixtures, including those containing natural gas. These devices will be able to be used, i.e., to test the hydrogen content in mixtures transported through distribution and transmission networks. The innovation of the HydroSens project is the use of polymer semiconductors as a material to produce hydrogen sensors. Currently, chromatographs are used to measure hydrogen in gas networks. However, these devices are expensive and require specialized maintenance. The sensors developed by the consortium of PGNiG and the Silesian University of Technology are to be cheap, reliable and easy to use. In addition to the use of sensors for rapid detection of hydrogen in distribution networks, they can also be part of controllers for devices adapted to supply fuels with variable composition, e.g. gas boilers. The project was submitted by a consortium of PGNiG and the Silesian University of Technology as part of the European M-ERA.NET 3 Call 2021 program.

Members of the Silesian-Malopolska Hydrogen Valley:

1. Województwo śląskie
2. Województwo małopolskie
3. Górnośląsko-Zagłębiowska Metropolia
4. Orlen Południe
5. Grupa Azoty S.A.
6. Polenergia
7. Columbusenergy
8. Katowicka Specjalna Strefa Ekonomiczna
9. Węglokoks
10. Politechnika Śląska
11. Akademia Górniczo-Hutnicza
12. Politechnika Krakowska
13. Uniwersytet Śląski
14. Instytut Techniki Górniczej Komag
15. Instytut Technologii Paliw i Energii
16. Główny Instytut Górnictwa

3.4.Lower Silesian Hydrogen Valley

Date of constitution: 25 February 2022

Address: Sikorskiego 2-8, 53-659 Wrocław

Leader/Founder: IIndustrial Development Agency/KGHM Polska Miedź S.A

Website: https://dolinah2.pl/

Planned and ongoing projects:

- On 27 October, in Bogatynia, a meeting was held, which was part of the European Hydrogen Week, the main purpose of which was to discuss the global challenges of implementing the European Hydrogen Strategy, as well as the key issues of using the potential of renewable energy for hydrogen production. The event was organized by the Lower Silesian Hydrogen Valley.

- 20 hydrogen-powered buses will run on the streets of Wałbrzych. This is the result of co-financing and loans that the city will receive from the National Fund for Environmental Protection and Water Management. Wałbrzych is also one of two production sites of Toyota Motor Manufacturing Poland making components for hybrid drives. Toyota is one the largest automotive companies, which promotes FCEV.

- Scientists from the Wrocław University of Science and Technology are working on a coating that improves the tightness of composite hydrogen tanks. The oxide coatings developed in Wrocław improve the barrier content of HDPE polyethylene by 36%. Scientists continue to investigate polymer sealing, investigating the details of the blocking mechanism, the interaction between gas molecules and the coating material, and the influence of the mechanical field on these interactions. It is also necessary to develop a method of production of tanks.

Members of the Lower Silesian Hydrogen Valley:

1. Agencja Rozwoju Przemysłu S.A.
2. ALSTOM KONSTAL S.A.
3. BEST SYSTEMY GRZEWCZE Sp. z o.o.
4. Dozamel Sp. z o.o.
5. Fundacja „Dolnośląski Instytut Studiów Energetycznych”
6. Grupa Azoty S.A.
7. Grupa Azoty Zakłady Azotowe Kędzierzyn S.A.
8. Instytut Automatyki Systemów Energetycznych Sp. z o. o.
9. Instytut Energetyki, Instytut Badawczy
10. Inwebit Sp. z o.o.
11. KGHM CUPRUM Sp. z o.o. – Centrum Badawczo-Rozwojowe
12. KGHM Polska Miedź S.A.
13. Legnicka Specjalna Strefa Ekonomiczna S.A.
14. Operator Gazociągów Przesyłowych GAZ-SYSTEM S.A.
15. PKP Energetyka S.A.
16. Politechnika Opolska
17. Politechnika Wrocławska
18. Polska Spółka Gazownictwa Sp. z o.o.
19. Polskie Domy Drewniane S.A.
20. Polskie Stowarzyszenie Magazynowania Energii

21. Promet-Plast s.c. Ekologiczny Klaster Oławski
22. SBB Energy S.A.
23. Stowarzyszenie Rozwoju Innowacyjności Energetycznej w Zgorzelcu
24. TAURON Dystrybucja S.A.
25. TOYOTA Motor Manufacturing Poland Sp. z o.o.
26. Uniwersytet Opolski
27. Uniwersytet Przyrodniczy we Wrocławiu
28. Uniwersytet Wrocławski
29. Urząd Marszałkowski Województwa Dolnośląskiego
30. Wałbrzyska Specjalna Strefa Ekonomiczna „INVEST-PARK" Sp. z o. o.
31. Wałbrzyskie Zakłady Koksownicze „Victoria" S.A

3.5. Wielkopolska (Greater Poland) Hydrogen Valley

Date of constitution: 05 July 2021

Address: Al. Niepodległości 34, 61-714 Poznań

Leader/Founder: Self-Government of the Wielkopolska Region

Website: https://h2wielkopolska.pl/en/homepage/

Planned and ongoing projects:

- Nexus Consultants provided economic consulting as part of the Valley's operation, as part of the „Gospodarna 2050 – H2Wielkopolska" program. So far, the consultations have covered the following companies: HHO Power inż. Damian Michalak, Go&Management GmbH S.K., Graphen Fligier Sp.j., VIRTUD Sp. z o.o., Alter Energia Sp. z o.o., Marathon International sp. z o.o. sp.k., Brewa Sp. z o.o. Sp.k., Qubiqa Sp. z o.o., Przedsiębiorstwo Oczyszczania Miasta EKO Sp. z o.o., ENERGO-TECH Sebastian Zaradzki, eN-TANK Sp. z o.o. s.k., STEEL RBB Sp. z o.o. s.k., PHU Trans-Kol Zenon Sobczak, MiBM Sp. z o.o. Sp.k., Simpax Sp. z o.o.

- The authorities of the Wielkopolska local government, acting in cooperation with the Wielkopolska Hydrogen Valley, signed a letter of cooperation with Enea Nowa Energia (New Energy) – a subsidiary of the state-owned energy company Enea. The cooperation will concern the creation of energy storage systems and stabilizing the energy grid, using renewable hydrogen produced from renewable energy installations. Enea Nowa Energia manages projects based on renewable energy sources, including RES assets: hydroelectric power plants, wind and photovoltaic farms and biogas plants. An important role in the activities of the Wielkopolska Hydrogen Valley is played by the Wielkopolska Council of Thirty (WR30), which is an opinion-forming and advisory team operating at the Marshal of the Wielkopolska Region. The Council is a platform for cooperation between the local Government of the Wielkopolska Region and regional economic organizations.

- The area of activity of the Wielkopolska Council of Thirty covers the issues of economic development of the region and the challenges faced by entrepreneurs in the face of economic globalization. The scope of the Council's activities is to build a stable regional economy, develop the Wielkopolska Brand and give opinions on program and strategic documents related to the economic development of Wielkopolska.

- The Wielkopolska Hydrogen Platform (WPW) is an advisory body of the local Government of the Wielkopolska Region on issues of conducting economic policy within low- and zero-emission technologies, including hydrogen. WPW is a platform for cooperation between business, science, local governments, and non-governmental organizations. WPW meetings are held once a month, and the work is carried out in four panels: Business, Local Government Leaders, Science and Citizenship.

Members of the Wielkopolska Hydrogen Valley:

1. Miasto Poznań
2. Miasto Kalisz
3. Miasto Piła
4. Miasto Ostrów Wielkopolski
5. Miasto Leszno
6. Miasto Konin
7. Zespół Elektrowni Pątnów-Adamów-Konin
8. Enea Nowa Energia
9. Solaris Bus & Coach
10. Politechnika Poznańska

11. Uniwersytet Przyrodniczy w Poznaniu
12. Uniwersytet im. Adama Mickiewicza w Poznaniu
13. Wielkopolska Rada 30
14. Wielkopolska Platforma Wodorowa

3.6. Subcarpathian Hydrogen Valley

Date of constitution: 18 May 2021

Address: Poznańska 2D, 35-084 Rzeszów

Leader/Founder: Industrial Development Agency

Website: https://www.dolinawodorowa.org/

Planned and ongoing projects:

- ML System, a member of the Hydrogen Valley, was the first to construct a prototype of a high-pressure electrolyser to produce hydrogen, operating at low voltage, which allows integration with photovoltaic installations.

- On May 12, 2022, the Scientific and Technical Seminar of the Podkarpackie Hydrogen Valley took place. During the event, the main trends in the development of the Podkarpackie Hydrogen Valley and working areas were identified: transport (including land and air transport), energy (including thermal energy and electricity generation), industry and municipal economy

- The first self-government hydrogen company in Poland was established in Sanok, the aim of which is to decarbonize the heating system and produce renewable hydrogen. In addition, Autosan Sp. z o.o. developed plans to produce the zero-emission hydrogen bus SANCITY 12LFH. It is a low-floor bus with a length of 12 meters. It was designed based on an electric bus. An electric motor with a fuel cell power module was installed in the bus.

- Polenergia S.A., a member of the Hydrogen Valley has started work on partially powering its gas turbines in power plants with hydrogen.

- Rzeszów University of Technology launched the Laboratory of Hydrogen Combustion in Aircraft Engines, establishing cooperation with the international aviation industry in this area. It is worth noting that a member of the Podkarpacka Hydrogen Valley is the „Aviation Valley" Association, considered one of the best industry clusters in Poland. The Association brings together 179 companies from the aviation industry, most of which are in the Podkarpackie Voivodeship, and many provide components for the global aviation industry.

Members of the Subcarpathian Hydrogen Valley:

1. Politechnika Rzeszowska
2. Uniwersytet Rzeszowski
3. Polenergia Elektrociepłownia Nowa Sarzyna sp. z o. o.
4. Agencja Rozwoju Przemysłu S.A.
5. Polenergia S. A.
6. ML System S. A.
7. Fibrain Sp. z o. o.
8. Autosan sp. z o. o.
9. Stowarzyszenie Grupy Przedsiębiorców Przemysłu Lotniczego „Dolina Lotnicza"
10. Instytut Energetyki - Instytut Badawczy
11. Instytut Badawczy, Oddział Ceramiki CEREL w Boguchwale
12. Urząd Miasta i Gminy w Nowej Sarzynie
13. Województwo Podkarpackie
14. Miejskie Przedsiębiorstwo Gospodarki Komunalnej - Krośnieński Holding Komunalny Sp. z o. o.
15. Elektrociepłownia Stalowa Wola S.A.
16. BorgWarner Poland Sp. z o. o.
17. Sanockie Przedsiębiorstwo Gospodarki Komunalnej Sp. z o. o.
18. Gmina Stalowa Wola
19. PAD RES Development Sp. z o. o.
20. Impact Clean Power Technology S.A.
21. Danfoss Poland Sp. z o. o.
22. H2R Hydrogen Renewable Sp. z o. o.
23. AGZ Sp. z o. o.

3.7. West Pomeranian Hydrogen Valley

Date of constitution: 28 November 2022

Address: N/A

Leader/Founder: Grupa Azoty

Website: N/A

Planned and ongoing projects:

- The West Pomeranian Voivodeship has a very high potential to produce renewable hydrogen. Nearly 20 percent of energy from RES in Poland is produced in this region. The members of the valley have a high potential for the construction of new installations, including offshore wind farms. Along with further investments in RES, surpluses will be created, which can be stored, i.e. in the form of hydrogen.

- The energy produced here from renewable sources, could satisfy the local demand by more than 80%. The voivodeship has a high potential for the construction of new installations, and offshore wind farms will be built in its immediate vicinity. This means that it will have a significant volume of renewable capacity, the surplus of which can be stored in the form of hydrogen.

- Tomasz Hinc, President of the Management Board of Grupa Azoty S.A.: *From 2023, we will be able to talk about the annual production of over 120,000 tons of hydrogen by Grupa Azoty Police and Grupa Azoty Polyolefins. Importantly, it is already predicted that ports will play a key role in the energy transformation, hence the Police Sea Port may play a key role in this aspect for our region, becoming a „renewable raw material hub", including renewable hydrogen and renewable ammonia.*

Members of the West Pomeranian Hydrogen Valley:

1. Agencja Rozwoju Przemysłu S.A.
2. Wojewoda Zachodniopomorski
3. Zarząd Morskich Portów Szczecin
4. Grupa Azoty S.A.
5. Enea Operator Sp. z o. o.
6. Grupa Enea S.A.
7. Grupa Azoty Zakłady Chemiczne Police
8. Grupa Azoty Polyolefins S.A.
9. Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej
10. Zarząd Morskiego Portu Police Sp. z o. o.
11. Wojewódzki Fundusz Ochrony Środowiska i Gospodarki Wodnej w Szczecinie
12. Zachodniopomorski Uniwersytet Technologiczny w Szczecinie
13. Uniwersytet Szczeciński
14. Politechnika Morska w Szczecinie
15. Politechnika Koszalińska
16. Sieć Badawcza Łukasiewicz

4. Mapping strengths and weaknesses of the hydrogen supply chain

An important source on the potential of hydrogen technologies in Poland is the „Analysis of the potential of hydrogen technologies in Poland until 2030 with a perspective until 2040", developed by the Institute of Power Engineering, the Faculty of Management of the University of Warsaw and the Institute for Ecology of Industrial Areas commissioned by the Ministry of Climate and Environment. The authors of the analysis classified the potential of building a hydrogen economy in Poland in individual areas at three levels: high, medium, and low. The potential of the economy was assessed in the following areas: R&D advancement, implementation, and production advancement level according to the so-called GE/McKinsey matrix. The classification was made based on surveys on a sample of 27 respondents operating on the hydrogen market in Poland. This method makes it possible to classify known technologies at a medium or significant stage of development. On the other hand, it is much more difficult for respondents to predict emerging technologies or those whose existence or availability - e.g., from abroad - has not yet been sufficiently publicized at the forum of Polish experts.

The material was supplemented based on public information, materials obtained by the Wodór2030.pl initiative, expertise of the TOR Consultants, as well as prospects for the development of individual segments of the hydrogen market until 2030 in accordance with the National Hydrogen Strategy (see description in the introduction).

The overall supply and value chain of renewable hydrogen consists of the following elements:

- Zero-emission energy obtained from the sun, wind, and biomass.
- Production of renewable hydrogen by electrolysers using energy from renewable sources.
- Manufacturing and servicing machines and components using H2.
- Storage and transport using batteries and cylinders.
- Distribution of renewable hydrogen by a network of refuelling stations.
- Sale of renewable hydrogen for public transport (hydrogen-powered buses and trains), special purpose vehicles (e.g. garbage trucks), commercial vehicles (e.g. vans and trucks) and passenger cars.

It should be noted that Poland, as a large producer of hydrogen, should already offer hydrogen for transport, without looking at its colour and without waiting to produce renewable hydrogen from electrolysers. In the transitional phase, supply of hydrogen for internal combustion engines (heavy transport, locomotives) can also be considered. Such activities can perfectly contribute to the popularization of this energy carrier and a smooth transition to the second, completely zero-emission phase of the hydrogen economy.

SUPPLY CHAIN AREA	STRENGTHS/OPPORTUNITIES	GAPS / WEAKNESSES
Zero-emission energy obtained from the sun, wind and biomass	• the production of energy from the sun and wind significantly increased during the last few years thanks to NFOŚiGW support programs • there is a big interest in transformation of the coal mining sector, including CCS CCUS technologies	• domestic fuel mix dominated by fossil fuels (coal made 72% of electric energy production in 2021 alone) • wind offshore farms are already developed no announcements about H2 on-site production has been made yet
Production of renewable hydrogen by electrolysers using energy from renewable sources	• several companies and local governments announced plans to invest in electrolysers • big chemical companies have significant experience with SMR technologies and are planning to transform them to renewable technologies • several energy tech companies listed • on the WSE are working on H2 technologies	• Technologies to treat sewage to obtain water for electrolysis • PEM electrolysers • Hydrogen fuel cells • Only one SOFC cells and electrolysers R&D site
Production of hydrogen from waste	• helps to solve problem with garbage disposal • new technologies (such as W2H2 concept) show large potential for implementation • no shortage of input to the process	• technology is still young • there are no working implementations
Production of hydrogen from biomass	• helps to solve problem with biomass disposal • can be economically • no shortage of input to the process	• missing regulations for biogas and biomethane • biogas to biomethane cleaning technologies
Manufacturing and servicing machines and components using H2	• certification of the first fuel cell shunting locomotive is underway • 3 million registered LPG-powered cars supported by a network of workshops, importers, manufacturers of tanks etc. • a leading supplier of drive systems (inverters, converters, and high-voltage switchgear) - Medcom	• hydrogen tanks, compressors, cooling equipment, fittings • lack of integration experience
Storage and transport using batteries and cylinders	• R&D projects in cylinders' production • Cryogenic technologies are accessible but not economically viable.	• design and manufacture of composite and aluminium gas cylinders
Distribution of renewable hydrogen by a network of refuelling stations.	• state owned petrol giant – PKN Orlen has announced plans to open a network of HRSs	• Complete design and construction of Hydrogen Refuelling Stations • *Limited market for H2 transport, given both the still scarce number of HRS in operation and a limited number of FCEV's registered in Poland*
The sale of renewable hydrogen for public transport (hydrogen-powered buses and trains), special purpose vehicles (e.g., garbage trucks), commercial vehicles (e.g., vans and trucks) and passenger cars.	• One of the top European manufacturers of hydrogen buses. Several other buses manufacturers • Toyota is the biggest player on the Polish automotive market	• lack of proven special purpose vehicles implementations (both using retrofitted internal combustion and with fuel cells) • development of H2 distribution environment – like the one created within electric cars industry (certification, sales, distribution, aftermarket, insurance, service etc.)

4.1. High potential of Polish industry

Vehicle production - buses

Of all the areas of the hydrogen economy, manufacturers of hydrogen fuel cell city buses have the greatest domestic potential. There are two manufacturers of this type of vehicle in the country, and the third is currently building a factory to be completed in 2023. The largest domestic bus manufacturer - Solaris initially functioned as a company with Polish capital, and in 2018 it was taken over by CAF, a Spanish manufacturer of rail vehicles. It is Solaris that has the greatest experience and potential when it comes to the production of hydrogen buses. So far, it has produced more than 20,000 vehicles, including more than 60 hydrogen-powered vehicles, which operate in Italy, Germany, the Netherlands, Sweden and Poland.

Road tests of its own hydrogen bus were completed by Autosan, a subsidiary of Huta Stalowa Wola S.A., a state-owned company producing military equipment. Autosan, however, has been struggling with problems in recent years, and the sales of the once largest Polish bus manufacturer in 2021 amounted to only 60 units. Nesobus is another hydrogen-powered bus that currently undergoes road tests, manufactured by a consortium of listed companies ZE PAK and Polsat Plus. The company has started the construction of a production plant in Świdnik with a capacity of up to 100 buses per year.

The prospects for the city bus market in Poland are promising not only because of the manufacturers (OEMs) located in the country. The potential of the local market is also an important factor. In Poland, over 12,000 city buses are used, and nearly 90% of them are vehicles with internal combustion engines. The rolling stock will need to be replaced in the coming years, which is conditioned by the regulations obliging local governments to use at least 30% of the emission-free fleet from 2025 in the case of local government units with a population of over 50,000.

Over 40% of the city buses used in Poland are more than 10 years old, and another 30% are between 6 and 10 years old. Considering that the optimal lifetime of a city bus is 12 years, by 2030 more than 70% of the currently used rolling stock should be replaced. According to the Polish Hydrogen Strategy, by 2025 there will be from 100 to 250 . hydrogen buses in operation, and in 2030 from 800 to 1,000.

Warsaw, Upper Silesian-Zagłębie Metropolis, Wrocław, Kraków, Poznań, Łódź and Tri-City have a total of over 4,000 city buses, which constitutes over 30% of the entire fleet in Poland. It will mainly depend on orders in large cities how many such vehicles will eventually appear on the roads. A significant part of orders may go to companies operating in Poland due to cost competitivenes and available financing. In 2022, Solaris signed an order for 25 units for Poznań as part of the NFOŚiGW „Green Public Transport" program.

4.2. Medium potential

Manufacturing of railway vehicles

PESA Bydgoszcz S.A., the largest Polish manufacturer of rolling stock, belonging to the Polish Development Fund, is conducting advanced work on a prototype of a shunting locomotive with hydrogen fuel cells, in December 2022 it completed tests of the vehicle on a closed track. In 2019, Pesa established a special research and development team, which, in addition to the hydrogen shunting locomotive, is also working on passenger units with hydrogen fuel cell drives. Pesa cooperates with PKN Orlen in the implementation of hydrogen-powered rail transport on the Polish railway. Studies on the use of fuel cells in rail vehicles are also carried out by the listed Newag S.A. **PKN Orlen is to become the first user of the new Pesa locomotive, as well as a supplier of renewable hydrogen.**

Components including hydrogen tanks, compressors, cooling equipment, fittings

It is in this market segment that there is the greatest national potential for the possibility of involving many different types of enterprises. The reference point may be the LPG market, in which a network of small entrepreneurs – workshops, importers, manufacturers of tanks, compressors and fittings has built a market that meets the needs of over 3 million registered LPG-powered cars.

Polish companies produce hydrogen tanks and cooling devices, compressors, and fittings, i.e., components for end devices (e.g. flexible hydrogen supply lines, valves, gaskets, meters, detectors, etc.) for the needs of the hydrogen economy, as well as entire devices. Entire hydrogen tanks are made, for example, by CGH Polska. Techplast, in consortium with the AGH University of Science and Technology in Kraków, received a grant from the National Centre for Research and Development (NCBR) for the development of ultralight composite tanks for hydrogen storage for the amount of PLN 10.5 million. In 2023, Techplast will open a new production plant for ultralight composite and plans to launch a research centre on the use of hydrogen.

The Polish-Japanese Medcom is a leading supplier of drive systems (inverters, converters, and high-voltage switchgear), of which it has already delivered several dozen to hydrogen buses.

The supplier of energy for railways – PKP Energetyka, a company belonging to the national energy company PGE, has signed a contract with SBB Energy from Opole, which will provide a set of components for the construction of an energy storage system based on hydrogen produced from solar energy. The commissioning of the installation is planned for 2023. SBB has been operating in the energy and industrial sectors for 30 years, providing services in the field of start-up, mechanical assembly, electrical installations, automation and control and measurement equipment.

In this segment of the domestic market, companies lack integration experience, which means that initially they can appear in the hydrogen chain, i.e., as a direct supplier of components assembled directly by an OEM company (e.g., Solaris, Pesa). The need for constant monitoring of equipment operation and security is an opportunity for Polish IT companies that already provide this type of software for the power sector.

Electrolysers and hydrogen cells

It should be noted that all Solaris and Autosan hydrogen vehicles manufactured in Poland, as well as those prepared for serial production by ZE PAK (Nesobus) and Pesa rail vehicles, use Ballard cells. Recently, Ballard announced a contract for cells for 25 Solaris buses to Poznań. In Poland, research on hydrogen cells is conducted by the Łukasiewicz Research Network - Prof. Ignacy Mościcki Institute of Industrial Chemistry (Łukasiewicz--IPC). The Institute has built the third generation of a low-temperature PEM fuel cell powered by hydrogen. When it comes to SOFC cells and electrolysers, currently the only implementation entity that produces them in the country is the CEREL Ceramics Branch in Warsaw (a development unit of the Institute of Power Engineering).

The production of a Polish electrolyser with an average power of 0.5 MW is prepared by ZE PAK. The start of production is to take place in the first quarter. 2023 The company is also working on a project of a large PEM electrolyser with a capacity of 2.5 MW. In this case, the planned production is to start from the first quarter. 2024. The prototype of a high-pressure electrolyser for hydrogen production was designed and built in 2022 by ML System. The device is adapted to work at low voltage, so it can be integrated into photovoltaic installations. This will enable the creation of home micro-installations, as well as supplying public institutions, e.g., hospitals, with an independent power source in the event of, for example, a blackout.

The listed manufacturer of power supply systems, APS Energia based near Warsaw, offers an uninterruptible power supply system in which the basic power source is a fuel cell. The device has, i.e. protection against hydrogen outflow and a cell operation recorder. APS Energia has produced several hydrogen fuel cell systems for the needs of national scientific institutes. The company declares its interest in the hydrogen market and providing local content for the needs of the Polish nuclear program.

Biomethane

PKN Orlen, the state-owned fuel giant, as part of its strategy to increase the production of ecological fuels, is conducting an investment program in biomethane plants producing biomethane from renewable energy sources. The company assumes that biomethane will also be used to produce biohydrogen.

Orlen Południe – a subsidiary of the concern bought biogas plants in Konopnica (Łódź Province), Wojny-Wawrzyńce (Podlaskie Province). The company plans to expand these installations and convert them into biomethane plants producing biomethane, which could potentially be used to produce renewable hydrogen. Another Orlen Południe biogas plant is in Jeżewo in the Kujawsko-Pomorskie Voivodeship. The installation, with a capacity of 1.8 MWe, produces electricity for the local market. The company plans to expand the plant by 2024, which will enable the production of approx. 8 million m3 of biomethane per year. In Głąbowo (Warmińsko-Mazurskie Province), the company will build another biogas plant with a production capacity of PLN 7 million by 2024.

In addition, in Trzebinia, Orlen Południe launched an installation to produce renewable glycol, which includes a hydrogen hub. The annual production of hydrogen there will amount to 16 Nm3, of which as much as 75% will be intended to produce glycol, and the remaining 25%, after purification, as a low-emission hydrogen fuel.

The production capacity of the hub will amount to 350 tons of pure automotive quality hydrogen per year.

Cryogenics

Cryogenic tanks are designed to store various gases, including hydrogen, in liquefied form. Polish companies have extensive experience in the construction and operation of liquefied gas (LNG) tanks, where it is necessary to keep fuel at a temperature of minus 162 degrees Celsius. LNG is currently an important alternative to natural gas from Russia and the role of LNG, like hydrogen, in the Polish economy will grow in the coming years. National competences in this area are expected to remain high.

To operate liquid hydrogen tanks, it will be necessary to consider a much lower temperature of – 253 degrees Celsius. In Poland, there is a lack of solutions of domestic industry, but this is not due to a lack of competence. This market segment will be promising when the transport of hydrogen in such conditions will have economic justification. The current method of transport, storage and distribution of hydrogen does not give a chance for the development of this market segment. Liquid hydrogen has a chance to be popular, but only in the years 2030-2040.

4.3. Low potential

HRS – Power stations

The Polish Hydrogen Strategy assumes that by 2025 32 hydrogen stations will be built in Poland, and by 2030 there will be further development of this type of infrastructure. Considering that the hydrogen substation market is already occupied by several significant global players, Poland will probably rely on ready-made solutions provided by foreign entities.

Commercial vehicles, vans (LFCEV) and passenger vehicles (FCEV)

Apart from buses in Poland, there is currently no production as well as prospects for commissioning, production of other vehicles - utility, delivery, and passenger cars, powered by a hydrogen fuel cell at the level of an integrator (OEM). In this case, the market is dominated by global automotive concerns (Toyota, Hyundai, BMW) and it is practically impossible to compete with them from the perspective of Polish companies. Nevertheless, the automotive sector in Poland produces components for the needs of market integrators, including those that can be used as part of the hydrogen economy. Currently, however, Polish companies from this sector do not supply them to manufacturers of hydrogen vehicles.

5. Identifying key stakeholders on of the Polish market

5.1. Central

The Ministry of Climate and Environment

The Ministry plays a pivotal role in the efforts of Polish energy sector transition from fossil fuels to renewables. The Ministry of Climate and Environment is responsible for the regulatory framework, hydrogen strategy and other key documents concerning hydrogen market.

Development and Technology and the Ministry of Finance. Apart from the Ministry of Climate and Environment several other central institutions and state-owned companies are involved in the creation of hydrogen value chain in Poland.

The Ministry of Climate and Environment monitors the state of development of the hydrogen technology market and activities aimed at implementing the hydrogen economy on a local and nationwide scale. A dedicated Department of Electromobility and Hydrogen Economy (DEG) is responsible for all hydrogen related issues.

The scope of activities of DEG includes i.e. initiating developing and implementing the Minister's policy and tasks in the field of hydrogen and hydrogen technologies. DEG carries out work related to the creation and implementation of the national hydrogen strategy and the Polish hydrogen agreement, monitoring global technology development in the field of electromobility and clean energy technologies.

Contact: wodor@klimat.gov.pl

Industrial Development Agency (ARP)

Industrial Development Agency (Agencja Rozwoju Przemysłu - ARP) is a joint stock company supervised by the Prime Minister with 100% Treasury shareholding. ARP combines its public mission with business activity. As part of the Polish Development Fund Group, ARP holds assets in 76 companies, with majority stakes in 51 of them as well as supervises over 89 companies with State Treasury shareholding. ARP is an integrator of industrial hydrogen projects, within Hydrogen Valleys. It is also planning to involve its companies into the hydrogen value chain.

Contact: poczta@arp.pl

Industrial Development Agency (ARP)National Fund for Environmental Protection and Water Management (NFOŚiGW)

The National Fund for Environmental Protection and Water Management (Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej - NFOŚiGW) is one of the main institutions supporting investments in environmental protection. As part of the financing

programs, support is given for the development of hydrogen technologies implemented by local governments. The beneficiaries of the fund are also enterprises, public administration units and non-governmental organizations. The most important source of income for the Fund is the so-called emission fee, paid by companies marketing liquid fuels in Poland (PLN 80 for every 1000 litres of fossil fuel). The Fund functions as a state legal entity and its activities are supervised by the Minister of Climate and Environmental Protection.

The flagship project of NFOŚiGW supporting hydrogen is Green Public Transport, which in the second iteration completed in 2022, covered the purchase of 48 pcs. hydrogen buses and 2 refuelling stations. The program covers as much as 90% of the purchase costs of a hydrogen bus and 50%, but not more than PLN 3 million, in the case of construction or modernization of a hydrogen refuelling station. The third edition of the program is planned for 2023.

NFOŚiGW also runs the New Energy program. As part of it, in the first call for proposals in 2022, projects covering the production, transport, storage and use of hydrogen had a chance to co-finance, including:

- the production of ‚zero-emission' hydrogen, e.g., using wind or solar energy.
- adapting the infrastructure for the transport of hydrogen or the construction of hydrogen transport and storage structures.
- liquefaction, transport, and storage of hydrogen in liquid form using cryogenic technologies.
- large-scale storage of hydrogen from RES.
- exploiting synergistic effects between sector coupling and highlighting the role of hydrogen in industry, e.g., in steel production.
- allowing the availability and use of hydrogen in road, rail, or waterborne transport.

By decision of the NFOŚiGW in August 2022, the amount of PLN 50 million was supported, for the construction of a production plant for innovative hydrogen buses. The investment is carried out by PAK-PCE Polish Hydrogen Bus.

Contact: fundusz@nfosigw.gov.pl

National Centre for Research and Development

The National Centre for Research and Development (Narodowe Centrum Badań i Rozwoju - NCBR) is an executive agency supervised by the Minister of Development Funds and Regional Policy. NCBR is a centre for supporting and creating innovative technological and social solutions. The institution implements projects contributing to the civilization development of Polish, including hydrogen.

In 2021, NCBR announced the first competition in the strategic program „New technologies in the field of energy" with a budget of nearly PLN 380 million for projects in the field of onshore and offshore wind energy, energy storage and microgrids and hydrogen technologies. Under it, contractors were required to implement the results of the project within three years of the completion of its third phase.

As part of the project, NCBR will co-finance the m.in research and development project of Polenergia „H2 HUB Nowa Sarzyna: Storage of Renewable Hydrogen". The agreement signed in 2022 specifies the total amount of subsidies at the level of up to PLN 95 million. The aim of the project is to use renewable hydrogen, produced in the process of electrolysis of water powered by renewable energy, to produce renewable aviation fuel. It is implemented as part of a consortium led by Polenergia, and the other partners of the project are Elektrociepłownia Nowa Sarzyna and Wrocław University of Technology.

Contact: info@ncbr.gov.pl

Bank Gospodarstwa Krajowego

Founded in 1924, the state-owned development bank supports the sustainable socio-economic development of the country. BGK cooperates in the implementation of financial programs from European funds and is a partner of central and local government administration in the implementation of EU programs. Thanks to its involvement in numerous projects, the Bank's balance sheet total amounted to PLN 196.4 billion at the end of 2021, compared to PLN 160.3 billion at the end of 2020.

The Bank is the co-founder, and main shareholder of the Three Seas Fund. Through it, it invests in transport, energy, and digital infrastructure in the countries of the Three Seas region. initiatives of twelve countries located between the Adriatic, Baltic, and Black Seas. The value of BGK's involvement in the Three Seas Fund amounts to EUR 750 million.

The bank's areas of activity include m.in investments in transport and energy infrastructure, including hydrogen. In 2021, the bank granted financing for three hydrogen stations for PKN Orlen. In the future, BGK intends to support the construction of wind and photovoltaic farms in Poland, from which energy will be used in the electrolysis process to produce hydrogen.

BGK prefers projects that are secured by long-term contracts. For hydrogen producers, this means that the investment of, for example, a hydrogen production plant that already has long-term contracts for collection, has a better chance of financing.

BGK is a member of the Mazovian Hydrogen Valley. Members of hydrogen valleys, thanks to the geographical proximity of entities, including entities involved in the production, distribution, storage, and use of hydrogen, should have a better chance of financing their hydrogen projects by BGK.

5.2.Self-government authorities

Regional level

In Poland there are 16 self-governing regions (or voivodships) that play an important role in development programs and distribution of EU funds. Regional governments and councils are key for the adoption and implementation of any new program, including the hydrogen strategy, as they are responsible for drafting the regional strategies and applying for EU funds (e.g., zero-emission railway rolling stock).

Local level

Local administration (either 2nd tier “powiat” or 3rd tier “gmina”) might also be crucial for the implementation of a hydrogen strategy, as they are independent in defining the policies and choosing the tools. That would apply certainly to big cities – e.g., Poznań decided to buy 25 hydrogen buses Among smaller towns there are a few leaders such as Sanok, which is home to bus manufacturer Autosan.

6. Case study – best practices to enter the hydrogen market

Poland as a rapidly developing member of the European Union is an attractive market for foreign investors. However, it is worth remembering about the specificity of the Polish market. When deciding to expand into the Polish market, many factors must be considered, such as rapidly changing laws, complicated tax system, the impact of local and central politics on the shape of investments, knowledge of cultural conditions, customs, etc.

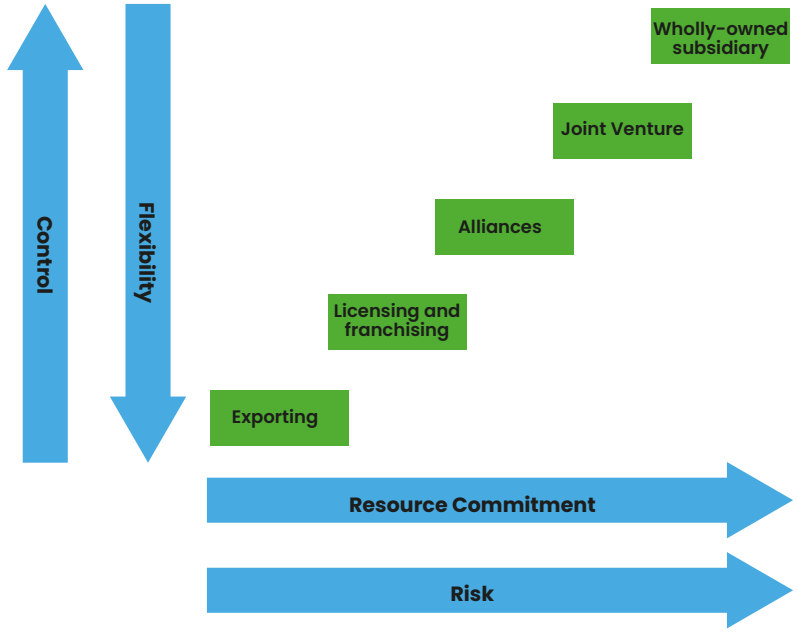
At the same time, Poland is a country with very favourable development conditions for foreign capital. Many international corporations have decided to open their branches in Poland because, on the one hand, Poland is a market with great development potential, which often allows for the introduction of more advanced products than on markets that are already highly developed and characterized by low dynamics. In addition, labour and employment costs of qualified specialists are lower than in the „old" EU countries.

The most common mistakes in entering the Polish market.

Many companies that had the necessary resources, product and organizational capabilities failed on the Polish market (e.g. e-Bay or the recent case of the Asian shopping platform Shopee). In the cited examples, the main failure was the lack of appropriate adaptation to the needs of customers, their customer protection and the business model copied from other markets.

Based on the analysis of cases of unsuccessful entry into the Polish market, several key failure factors can be distinguished:

- insufficiently in-depth analysis of the market potential
- ignorance of local regulations and the tax system
- the use of marketing tools that do not correspond to the experience of local customers.
- lack of organizational support on the part of the Polish entity (e.g. investment advisors/creators of the communication strategy).
- lack of appropriate competences among employees delegated to the expansion project.
- ignorance of cultural conditions and habits in Poland



Source: Arnstorp, Henrik. "Foreign market entry strategies in developed and emerging economies: A case study of how the entry strategies of Norwegian oil service firms are affected by the differing institutional contexts of Australia and Brazil." (2013).

There are several models of entering a foreign market. Direct and indirect export is relatively simple and does not require significant financial outlays. The risk of entering the Polish market is the lowest in this case, due to the lack of the need to appoint a separate representative office and lower initial costs.

More advanced stages require further expenditures and in-depth analysis, financial planning as well as strategy, including securing the human resources delegated to the project, other resources, and production capacity. The most engaging model is running a foreign branch or subsidiary.

Selected examples of successful expansion into the Polish market:

6.1. Ørsted + PGE Polska Grupa Energetyczna (joint--venture)

Ørsted, a Danish wind energy producer, and PGE have decided to sign an agreement for the purchase of 50 percent of shares in two projects for the construction of Baltica 2 and Baltica 3 offshore wind farms, with a total capacity of up to 2.5 GW, and in the implementation of these projects. In March, the Office of Competition and Consumer Protection approved the execution of the joint venture agreement. PGE Baltica started the process in December 2018 by inviting potential business partners for talks. At the end of January 2019, the first stage of the selection was closed, in which a dozen or so companies from the global offshore industry applied for negotiations.In September 2019, four companies from the offshore industry were selected on the negotiation list. A month later, on October 22, the Management Board of PGE decided to conduct further talks with one entity - Ørsted. On October 20, 2022, the Regional Director for Environmental Protection in

Gdańsk issued a decision on environmental conditions for the connection infrastructure. The next stage of the investment will be obtaining building permits.

According to the schedule of the first stage of the project, i.e. Baltica 3 with a capacity of up to 1045.5 MW, the introduction of the first energy to the grid is planned for 2026. The next stage, i.e. Baltica 2 with a capacity of up to 1,497 MW, is to start production in 2027. Until now there was no announcement about a possible hydrogen technology implementation in this project, although Polish officials mentioned such possibility referring to the Polish offshore projects.

6.2. CAF (Solaris acquisition)

Solaris, a family company started producing buses in 1996 and over the next 20 years became one of the largest producers in Europe. The company was looking for an investor who would allow it to become a leader in the segment of innovative solutions for public transport in Europe and strengthen the company's position outside Europe. The achievement of these goals was made possible by the Spanish CAF (Construcciones y Auxiliar de Ferrocarriles), which bought 100 percent shares in the company back in 2018. The Solaris sale transaction was worth an estimated EUR 300 million.

For CAF, the transaction, apart from an increase in value, meant entering new market areas. Until then, the company had focused on the design, production, maintenance and delivery of rolling stock and rail vehicles, tramways as well as operating in the e-mobility segment. CAF acquisition of Solaris not only allowed to enter the bus manufacturing market, but also acquire a company with significant hydrogen experience.
Solaris generated revenues of EUR 721 million in 2021, employs nearly 2,500 people and is active on 32 markets worldwide, where nearly 17,000 vehicles of this company are in use, including more than 60 hydrogen-powered buses.

6.3. Ballard (export)

The dynamic expansion of the Canadian company Ballard Power Systems on the Polish market is largely due to its leading technological role and credibility. Ballard products, in the absence of similar equivalents of Polish production, are installed e.g. in hydrogen buses manufactured in Poland, such as NesoBus, but also in a hydrogen-powered shunting locomotive developed by PESA Bydgoszcz. Recently, Ballard announced signing a contract for fuel cells for 25 Solaris buses to Poznań.

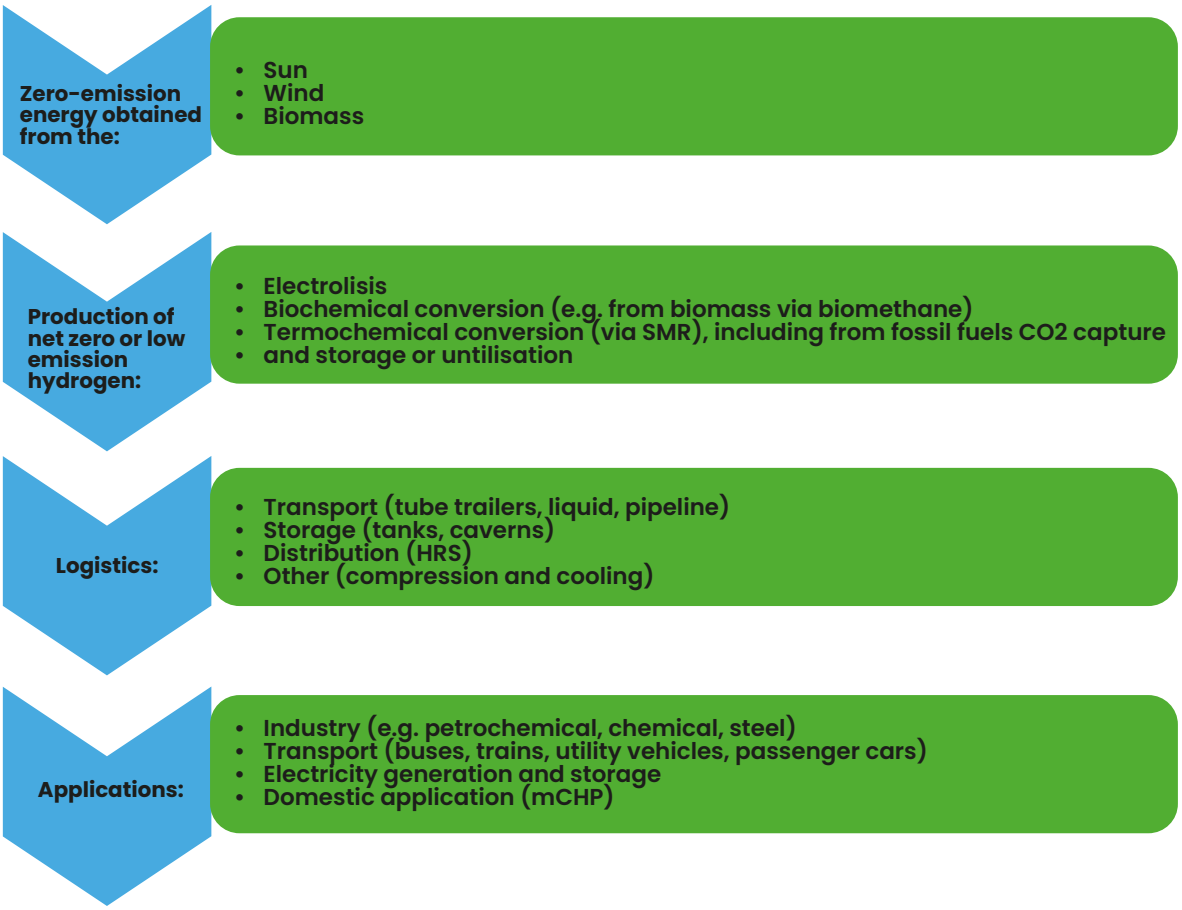
Ballard Power Systems has also partnered with ABB to develop a high-performance fuel cell concept capable of generating 3 MW of energy. The main goal of the project is to create zero-emission hydrogen fuel cell technology for larger ships on a commercial scale, which has potential in implementations for Polish shipping in the Baltic Sea.

It should be added that entering the Polish market was for Ballard another step in its expansion into foreign markets. The company has experience in the field of hydrogen technology in transport. In 2017, together with the Chinese company CRRC Qingdao Sifang, Ballard produced vehicles for world's first commercial fuel cell powered tram line.

7. Conclusions

Polish industry has competence in most of the hydrogen economy chain. **The industry located in Poland has the greatest potential in the case of the production of hydrogen buses. It is also the area with potential for the fastest development of the entire chain from production through transport, distribution, and consumption of hydrogen.** Orders for new hydrogen-powered buses create an opportunity for foreign suppliers of electrolysers and refuelling stations, key areas where Polish industry has not yet developed the potential to integrate at a sufficient level to provide domestic solutions. Around the main centres of future hydrogen public transport, such as Poznań or Katowice, business processes are already being carried out aimed at producing renewable hydrogen close to the place of its consumption.

The experience of the domestic industry in the production of buses, i.e., at the OEM level, means that Polish companies have the potential to quickly integrate around prospective sectors of the hydrogen market. Dynamic growth is recorded especially in the case of private entities (Solaris, ZE PAK). Polish manufacturers of hydrogen vehicles (ZE PAK, Autosan, Pesa) would be happy to use as many locally produced components as possible.



However whole supply chain as presented on the graph above shows opportunities for technology owners, investors, vendors, and buyers, including machines and components necessary at every step of the life cycle (design, implementation, maintenance, aftermarket). The supply of flexible hydrogen supply lines, valves, gaskets, meters, or detectors, i.e., components for end devices, is within the reach of Polish manufacturers. The challenges of the Polish market include the integration of more advanced designs, including the electrolysers (production) and hydrogen fuel cells (fuel application).

Supplies of electrolysers of foreign production will be necessary to quickly start hydrogen production in Polish hydrogen valleys. An opportunity for suppliers will also be local governments investing in RES, including offshore (e.g. construction of offshore wind farms on the Słupsk and Central Banks with a capacity of over 30 GW), which at the same time participate in hydrogen valleys. Energy from RES in combination with an electrolyser will be a way to obtain renewable hydrogen. Thus, regions with a large share of RES in production, e.g., the Pomeranian Voivodeship, should soon be an attractive market for foreign entities offering equipment for hydrogen economy, e.g., electrolysers and photovoltaic installations or offshore wind farms or complete hydrogen production systems using RES.

8. Hydrogen supply chain in the UK

The Association for Renewable Energy and Clean Technology (REA) has been commissioned to prepare the UK portion of this report looking at the British net-zero hydrogen supply chain. All relevant parts of the supply chain from the production of variable renewable electricity which at times generates excess supply, to the hydrogen fuelled consumer equipment and every step in between, were examined. The current active companies in the hydrogen sector were identified as well as many up-and-coming participants. The sector is still at a very early stage of development, but it is already having a clear influence on considerations for energy storage, network management, innovative utilisation of Biogas and driving strong interest in carbon capture and storage technologies. The REA is the largest pan-technology trade association in the renewable sector with the strongest representation for the full net-zero hydrogen supply chain in the UK, please contact international@r-e-a.net for more information.

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8.1. Renewable Energy Production for Hydrogen

The energy industry experienced a ‚year like no other' in 2022, as a record amount of energy from renewable sources was generated in the UK, 40% of the UK's electricity generation in 2022 was produced from solar, wind, biomass and hydropower[1] . The increase in electricity generation from renewable sources in the UK resulted in a lowering of carbon dioxide emissions by almost three million tonnes compared to 2021. Power generation from renewables has quadrupled in the past ten years[2]. Forecasters expect the growth in investment and deployment to accelerate as the UK works toward delivering its net zero policy.

The flourishing renewable energy market in the UK can be both an opportunity and a challenge. Power output from many renewable sources such as wind and solar depend on variable natural resources, which makes output from these plants more difficult to balance across the network and presents challenges for grid operators in terms of forecasting and meeting load[3]. Establishing methods of balancing the grid without having to constrain the generation (turn off) of these variable but cheap resources, will be a major opportunity going forward and hydrogen production using excess power will have a significant role to play.

Managing Variable Renewable Electricity Generation

Over 60% of the primary energy used to create renewable electricity is wasted before they can reach the customers[4]. The growth of wind and solar has outpaced the corresponding development of grid infrastructure. When high output from renewable energy plants, typically when there are good wind and sun conditions, and this is not matched by a corresponding high demand, the wind and solar farms are the first to be turned off. As more renewable generation comes onto the grid, oversupply frequency is likely to increase, and the practice of curtailing variable solar and wind resources will become more frequent. To tap into the full potential of wind and solar resource, storage technologies and other innovative ways to utilise excess renewable electricity will be essential for speeding up the phase out of fossil fuelsbecome more frequent.
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Grid Energy Storage

A number of methods can be used to store energy during times when electricity is plentiful and inexpensive (especially variable and non-dispatchable renewable energy) or when demand is low, and later returned to the grid when demand is high, and electricity prices also tend to be higher.

1 REview 2022 by REA

2 World Economic Forum. 2023, https://www.weforum.org/agenda/2023/01/2022-renewable-energy-uk-electricity

3 Kathryne Cleary and Karen Palmer, 2020, https://www.rff.org/publications/explainers/renewables-101-integrating-renewables/

4 Bob Shively, https://www.enerdynamics.com/Energy-Currents_Blog/How-Much-Primary-Energy--Is-Wasted-Before-Consumers-See-Value-from-Electricity.aspx

Common forms of grid energy storage include hydroelectricity and battery storage. Hydroelectricity includes both conventional hydroelectric generation as well as pumped-storage technology. Grid-scale battery storage can traditionally provide hourly, daily and maybe seasonal energy storage at the longest time frame, depending on the capacity of the batteries. The UK government is in urgent need of technology innovation in energy storage, seeking technologies with better storage efficiency and have provided over £32 million in government funding. For example, five projects based across the UK will benefit from funding in the second phase of the Longer Duration Energy Storage (LDES) competition. These cover novel energy storage technologies, including an approach that utilised the formation of Hydrogen as a storage medium.

StorTera Ltd, based in Edinburgh, will receive £5.02 million to build a prototype demonstrator of their sustainable, efficient, and high energy-dense single-liquid flow battery (SLIQ) technology. SLIQ will offer flexibility to the grid by storing electricity which can then be released when weather-dependent technologies such as wind turbines and solar panels have periods of decreased energy generation.

Sunamp Ltd, based in East Lothian, will receive £9.25 million for a trial project that will experiment with their advanced thermal storage system in 100 homes across the UK. They will extend their existing heat battery to provide increased storage duration and capacity and pair it with household energy systems to tackle periods of low renewables generation on the grid.

The University of Sheffield will receive £2.60 million to develop a prototype modular thermal energy storage system, enabling optimised, flexible storage of heat within homes, providing benefits for both the occupant and the grid. The prototype energy systems will be manufactured by Loughborough University and deployed at the Creative Energy Homes campus at the University of Nottingham, demonstrating the technology within lived-in homes.

RheEnergise Ltd Ltd will receive £8.24 million to build a demonstrator near Plymouth of their ‚High-Density Hydro®' pumped energy storage system. The system uses an environmentally safe mineral-rich fluid more than two and half times denser than water, to create electricity from gentle slopes, without requiring steep dam walls or high mountains like traditional hydropower. The project will use surplus electricity to pump the fluid uphill, and then later when electricity is needed by the grid, the fluid will be released back down the hill through turbines to generate electricity.

EDF UK R&D, , in partnership with the University of Bristol, Urenco and the UK Atomic Energy Authority (UKAEA), will receive £7.73 million to develop a hydrogen storage demonstrator utilising depleted uranium at UKAEA's Culham Science Centre in Abingdon, Oxfordshire. Electricity will be converted to hydrogen via electrolysis and stored for future use - either directly as hydrogen or converted back to electricity via a fuel cell when required[5].

5 BEIS and Hon Graham Stuart MP, 2022, https://www.gov.uk/government/news/energy-storage--backed-with-over-32-million-government-funding

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Utilising Excess Renewable Energy for Hydrogen Electrolysis

The UK's current storage capacity cannot meet the amount of electricity generated in times of high production and low demand, and using electricity to produce hydrogen will be an attractive option to increase grid flexibility and renewable energy uptake. Switching the excess electricity to the production of hydrogen by electrolysis, as a form of energy storage, will help to reduce the amount of renewable electricity curtailed and is likely to become a key technology to decarbonise the UK grid.

Hydrogen can also be the key to overcoming challenges in local energy systems, by producing hydrogen from excess renewable electricity that would otherwise have been curtailed and using it to support the decarbonisation of road transport and heating. Across the UK, pioneering projects focused on the production and use of hydrogen have provided lessons, stimulated further research and innovation, and pointed the way to what is needed to deploy production capacity at pace and scale and unlock hydrogen as a low-carbon fuel for new and existing applications across the energy system. Hydrogen has great potential to be used as an energy storage carrier and can be a major contributor towards the UK national energy mix, both as a short-term dispatchable power source and as a means of storage for the long term. It can make power systems more flexible, helping to integrate high shares of variable renewable sources.

As an example, a large solar PV array installed by **ENGIE UK** fuels the electrolyser. This will produce green hydrogen, which is to be supplied to the refuelling station for hydrogen vehicles. **The Tees Green Hydrogen** project by **EDF Renewables** is a pioneering project which powers an hydrogen electrolyser using green electricity produced locally by Teesside Offshore Wind Farm and a new solar farm at the same location.

8.2. Electrolysers for Hydrogen Production

Net-zero hydrogen is produced with zero or negative net emissions. The most common net-zero hydrogen production process is water electrolysis, which is the process in which electrolysers utilise electricity to power the electrochemical liberation of hydrogen. Where the renewable electricity is not co-located with the electrolyser it is important to show a clear, contractual link with the source of generation – otherwise, the hydrogen produced will reflect the embedded greenhouse gas emissions of the electricity grid as a whole.

Currently, there are three types of electrolysers based on the different reactions at the anode and cathode:

- Alkaline electrolysis
- Proton exchange membrane (PEM) electrolysis
- Solid oxide electrolysis (not commercially available yet)

Alkaline electrolyser (AEL) has the advantage that it requires fewer or no special materials. The electrolyte is a potassium hydroxide solution. The anode in commonly available electrolysers is made of nickel, and the cathode consists of either nickel or

stainless steel. While AEL systems are relatively inexpensive, they are quite large, making them unsuitable for locations requiring compact solutions..

PEM electrolyser (PEMEL) is the technology of choice if space is limited or alkaline solutions are not an option, for example, in the proximity of offshore wind farms. The electrolyte of a PEMEL system consists of a proton-conducting polymer membrane and the catalyst is made of a platinum group metal, either iridium or platinum. Both components can increase system costs considerably[6].

Suppliers of Electrolysers in the UK

Of the suppliers of commercially available electrolysers for hydrogen production at greater than 1 MW capacity, there are approximately 20 global suppliers of either PEM or alkaline electrolyser packages, one being a UK supplier: ITM Power. ITM Power has invested in increasing both production capacity at its facility in Sheffield and the maximum size of its standard offering. ITM Power's manufacturing base has a production capacity of 1 GW per annum and plans to expand capacity by an additional 1.5 GW per annum by the end of 2023. However, given the scale of ambition for the construction of green hydrogen plants over the next two decades in the UK, Europe and globally, further expansion in the capacity of existing suppliers and the arrival of new entrants to the market is expected.

There are also UK-based electrolyser suppliers that can supply electrolysers at a smaller scale. Incentives from the UK government, such as Net Zero hydrogen Fund and hydrogen Business Model, might trigger potential future growth of these companies:

- **Amalyst:** Producer of fuel cell and water electrolysis catalyst.
- **Clean Power H2 Group (CPH2):** Manufacturer of the unique Membrane-Free Electrolyser model.
- **Supercritical Solutions:** The company is developing the world's first high-pressure, ultra-efficient electrolyser.

Electrolytic Hydrogen Projects in the UK

Iberdrola, through its subsidiary **Scottish Power**, plan to install a pilot plant in the UK to test a new electrolyser technology that could reduce green hydrogen production costs. The project will be developed together with **Proton Ventures** - a provider of green engineering solutions - and **Supercritical**, which has developed a new type of high--pressure electrolyser. Supercritical's design allows gases to be delivered at over 200 bar pressure without the use of compressors, saving up to 20% of the electricity consumed to produce the same amount of hydrogen.

The UK Government recently announced up to £6 million in support for these initiatives through the Net Zero Innovation Portfolio Low Carbon hydrogen Supply Program. This new high-pressure electrolyser, powered by renewable energy, will be used in an ammonia module supplied by Proton Ventures, where green hydrogen, at extremely high pressures, will combine with nitrogen from the air to produce ammonia.

6 Hydrogeit, 2020, https://h2-international.com/2020/12/10/specialty-metals-for-water-electrolysis/

Storegga is developing a project in Comarty, north of Inverness, Scotland, which will enable the decarbonisation of distillery heating processes. The project is also supported by the UK Government, which has committed £9.4 million to its construction. The initial project phases will be focused on the Cromarty Firth region (north of Inverness) and will provide green industrial heat across the region for a range of customers including distilleries and the transportation sector. The projects are expected to deliver hundreds of MW of green hydrogen production capacity before the end of the decade, with plans for the first project to be operating by 2024.

Scottish Power is also participating in **‚Scot2Ger'**, an international collaboration project to explore future opportunities for exporting net-zero hydrogen from Scotland to Germany. The **Iberdrola group** has just inaugurated Europe's largest green hydrogen plant for industrial use in Puertollano and currently has a portfolio of green hydrogen projects that will attract investments of €9 billion by 2030, with the aim of developing 400,000 tonnes/year of green hydrogen.

ITM Power recently provided an update on the Green hydrogen project where they are working with project partners Scottish Power and **BOC**. A planning application has now been made for a 20MW electrolyser to be sited at Scottish Power Renewables' Whitelee Wind Farm near Glasgow, the UK's largest onshore wind farm. This represents a doubling in the planned electrolyser scale capacity and is an early indication of increasing market demand.

Challenge: Supply of Raw Materials

Producing adequate amounts of hydrogen is crucial to establishing a fully sustainable energy supply and production of sustainable products. An important issue in the consideration for the large-scale manufacture of the electrolysers themselves is the availability of raw materials, such as iridium, platinum, tantalum, cobalt and nickel. Based on the global production share of raw materials needed for manufacturing electrolysers, the capacity of hydrogen electrolysis could be restricted by raw material supply.

Among all critical materials, iridium is one of the rarest elements on Earth with less than ten tonnes produced each year[7]. In high-demand scenarios, Europe alone would need about 110% of the world's annual iridium supply for the production and service of PEM electrolysers. Therefore, in the development of PEM electrolysers, it is paramount to reduce the need for iridium and other critical materials. Researchers at leading institutes are working to determine catalysts that could reduce the use of these rare resources[8].

7 Ellen Phiddian, 2022, https://cosmosmagazine.com/science/chemistry/H2-electrolysis-precious--metals-catalyst/

8 VoltaChem, 2019, https://www.voltachem.com/news/the-materials-issue-of-H2-production

8.3. Hydrogen Storage and Transport Equipment

After the hydrogen is produced, transportation and storage are required. Hydrogen transport and storage infrastructure will be critical enablers for the necessary growth in the hydrogen economy required to meet UK's 10GW ambition[9], which could support over 12,000 jobs in hydrogen production, distribution, and storage by 2030[10].

Hydrogen Storage

Common hydrogen storage technologies include short-term and small-scale storage as well as large-scale long duration solutions. In small-scale storage such as refilling stations, hydrogen is being stored in compressed gas tanks and vessels. Compressed gas tanks and vessels are normally high-pressure cylinders with an internal pressure range from 200 to 700 bar. The high-pressure cylinders have relatively low capital costs but are difficult to scale up. Another small-scale alternative is storage with higher volumetric density, such as liquid hydrogen in cryogenic tanks. They are less cost effective because of the energy loss during compression and liquefaction. For large--scale and seasonal energy storage, high-pressure cylinders or cryogenic tanks will not be sufficient. Britain's decades-long experience in underground gas storage technologies will be advantageous in unlocking the potential of hydrogen.

There is a wide consensus that salt caverns are one of the most cost-effective, efficient and proven ways to store large volumes of hydrogen onshore[11]. With multiple salt caverns having been used to store fossil gas, nitrogen and hydrogen since the 1970s, the technology is well understood in the UK.

Throughout their use for gas storage, salt caverns have proven to be leakproof, with the only leakage possible through the wells. The inert nature of rocksalt means there is a low risk of undesired microbial and chemical reactions affecting the quality of stored hydrogen. Due to the low temperature of the salt caverns, hydrogen can also be compressed more energy-efficiently than in above-ground circumstances. Moreover, the low land and operational costs make salt caverns cheaper than batteries by a factor of 100, costing less than £0.50 per kg of hydrogen[12]. Given the strong geomechanical structure of the hydrogen salt caverns, high pressure can be attained with either less cushion gas compared to depleted gas fields, or with brine used instead of cushion gas, reaching approximately 100 times higher volumetric energy density than compressed air energy storage (CAES) of the same size. However, salt caverns are not geographically widespread, and their capacity to store hydrogen also varies.

Aldbrough Gas Storage facility was commissioned in 2011 and has been providing fossil gas storage for the Humber region and beyond since. With its capacity to store up to 30 billion cubic feet of gas, the potential for its nine underground salt caverns can be converted to support hydrogen storage, avoiding the long lead times and high capital costs of building new facilities, is currently being investigated. **Equinor** and **SSE Thermal** commissioned a feasibility study in early 2022 to assess the design of the salt caverns

9 Hydrogen investor roadmap: leading the way to net zero - GOV.UK (www.gov.uk)
10 BEIS and Hon Graham Stuart MP, 2022
11 Hydrogen Storage in Caverns 2022 (era.ac.uk)
12 Microsoft Word - WG04 Storage Report v4.3 Final.docx (hydrogen-uk.org)

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for hydrogen storage and the connection to the **Humber Low Carbon Pipelines**. With an expected storage capacity of 320 GWh, Aldbrough could become the world's largest hydrogen salt cavern facility as early as 2028.

UK Oil & Gas (UKOG) (UKOG) aims to convert **the Dorset salt cavern** to a hydrogen storage facility. UKOG's subsidiary **UK Energy Storage** (UKEn) will lease two former Royal Navy sites in Dorset to develop hydrogen-ready gas storage and green hydrogen generation capability. The underground salt cavern storage sits beneath the land offering a capacity of 43bn sq ft (1.2bn sq metres). UKEn is working with consultant **Xodus Group** to use established engineering techniques. Completion of the envisioned project would significantly increase the UK's storage capacity, which has been significantly reduced since **Centrica** closed its Rough storage facility in 2017, and has only brought part of it back into service.

The other suitable option for hydrogen storage is depleted hydrocarbon fields. These reservoirs are sufficient in size and have been proven to seal fossil gas and oil adequately, with 74% of fossil gas already being stored within depleted hydrocarbon fields globally. As highlighted by the H21 report, converting a depleted gas field can be more cost-effective in terms of cost per unit volume of storage than creating new salt caverns. Furthermore, depleted gas fields are preferred over oil fields as gas may not be trapped by the same seal that contained oil.

An issue which is frequently raised in relation to storage and use of porous media is the risk of diffusion given the much smaller diameter of hydrogen molecules compared to fossil gas: methane (CH4). However, recent findings suggest that losses from dissolution and diffusion can be minimised to 0.1%[13]. Further investigation, including academic-led projects such as the **HyStorPor** (Hydrogen Storage in Porous media) and **HyUSPRe** (Hydrogen Underground Storage in Porous Reservoirs), showed no significant risk of hydrogen loss during laboratory testing and numerical modelling.

Centrica recently announced the reopening of Rough storage field, the UK's largest fossil gas storage facility, with the first injections made in September 2022. In the short term, Rough's initial capacity of 30 billion cubic feet will strengthen the UK's energy security by balancing the volatilities of the global fossil gas market. With Centrica aiming to redevelop Rough as a 10TWh hydrogen store in the long term, the UK can soon have direct access to the world's largest hydrogen storage facility. To provide context, 10 TWh of storage capacity is equivalent to approximately 150 average-sized salt caverns, each of which would take one year to build. As Rough has favourable geological characteristics such as high temperature, salinity and dryness, and low risks associated with microbial processes and hydrogen sulphide contamination. Being developed in three 3.3 TWh phases to match the growth of the hydrogen economy, Rough can provide large-scale hydrogen storage as early as 2030. With the long lead time and high capital costs of new salt cavern projects, Rough is currently one of the most cost-effective options in terms of a unit volume of storage to meet our hydrogen and carbon reduction ambitions.

13 Hydrogen UK, Storage Working Group, Hydrogen Storage: Delivering on the UK's Energy Needs, 2022

Besides underground storage which requires specific geological structures, large-scale above-ground storage technologies can also help to store hydrogen. In a practice known as linepacking, hydrogen is stored within the gas transmission and distribution network. Even though the high-pressure pipelines of the national transmission system can store about 4,146 GWh of fossil gas per hour, due to the low volumetric density of hydrogen this same network would be anticipated to store only 25% of this level of energy.

There are multiple innovative above-ground technologies in the initial research process, with many of them receiving funding under the Long Duration Energy Storage Competition.

EDF's HyDUS (depleted uranium storage) received considerable support from BEIS to use Urenco's depleted uranium for storing hydrogen as uranium hydride. Besides utilising nuclear waste products, the project can potentially deliver a storage alternative which can reach twice the volumetric density of liquid hydrogen.

Like HyDUS, the **LAVO's** Hydrogen Energy Storage System (HEOS) project is also investigating metal hybrid technology for future long-term storage. **Corre Energy** in Wales is working on a unique long-duration energy system by utilising their patented Carbon280 HydrilyteTM hydrogen carrier.

There is active research on safe, stable and easy-to-transport hydrogen carriers such as liquid ammonia which have almost three times higher volumetric density than compressed hydrogen (12.7 MJ/L vs 4.5 MJ/L) and liquid organic hydrogen carriers (LOHC), in which hydrogen is chemically bonded to a stable organic liquid carrier as they are compatible with existing fuel infrastructure.

Under the Government's Low Carbon hydrogen Supply 2 competition, the Solid hydrogen at Low Pressures (SHyLO) project by **H2GO Power** secured £4.3 million to develop their innovative storage system in the Orkney Islands. As compressed gas storage can have efficiency limitations and high compression costs in addition to large floor space requirements, H2GO Power's low-pressure solid-state hydrogen storage technology aims to provide a suitable alternative to on-grid and off-grid off-takers. By removing the need for compression potential storage savings compared to compressed hydrogen can be increased by up to 55%. Whilst 350 bar cylinders have a storage capacity of 26.1 grams of hydrogen per litre, one H2GO Power unit can store up to 50-100 grams per litre. This is higher than the volumetric density of liquid hydrogen. As hydrogen can be stored at ambient temperatures and pressure, this technology not only has the potential to reduce costs and increase efficiency but also to remove key policy and regulatory barriers.

Transporting Hydrogen

Hydrogen is a particularly challenging product to safely transport. It has the lowest density of all gases and is also highly flammable when mixed with the smallest amount of air. Today, Hydrogen is transported from the point of production to the point of consumption via pipeline and over the road in cryogenic liquid tanker trucks or gaseous tube trailers. Pipelines are deployed in regions with substantial demand (hundreds of tons per day) that are expected to remain stable for decades. Liquefaction plants, liquid tankers, and tube trailers are deployed in regions where demand is at a smaller scale or emerging. Demonstrations of hydrogen delivery via chemical carriers (e.g., barges) are also underway in large-scale applications.

The ability and safety of fossil gas transmission and distribution networks being used for transporting 100% hydrogen are being assessed by the **National Grid** and the **Gas Distribution Networks** (GDNs). Depending on the outcomes of these assessments, repurposing existing infrastructure could be possible. **FutureGrid** is building an offline hydrogen test facility from decommissioned equipment to demonstrate whether National Grid's network can safely transport up to 100% hydrogen. **Local Transmission System Futures** is looking at the feasibility of repurposing the local transmission system owned and operated by the GDNs. **H21** is looking at the feasibility of repurposing the distribution network owned and operated by the GDNs.

HyDeploy is a £22.5m Ofgem Network Innovation Competition project delivered by a consortium, including partners **Northern Gas Networks, Cadent, Progressive Energy Ltd, Keele University, HSE – Science Division** and **ITM Power**. Progressive Energy is project managing the UK's first demonstration of hydrogen blended into an operating gas network. This project will help reach the UK Government's target of net zero carbon emissions by 2050. HyDeploy has secured the UK's first-ever safety approval to blend 20% hydrogen into a gas network. Two large trials in ‚public' networks have already taken place – in residential homes at Keele and Winlaton. Successful blending trials in the industry in the glass, FMCG, ceramic and baking sectors. HyDeploy will conclude in 2023, having supplied the evidence base necessary to enable wider hydrogen injection into gas distribution networks in the UK.

The **HyNet North West Hydrogen Pipeline** will be the UK's first 100% hydrogen pipeline network at scale. From 2025, it will replace fossil fuel gas with low carbon hydrogen and carbon capture and storage, setting the North West and North Wales on the path to Net Zero whilst also protecting and creating jobs[14].

Project Union is National Grid's development of an hydrogen 'backbone' to link industrial clusters around the country. Repurposing around 25% of the current gas transmission pipelines, Project Union will build on the government's 10-point plan to invest more than £1 billion to unlock the potential of hydrogen. The project is exploring an hydrogen backbone connecting the Grangemouth, Teesside and Humberside clusters, as well as linking up with Southampton, the North West and South Wales clusters. Project Union will also look at how to connect the backbone to the existing interconnectors coming into the Bacton gas terminal in Norfolk, so allowing the UK to link with the EU hydrogen backbone that is also being developed. This could open future import and export of hydrogen with other European countries. The link down to Project Cavendish at the Isle of Grain, where National Grid and a consortium of energy companies are currently looking to develop hydrogen production capacity, will also be key[15].

DNV has won a 3-year contract in the UK for safe use and conversion of pipelines to transport 100% hydrogen. DNV has been engaged to provide the evidence required to demonstrate the safe use and conversion of the local transmission systems (LTS) high-pressure pipelines for transporting 100% hydrogen. The gas distribution company **SGN** manages around 3,100km of the LTS pipelines in the UK and is leading this project working in collaboration with the other UK gas networks. The LTS is owned and operated by gas distribution networks. These are the pipelines that connect the high-pressure National Transmission System (NTS) with the lower-pressure tiers.

14 HyNet North West H2 Pipeline, 2022, https://www.hynetH2pipeline.co.uk/

15 National Grid, 2021, https://www.nationalgrid.com/stories/journey-to-net-zero-stories/making--plans-H2-backbone-across-britain

These pipelines are considered the ‚backbone' of the energy network, currently delivering gas from NTS offtakes to towns and cities across the country.

Plans have been revealed for a new 400km pipeline underneath the North Sea to transport hydrogen produced by offshore wind farms to the continent. Proposals have been put forward by gas transmission firms **Gascade** and **Fluxys** that would see the 400km-long AquaDuctus line initially connect from a German wind farm near Helgoland. According to the firms, by 2035 the line would develop into a major hydrogen corridor transporting up to 1 million tonnes of hydrogen a year. According to the study, the potential for hydrogen production in the German and European North Sea is 100GW per year. If built-in full, the pipeline will be able to connect to other planned hydrogen flows and could connect to the UK in northern England and Scotland.

Non-pipeline transportation of hydrogen includes transport by road, rail, and sea. Although included in the development of hydrogen transport infrastructure, hydrogen transport through the gas network by pipelines is a prioritised choice in the UK, considering its relatively low cost and the ability to transport long distances and high volume. Analysis by Bloomberg NEF estimates that transporting hydrogen 100km by road could cost a maximum of £1.46/km while transporting hydrogen 100km via a distribution pipeline is expected to cost a maximum of £0.19/km (BEIS, hydrogen transport and storage infrastructure).

8.4. Hydrogen Distribution and Refuelling Station

Hydrogen is an ideal substitute for fossil fuel for powering vehicles. As hydrogen fuel cells begin to play a greater role in meeting energy needs, hydrogen fuel cell vehicles are growing rapidly alongside electric vehicles which are playing an increasing role in the green transportation market. Fuel cell vehicles are fuelled with pure hydrogen gas stored in a tank on the vehicle.
Similar to the mechanics of traditional refuelling stations for conventional internal combustion engine vehicles, a hydrogen refuelling station (HRS) refills hydrogen fuel cell vehicles with pressurised hydrogen.

The UK has a growing network of HRS, which are critical for the growth and adoption of hydrogen fuel cell vehicles. The UK government has identified the need for hydrogen infrastructure as a crucial component of its plan to decarbonize the transport sector. In 2022, the UK Government has noted 15 public hydrogen fuel stations across the UK for fuel cell-powered electrically propelled vehicles. Most of these stations are located in England, with some in Scotland and Wales. There are several companies involved in the development and operation of HRS in the UK, including:

ITM Power: Designs, builds and operates hydrogen refuelling stations. As a leading company that focuses on providing clean fuel and energy, it has created and run two refuelling stations in London. Other sites are being proposed after the success of one at Heathrow Airport and another in Hendon, North London.

Linde: A global engineering company that provides hydrogen production and dispensing equipment for HRS. Linde has successfully built more than 15 hydrogen refuelling stations for buses worldwide.

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BOC: A subsidiary of The Linde Group, BOC provides hydrogen production and dispensing equipment, as well as hydrogen fuel, for HRS in the UK and around the world.

Air Liquide: French multinational corporation that supplies hydrogen fuel and operates hydrogen refuelling stations in various countries, including the UK. In 2012, Air Liquide opened its first hydrogen charging station, open to the general public for private cars, in the town of Düsseldorf, Germany. Following this cutting-edge station, 100 hydrogen stations have been designed and built by Air Liquide around the world, including for private cars and public transportation.

Ballard Motive Solutions: A UK-based company specializing in hydrogen and fuel cell technology. The company develops and operates HRS, as well as provides related consulting services. They deliver to commercial fleet operators hydrogen fuel supplied by ITM Power.

Logan Energy: UK company based in Scotland that provides storage and compression facilities, also delivers hydrogen refuelling stations ranging from 300-700 bar delivery. Logan Energy is to design and supply one of the largest capacity hydrogen refuelling stations in Europe, facilitating the roll-out of one of the UK's biggest zero-emission bus orders in Belfast. Additionally, the company is in charge of the production, distribution and refuelling process of many other HRS' in the UK.

Storengy UK: Storengy owns and operates the Stublach Gas Storage Facility located in Cheshire. This storage facility is the UK's largest onshore gas storage. The storage site will ensure supply for the first green hydrogen station in North West England. A large solar PV array installed by ENGIE UK fuels the electrolyser. This will produce green hydrogen, which is to be supplied to the refuelling station.

BIG HIT uses renewable electricity generated from wind turbines on the islands of Eday and Shapinsay to produce hydrogen by PEM electrolysers. The hydrogen is then stored as high-pressure gas in tube trailers, which can be transported to mainland Orkney and used in refuelling vehicles. The BIG HIT hydrogen refuelling station in Kirkwall supports the Orkney Island Council van fleet.

Calvera is developing new products for compressed hydrogen storage and transport. Calvera manufacture compressed gas trailers for hydrogen, being a leader in the sector for this range of product. The design, construction and manufacture of tube trailers are a Calvera speciality.

Symbio FCell is a pioneering company in fuel cell technology and the inventor of the first range extender for hybrid (combined electricity and hydrogen) vehicles.
Translink Belfast Project: The £1.6 million Belfast refuelling station, set to be installed in Newtownabbey Bus Depot, will supply a fleet of 20 purpose-built hydrogen Fuel Cell buses operated by Translink. These buses are being introduced alongside a fleet of new Battery Electric vehicles, which will see Translink operating the 4th largest Zero Emission bus fleet across all UK regions. The refuelling station will have a total capacity to dispense a minimum of 2,500kg of green hydrogen per day which will allow Translink to increase its fuel cell bus fleet in the future without the need to modify the refuelling station.

Element 2, has announced its partnership with **Exelby Services** to develop hydrogen refuelling stations at its Coneygarth and Golden Fleece service station locations

along the A1(M) and M6 motorways respectively, serving roads in the surrounding area.

Tees Valley Hydrogen Transport Hub: The hub will act as a living lab to understand hydrogen's role in decarbonising the transport sector, through large-scale trials across different transport modes and use cases. The first of its kind in the UK, this project will comprise a set of facilities for the production, storage, and distribution of green hydrogen to supply a network of refuelling stations and support operational trials of hydrogen -powered vehicles including road, waterways and aviation. The hub brings together government, industry and academia, and is expected to be fully operational by 2025. In 2023, the Tees Valley area will see various pilot projects of hydrogen vehicle demonstrations across modes and use cases including, but not limited to, forklifts, cars, buses, HGV (heavy goods vehicles) and marine vessels.

Since both fuel cell vehicles and refuelling stations are in an early stage of implementation, the operation of refuelling stations faces challenges such as the accurate metering of the hydrogen delivered, a low volume of manufacturers and a lack of component standardization. More importantly, minimizing the safety hazards related to the use of hydrogen as a fuel is essential.

The UK government recognises hydrogen as a key alternative to the use of fossil fuels in transport. The decarbonization of transport will see rapid growth with UK's hydrogen Strategy. In 2008, the UK government launched the Renewable Transport Fuel Obligation (RTFO) aims to increase the use of renewable transport fuels. Hydrogen produced by electrolysis using renewable electricity, as well as bio hydrogen, for example, produced through steam reforming of biomethane, are supported through the scheme.

8.5. Hydrogen Fuel Cells

A fuel cell works by converting chemical energy from a fuel, such as the conversion of hydrogen into electrical energy through a chemical reaction. Fuel cells are unique in terms of the variety of their potential applications and versatility, with compatibility with a wide range of fuels and feedstock and the ability to provide power for systems ranging from power stations to vehicles and small portable generators.

The fuel cell works by using a catalytic reaction to convert the chemical energy stored in hydrogen into electrical energy, which can then be used to power devices and equipment. The by-product of this reaction is water, making hydrogen fuel cells a potentially clean and efficient pathway of energy. There are a range of fuel cell technologies, and each has different applications and advantages. Currently, the focus of research in fuel cells is primarily on Polymer electrolyte membrane fuel cells (PEMFC).

At the centre of a PEMFC is the membrane electrode assembly (MEA), which consists of the membrane, catalytic layers, and gas diffusion layers. The polymer electrolyte membrane is a specially treated material that only conducts positively charged ions and blocks electrons. A layer of catalyst is covering both sides of the membrane, anode and cathode, the catalyst speeds up the reaction and help the fuel cell to generate a continuous flow of electricity. It is worth knowing the most common hydrogen fuel cell catalyst today contains a large amount of platinum. Lastly, the gas diffusion layers sit outside the catalyst layers and facilitate the transport of reactants into the catalyst layer, as well as the removal of product water. To integrate the MEA into a fuel cell, hardware

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components such as gaskets to seal around the MEA to avoid gas escape and bipolar plates to assemble the PEM fuel cells into a stack and manage the flow of fuel and air are employed.

Value of Platinum

Platinum is a valuable commodity in the manufacturing of fuel cell technology. On average platinum metals typically account for approximately 10-30% of the overall material costs for a fuel cell.

The UK has companies that specialise in platinum production. **Anglo American Platinum**, a subsidiary of the UK-based multinational **Anglo American**, is the global leader in platinum production, accounting for 40% of the world's platinum group metals (PGMs), which include platinum, palladium, rhodium, iridium, osmium, and ruthenium. These metals are prized for their high level of purity, high melting points, and unique catalytic properties that make them ideal for use in fuel cell technology. **The London Bullion Market Association** (LBMA), a UK-based trade association, facilitates platinum trading by setting standards and providing a framework to trade. Additionally, the **BHP Group**, a UK/Australian multinational mining company headquartered in London, is a global leader in the mining industry with a market capitalization of $179B USD in 2021. The company primarily mines iron ore and copper, which are both essential ingredients in the production of catalysts used in electrolysis.

Design and Development of Fuel Cell Research and Design

ITM Power is one of the key companies in the UK that specializes in manufacturing and servicing machines with hydrogen. They have an electrolyser system that generates hydrogen based on PMEFC technology.

JCB is a British multinational corporation and one of the world's largest manufacturers of construction and agricultural equipment. The company plans to develop hydrogen fuel cell technology for use in its heavy machinery but is also an active player in the wider fuel cell technology sector. JCB Power Systems, the engine factory in Derbyshire, UK, have developed the first hydrogen motor in the construction and agriculture industry. The prototype backhoe loader, fitted with a hydrogen motor has the same performance as a diesel-powered counterpart[16].

Ceres Power is a British clean energy technology company that specializes in the development of hydrogen fuel cell technology. The company has developed a unique solid oxide fuel cell (SOFC) technology that enables highly efficient and durable fuel cells for a range of applications, including stationary power generation, transportation, and combined heat and power (CHP) systems. The SOFC technology is based on a unique ceramic material that can withstand high temperatures, making the fuel cells more durable and long-lasting compared to traditional fuel cell technologies. Ceres Power's hydrogen fuel cell technology has been designed to provide a clean and efficient energy source for various applications, including homes, businesses, and transportation.

Intelligent Energy is a UK-based company that specializes in the development and commercialization of hydrogen fuel cell technology. The company was founded in

16 JCB, https://www.jcb.com/en-gb/campaigns/hydrogen/hydrogen-refuelling

2001 and has since become a important player in the hydrogen fuel cell industry, developing fuel cell systems for a range of applications, including portable power, stationary power, and transportation.

Intelligent Energy's IE-Lift series is a range of hydrogen fuel cell systems designed specifically for use in material handling equipment, such as forklifts. The IE-Lift series provides a clean and efficient source of power for material handling operations, reducing emissions, and providing longer run times compared to traditional battery-powered equipment[17]. The hydrogen fuel cells in the IE-Lift series are designed to be compact and lightweight, making them easy to integrate into existing equipment.

Experience in Integrating Hydrogen Fuel Cell Technology and Generators

Johnson Matthey is a UK-based company that specializes in hydrogen fuel cell technology. One notable example of their work in this field is the development of hydrogen production catalysts and components for fuel cells. In addition, they have also been involved in projects aimed at improving the efficiency of Net Zero hydrogen production processes.

One case study that demonstrates Johnson Matthey's expertise in this area is their work in developing components for hydrogen fuel cells in the aviation industry. In collaboration with aircraft manufacturers, Johnson Matthey has integrated its hydrogen fuel cell technology into ground power units, which provide clean and efficient electrical power for aircraft on the ground. The fuel cells used in these units are designed to be highly reliable and cost-effective and have been shown to significantly reduce emissions compared to traditional diesel-powered systems.

AFC Energy, a UK-based company showcased its experience in integrating hydrogen fuel cell technology through its collaboration with Mace and Dragados to support HS2. The company provided zero-emissions operations through its H-Power Towers hydrogen fuel cell system to generate clean power to charge an electric JCB telehandler. This project demonstrated AFC Energy's ability to design, build, and integrate a hydrogen fuel cell system for a specific application.

The Energy Systems Catapult and the University of Birmingham's Hydrogen and Fuel Cell Research Group are research institutions and universities with expertise in hydrogen technology. They undertake research and development in hydrogen fuel cells and hydrogen power generation technologies, contributing to the growth and advancement of the UK hydrogen market. This expertise and knowledge allow them to offer guidance and support in the implementation, design, and consultation phases of hydrogen projects, making them valuable assets to the UK's hydrogen supply chain.

Ceres Power has established several strategic partnerships to expand its reach and develop fuel cell systems for various applications. The company has formed a joint venture with **Weichai Power**, one of the largest heavy-duty engine manufacturers in China, to commercialize fuel cell systems for transportation and stationary power applications in the country. Additionally, Ceres Power has partnered with several data centre companies to develop fuel cell systems that can provide clean and reliable power, re-

17 Intelligent Energy, https://www.intelligent-energy.com/our-products/ie-lift-hydrogen-fuel-cell-module/

ducing their carbon footprint and improving their energy efficiency. Furthermore, Ceres Power has entered a strategic partnership with **Toyota**, a global automotive manufacturer, to develop and commercialize fuel cell systems for transportation applications. These partnerships demonstrate Ceres Power's commitment to expanding the use of fuel cell technology and contributing to a cleaner, more sustainable future.

8.6. Hydrogen Vehicles

Hydrogen is a highly advantageous fuel source for vehicles due to its various benefits. The lightweight design of hydrogen storage tanks has the potential to offer greater travel range and improved performance for vehicles. The current technology is especially favourable for heavy commercial vehicles like buses and delivery trucks, which require a lot of miles to be covered each day and benefit from the quick refuelling time that hydrogen vehicles offer. Additionally, many hydrogen -powered heavy vehicles have a longer driving range compared to many battery-powered heavy vehicles available today, making it possible for drivers to travel farther without the need for a recharge or refuel. Lastly, refuelling hydrogen vehicles can be quick and convenient, taking just a matter of minutes compared to the current time required to charge electric vehicles on a like-for-like basis.

Given the advantages stated above, hydrogen is an ideal fuel source for various types of vehicles. For instance, passenger cars can benefit from the similar driving experience offered by fuel cell vehicles (FCVs), making them suitable for everyday use. FCVs are a great choice for buses and other commercial vehicles that need to cover considerable mileage each day, as the quick refuelling time helps reduce downtime. This makes FCVs a popular choice for vehicles such as waste and resource recycling trucks. Furthermore, FCVs are also ideal for delivery trucks as they can be used for long-haul trips without the need for extended charging time.

Additionally, given the UK's investment in hydrogen technology and infrastructure, there is considerable expertise as UK companies specialise in hydrogen vehicles ranging from buses, commercial vehicles, trains, and aeroplanes.

Hydrogen Buses and Waste Collection Trucks

In the UK, there are numerous initiatives underway to deploy hydrogen -powered buses in various cities and councils. With the aim of reducing air pollution and carbon emissions, hydrogen fuel cell technology has become an ideal choice for public transportation. Therefore, there are multiple bodies which can offer knowledge in the integration and running maintenance of these hydrogen fleets across the UK.

Several cities are taking the lead in the adoption and deployment of hydrogen fuel cell buses. In 2014, Aberdeen introduced an hydrogen fuel cell bus fleet, which has since expanded to include 25 buses and potentially 35 more in near future. This fleet is managed by First Bus, which is a local bus operator providing services in the city and the surrounding area. In addition to operating this hydrogen bus fleet, First Bus in Aberdeen also has experience in the conversion of diesel buses to hydrogen. Bristol has

launched a hydrogen fuel cell bus trial, with a fleet of six buses operated by First West of England, which is a subsidiary of First Bus the Scottish bus operator.

Transport for London (TfL) continues to decarbonise its bus fleet. In 2021 TfL launched 20 new hydrogen fuel cell double-decker buses which join the fleet of over 500 electric buses. This is part of TfL's goal to make all London buses zero emissions by 2030. **The Wrightbus**, a Northern Ireland-based company, manufactured the buses, leading to the creation of new job opportunities. The gas cylinders, on the other hand, were produced by **Luxfer** located in Nottingham. Currently, **Air Liquide's** plant in Runcorn is producing the hydrogen for the buses by utilizing waste hydrogen as a by-product from an industrial chlor-alkali plant. The transportation of fuel to the fuelling station is managed by **Ryze Hydrogen** based in Oxford. Starting in 2023, the hydrogen production will become more environmentally friendly as it will be produced through electrolysis powered by a direct connection to an offshore wind farm.

Aberdeen City Council has also invested in other hydrogen vehicles such as sweepers and waste trucks. In 2018, the city council introduced two hydrogen -powered waste collection trucks. The vehicles were manufactured by **Dennis Eagle**, a manufacturer of waste collection vehicles which specialises in OEM designed and fully integrated refuse collection vehicles[18]. The hydrogen fuel was supplied by **BOC**, a member of the **Linde Group** and one of the largest suppliers of industrial gases and related equipment in the world.

JCB also just unveiled their brand-new hydrogen combustion engine in January 2023. "The JCB engineering team has made enormous strides in a short space of time to develop a hydrogen internal combustion engine and it already powers a JCB prototype backhoe loader and loadall telescopic handler," said Lord Bamford, Chairman of JCB. It comes after JCB revealed in 2021 it intended to invest £100m in a project that would see the development of new, innovative hydrogen engines. The company also unveiled the 'world's first' hydrogen-powered digger during the late Queen Elizabeth II's Platinum Jubilee in 2022.

Fleet Management

Fleet management technologies provide fleet managers with real-time information and data analytics that help them make informed decisions about their fleets, such as optimizing routes, reducing fuel consumption, and reducing vehicle downtime. Hydrogen fleet management technologies typically include GPS tracking, telematics, route optimization, and real-time data analytics. Other benefits of fleet management software can ensure that there is compliance with regional driving regulations, driver safety, performance and satisfaction, less paperwork and in cases where consumers are involved, greater customer satisfaction.

18 Dennis Eagle, https://www.dennis-eagle.co.uk/products/zero-emissions-ecollect/

Hydrogen fleet management software providers in the UK include

- **AMS Fleet Management**
- **CLM Fleet Management Services**
- **Tomtom Telematics Fleet**
- **Holman Fleet Services**
- **AssetWorks**
- **Fleetinsight**

Hydrogen Trains

The UK is considered a global leader in the development of hydrogen trains, with several major companies investing in the technology. In 2018, the first hydrogen trains in the UK were introduced through the **HydroFLEX** project, which involved the **University of Birmingham** and **Porterbrook**[19]. The project involved retrofitting an hydrogen power pack to an existing Class 319 train, resulting in the flexibility that the train could run on the conventional electrified routes as well as independently.

Alstom is a French company and Britain's leading train manufacturer and maintenance provider; they operate the UK's largest train factory in Derby with about 6,000 employees. In recent years, Alstom has been investing in the development of hydrogen trains. The company has developed its own hydrogen fuel cell trains, which use hydrogen to generate electricity for propulsion. More notably in November 2021 Alstom and **Eversholt Rail** announced a Memorandum of Understanding aimed at delivering the UK's first-ever brand-new hydrogen train fleet[20].

It is worth noting that the hydrogen train sector remains fairly nascent globally, with the sector continuing to address early stage barriers. Larger vehicles like trains are well suited for hydrogen, as hydrogen can be stored above the passengers and risk can be further mitigated due to the trains having a set route**.**

Hydrogen Aircraft

There is currently limited use of hydrogen as a fuel for aeroplanes in the UK. However, there have been some developments and research in this area in recent years, as the aviation industry seeks to reduce its carbon footprint. In 2019, the UK government announced funding for a project called HyFlyer, which aimed to develop a small-scale hydrogen fuel cell-powered aircraft. The project was a collaboration between several companies, including **ZeroAvia**, **Intelligent Energy**, and hydrogen fuel cell provider **Riversimple**. This was a joint government venture with funding from the ATI (Aerospace technology institute) programme. The goal of the project was to demonstrate that hydrogen fuel cell technology can provide a viable alternative to traditional aviation fuels.

19 Porter Brook, https://www.porterbrook.co.uk/innovation/hydroflex=-cop#:~:text-This%20innovative%20train%20is%20the,branch%20of%20the%20UK%20government

20 Alstom, 2021, https://www.alstom.com/press-releases-news/2021/11/alstom-and-eversholt-rail--sign-agreement-uks-first-ever-brand-new

ZeroAvia is a UK-based company that develops hydrogen fuel cell systems for aviation. The company's technology enables zero-emission aviation and aims to reduce the carbon footprint of the aviation industry. The company aims to be a leader in the transition to hydrogen as a primary source of power for aviation. ZeroAvia's hydrogen fuel cell system provides a clean and sustainable alternative to traditional aviation fuel and enables longer flight times compared to battery-powered electric aviation. ZeroAvia has developed a 10-seater hydrogen fuel cell-powered aircraft, which it plans to scale up to commercial aircraft sizes in the future.

Major Hydrogen Transport Pilot Projects in the UK

Caledonian Maritime Assets Limited (CMAL) is working on a project to deliver hydrogen-powered passenger ferry. The project involves the development of a double-ended, sea-going ferry that can carry 120 passengers and 16 cars or two trucks. The ferry will be powered by renewable hydrogen fuel cells and is designed to operate on the route between Kirkwall and Shapinsay on Orkney, where hydrogen fuel is generated through wind power. CMAL is working with **AqualisBraemar LOC** on the project's plans, including the design and engineering of the hydrogen fuel cell systems. The aim of the project is to demonstrate the feasibility of using hydrogen fuel cell technology for maritime transportation and to promote the wider adoption of hydrogen as a clean and renewable energy source.

The hydrogen Train project in Scotland aims to convert a 40-year-old Scotrail Class 314 train into a hydrogen fuel cell electric powertrain. **Ballard Motive Solutions** was appointed to provide the design, engineering, and integration of hydrogen fuel cell systems, as well as project demonstration services. **Arup** provided rail engineering consultancy services for technical concepts, high-level design, and safety strategies for the project. The project is part of a wider effort to explore and demonstrate the potential of hydrogen as a clean, efficient and reliable energy source for transportation in Scotland.

The hydrogen Hub project in **Tees Valley** is a hydrogen -focused pilot project aimed at trialling the use of hydrogen-powered vehicles, such as trucks, for moving goods around the area. It is being run with £3 million in funding and its goal is to demonstrate the viability of hydrogen as a clean and sustainable fuel source for transportation purposes. The project is focused on the Tees Valley area and involves partnerships with local delivery companies and supermarkets.

8.7. Net Zero Hydrogen Production From Biomass and Organic Wastes

Importance of Biomass to Hydrogen Pathway

Net-zero production from biomass and waste refers to the use of biogenic material as a source of renewable energy that results in low carbon emissions. This can be achieved by using feedstocks like wood pellets, wood chip, waste wood, or refuse derived fuel (municipal waste – a mixture of biogenic and fossil residual wastes) as a feedstock

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to produce hydrogen, while emitting biogenic carbon that is part of the naturally occurring carbon cycle. Such technology can also be combined with carbon capture and storage to deliver negative emissions.

Biomass and waste can be converted into energy through processes such as anaerobic digestion or Advanced Conversion Technologies (like gasification or pyrolysis). During these processes, organic matter is broken down and converted into either biogas or syngas. Once captured, such gas can have several uses, it can be combusted to produce electricity and heat, or further refined into other products, including hydrogen.

Bioenergy is already well used in the UK, with established supply chains both in terms of biomass imports and domestic feedstock production. The UK has a growing forest industry, which provides a steady source of wood chip and pellets, primarily produced from timber sector offcuts that can be used as a biomass fuel. In 2020, the UK produced approximately 9 million tonnes of wood pellets and 5 million tonnes of wood chips, which were primarily used for energy generation. Similarly, the UK has a significant agricultural sector, which includes the growth of energy crops, such as straw, as well as innovative biomass feedstocks such as miscanthus or short rotation forestry products. Waste wood, such as wood material coming from construction, is also used in energy production with 4.5 million tonnes of waste wood arising each year. Additionally, the country has a large dairy and livestock industry, which produces large amounts of agricultural waste that can be used to generate biogas via anaerobic digestion, alongside arable crops and food waste. Finally, the UK has a large amount of municipal waste that is currently used in energy from waste installations, primarily producing electricity, diverting material from landfill. There are options to also use this waste in Advanced Conversion Technologies to produce syngas, including hydrogen.

The UK also has very established supply chains for the import of biomass, following strict sustainability governance arrangements, primarily from North America in the form of Wood Pellets used in power production.

The use of biomass is considered low carbon due to the release of biogenic carbon. This is because plants consume carbon dioxide from the atmosphere as part of their natural growth process as they make biomass, compared to any fossil fuel method which releases carbon that would otherwise remain locked away from the atmosphere for millions of years. Carbon Capture and Storage technologies (CCS) technologies are in the process of reaching commercial deployment, which can capture the carbon dioxide released from producing hydrogen through biomass gasification. This has the potential to deliver negative emissions, actively removing biogenic carbon from the carbon cycle, which is seen as critical for getting to net zero. The potential for negative emissions and abundance of otherwise wasted resource is why the production of hydrogen from biomass is a major pathway in the immediate future.

The UK market has strong policy that encourages market development. Firstly, bioenergy is recognised as fitting within the wider landscape of the UK's decarbonisation targets. Later in 2023 the Government will publish its Biomass Strategy, that will define how biomass is expected to be used to help reach the UK's Net Zero targets in 2050. Secondly, there are specific policies that aid the sourcing of biomass feed stocks and the management of sourcing. This includes a well-established sustainability governance

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arrangement. The UK's Resource and Waste Strategy is also looking to increasingly encourage the recovery and recycling of waste, and to minimize the amount of waste that is sent to landfills. There are also incentives for the deployment of anaerobic digestion of organic waste (the Green Gas Support Scheme), which can be used to produce biogas, a renewable energy source. Expertise in environmental management and utilisation biomass feedstocks are supported by policy and have resulted in UK companies specialising in this sector.

Biomass Gasification

Hydrogen production from gasification involves the conversion of biomass materials, such as agricultural waste, wood chips, and other organic waste and animal wastes into hydrogen gas through a process called gasification. The process involves the application of heat, steam, and a controlled level of oxygen, to avoid combustion, producing hydrogen and other by-products. Since the growth of biomass helps remove carbon dioxide from the atmosphere, the net carbon emissions of this method are low, and can lead to negative emissions if combined with carbon capture and storage. Significant GHG savings can also be achieved with waste streams that are a mixture of biogenic and fossil residual wastes or even 100% fossil waste.

Birmingham Bio-Power plant, located in Tyseley just outside of Birmingham, provides 9MWe of renewable energy to the national grid and qualifies for the UK government's Renewables Obligation Hydrogen Scheme. The project was developed by **Carbonarius Ltd** [21], a private developer of local power production facilities, and was set up with the help of equity investors and debt providers, including the UK Government's Green Investment Bank.

The plant uses advanced gasification technology from Canadian company **Nexterra Systems Corp** to turn waste wood into energy. The gasification process uses a **Siemens** steam turbine to generate power, with emissions treated to meet EU air quality requirements. **MWH Treatment** was responsible for designing and constructing the facility and now handles its operation and maintenance.

Bioenergy Infrastructure Group (BIG), an independent power producer specialising in energy-from-waste and biomass, is pleased to announce that one of its largest assets in the UK, **Ince Bio Power**, has become fully operational after successfully completing its testing phase. The facility is located within Protos, a £700m energy hub owned by **Peel Environmental**, part of Peel L&P, an infrastructure developer in the waste, mineral, and environmental technology sectors.

Advanced Biofuel Solutions Ltd (ABSL) is a UK technology company and project developer dedicated to providing solutions to the challenges of Net Zero in the production of advanced biofuels. ABSL will demonstrate the production of biohydrogen at the Swindon plant. The facility can switch between biohydrogen and BioSNG production on demand. This flexibility will allow the plant to supply hydrogen projects as the market develops.

21 Carbonarious Ltd is now dissolved.

Anaerobic Digestion (AD) Plants

AD is a biological process that involves the breakdown of organic matter in the absence of oxygen to produce biogas, a mixture of bio-methane and carbon dioxide. In AD plants for hydrogen production, the organic matter is typically supplied as biomass, such as food waste, agricultural waste, or energy crops. The process begins by feeding the biomass into a reactor, where it is mixed with water and a population of microorganisms. The mixture is then maintained at a temperature and pH that is optimal for the microorganisms to break down the biomass into biogas. The biogas produced in the reactor is then treated to remove impurities such as sulphur and siloxanes, and the methane is separated from the carbon dioxide. The purified methane can then be converted into hydrogen through a process known as steam methane reforming. The biogas-to-hydrogen technology is still at its early stage, but many investors are actively looking at such projects.

Biofertiliser is a type of fertiliser that is derived from natural and renewable sources, such as microorganisms and other organic matter. It is used to enhance plant growth and improve soil health by providing essential nutrients, such as nitrogen, phosphorus, and potassium, as well as beneficial microorganisms. Biofertilizers can be produced through processes such as composting, vermicomposting, and anaerobic digestion. They can also be produced by culturing specific microorganisms, such as nitrogen--fixing bacteria, which can help to improve soil fertility. As a result, many UK companies who engage in the operation of AD plants also in turn specialise in biofertiliser.

Biogen a operator of AD plants with over 20 years of experience. Biogen has fourteen AD plants and three composting sites around the UK which recycle around half a million tonnes of organic waste annually. Biogen's facilities also ensure the highest quality of digestate and use the PAS110 standard to ensure quality[22].

The company specialises in a wide range of organic matter from animal by-products to all types of food waste and garden waste. Biogen has a whole process offer, where organic waste such as food waste is collected and ultimately treated at an AD plant to produce biogas and bio-fertiliser.

Agrivert is a leading developer and operator of AD plants both within the UK and internationally. The company specialises in providing a complete set of engineering and operating services for the organic recycling and renewable energy industries. The company focuses on practical solutions based on its extensive experience of running similar facilities for over 20 years. An example of one of their projects is The North London Anaerobic Digestion plant[23]. The site source separated food waste from local governments and commercial waste producers. The waste is first unpacked, minced, and then placed in large, airtight tanks for anaerobic digestion. The digestion process breaks down the food waste into biogas, consisting of methane and carbon dioxide, and a liquid fertilizer known as digestate. The biogas is transformed into clean, renewable electricity through gas engines and is supplied to the National Grid. The digestate, a rich organic fertilizer, is spread on local farms, reducing the need for chemical fertilizers derived from fossil fuels.

22 WRAP, 2014, https://wrap.org.uk/resources/guide/bsi-pas-110-producing-quality-anaerobic-digestate

23 Agrivert, 2018, https://www.agrivert.co.uk/projects/food-waste-anaerobic-digestion-facility-north-london

In the digestion process, excess heat is generated and utilized to warm the tanks and for pasteurization.

Future Biogas is a highly experienced developer and operator of AD plants across the UK, and able to provide full-service capabilities of development, construction, operations, ongoing compliance and asset management, both to their own projects and to those of third parties.

Converting Fossil Fuel Power Plants to Sustainable Biomass Plants

As one of the first countries to experience both industrialisation and deindustrialisation, the UK has experience in the conversion of coal-burning power plants to biomass plants. The conversion would help to reduce greenhouse gas emissions, support the development of the UK's renewable energy sector, and provide a source of sustainable energy.

The conversion of coal-burning power plants to burning biomass can also help to address the challenge of dependence on imported fossil fuels. Contextually, this has major significance in the UK as despite the UK's planned decommissioning of all coal-burning power plants three coal power plant sites remain operational in Nottinghamshire and County Antrim. The Government have in part delayed closure due to the heightened geopolitical energy crisis causing concerns about energy security and the dependence on external sources. Additionally, the use of biomass as a fuel source can provide a source of income for farmers and growers, as well as reduce the amount of organic waste sent to landfills.

The **Drax** power station, located in Yorkshire's Humber region, was initially constructed as a large coal-fired power plant to provide electricity to the national grid and the industrial area of Yorkshire. Built over a period of two decades starting in the 1960s, it eventually became the largest coal power station in the country, but also the largest greenhouse gas producer in Western Europe.

After the UK's electricity sector was privatized, the power station changed ownership several times until it became part of the Drax Group in 2005. In the following years, Drax embarked on a transformation from a coal-based power plant to one that generates electricity from biomass. With the goal of becoming carbon-negative throughout its supply chain by 2030, the station aims to achieve this using biomass energy and geological carbon capture and storage (CCS) technology. Today the Drax power station in Yorkshire is the largest biomass power plant in the world[24].

Drax Group, **Equinor** and **National Grid Ventures** have signed a Memorandum of Understanding committing them to work together to explore how a large-scale carbon capture usage and storage network and a hydrogen production facility could be developed. This is the first significant action from industry since the UK Climate Change Committee published its Net Zero report, which found that CCS and hydrogen technology developed in regional industrial clusters is essential if the UK is going to achieve a 'net zero' carbon economy by 2050.

24 Christian M, https://www.aquaswitch.co.uk/blog/drax-biomass-power-station/

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The partnership could lead to the Humber becoming the world's first net zero carbon region and home to a new world leading hydrogen economy starting from the mid-2020's.

8.8. Carbon Capture and Storage (CCS) Technologies

Importance of CCS Technologies

CCS is a process that captures carbon dioxide emissions from sources like industrial activity and transports them to a storage site. Storage sites are either located underground or in other geological formations. Through CCS carbon dioxide is prevented from entering the atmosphere, thereby reducing GHG emissions and helping mitigate the impacts of climate change. When combined with biogenic carbon sources, like bioenergy, they deliver negative emissions, actively removing carbon from the carbon cycle.

CCS technologies can be applied to a wide range of industrial processes and power generation sources, including coal-fired power plants, fossil gas-fired power plants, cement production, and petroleum refining, among others. The capture of CO2 from these sources can be achieved using a variety of technologies, including chemical solvents, membrane separation, and adsorption, among others.

The storage of CO2 can be achieved through geological storage, where CO2 is injected into deep geological formations, such as depleted oil and gas fields or saline aquifers and monitored to ensure that it remains securely stored over the long term.
The UK has a strong history of expertise and experience in CCS technologies, being an early developer of CCS technologies in the early 2000s. As a result, numerous UK organisations and institutions have built expertise, innovation, and experience. Moreover, bodies such as the UK CCS Research Community, which has over 300 academic members provide the link between research and industry. Lastly, CCS has been identified as a key technology by the UK government in the UK's transition to net zero. Therefore, domestically CCS technologies have policy support with CCS-specific laws and regulations that apply to the CCS project process. In summary, UK expertise stems from the support of academic and research institutions, the government, and the industrial sector.

UK CCS Projects

Across the UK there is a range of projects that implement CCS technologies varying on different scales. In this section, there will be a selection of case studies highlighting the capability of UK companies with CCS technology and how it has been implemented in various sites and scales.

Innovative carbon capture technology from **Drax**, **University of Nottingham** and **Promethean Particles**. Drax a leader in renewable energy, is collaborating with the University of Nottingham and Promethean Particles to test a cutting-edge BECCS process at its power station located in North Yorkshire. The innovative approach uses metal-organic frameworks (MOFs) solid absorbent developed by Promethean Particles to capture carbon dioxide emissions from the generation of electricity from sustainable biomass. This contrasts with traditional CCS techniques that utilize liquid solvents. Metal-organic

frameworks, with their simple structure, can be customized to selectively absorb specific molecules, making them ideal for carbon capture. The two-month trial will provide all three partners with valuable insights into the performance of this new carbon capture process.

C-Capture has patented a unique, solvent-based technology which offers a safe, low-cost way to remove carbon dioxide from emissions using a post-combustion capture approach. C-Capture was founded in 2009 as a spin-out from the Department of Chemistry at the University of Leeds, and recent investors include IP Group, Drax, and BP Ventures.

HyNet is one of the UK's flagship industrial decarbonisation project, where CCS technology plays a vital role to achieve the goal of decarbonisation. Stretching across Northwest England and Northeast Wales the consortium consists of ten partners. The CCS technologies component is a crucial element of the HyNet North West low carbon cluster initiative. The aim is to collect carbon dioxide emissions from existing industrial facilities located in the Ince and Stanlow regions, as well as from the new, low-emissions hydrogen production plant at Stanlow. The captured carbon dioxide will be transported through underground pipelines to the depleted gas reservoirs in Liverpool Bay, where it will be securely stored. The storage site will be in Liverpool Bay where for 25 years it has been the site of fossil gas extraction through production wells, which has created space within the sandstone reservoirs for carbon dioxide storage. Ultimately these carbon industrial clusters such as HyNet North West are seeking to implement the infrastructure on a scale to enable the UK to meet net zero greenhouse gas emissions by 2050.

HyNet North West Liverpool Bay Project: Eni (transportation and storage) and **Progressive Energy Limited** (hydrogen generation and capture) announced in May 2021 that they had signed a framework agreement within the HyNet North West low carbon cluster project's carbon capture and storage (CCS) efforts. As per the agreement, Progressive Energy will lead and coordinate the project's hydrogen generation and capture activities on behalf of HyNet North West, connecting the sources of CO2 emissions to Eni's transportation and storage infrastructure. Eni will develop and operate both onshore and offshore CO2 transportation and storage in their Liverpool Bay assets. This will include repurposing existing onshore fossil gas pipelines from Connah's Quay to Point of Ayr. More importantly, the key element of this project is the conversion of Eni's existing infrastructure, emissions from part of HyNet's North West region will be captured and stored in exhausted hydrocarbon fields. These specific are Eni assets of Eni UK Hamilton, North Hamilton, and Lennox offshore fields.

Through the Industrial Decarbonization Challenge (IDC) initiative, UK Research and Innovation (UKRI) provided the project with £33 million in financing in March 2021. The financing covers approximately 50% of ongoing planning with the aim of the site becoming operational by 2025.

The Acorn CCS is a large-scale CCS project in the UK, the main role of the project is to create infrastructure and facilities to allow industries to capture, transport and store carbon dioxide emissions. This project in Scotland aims to capture carbon dioxide from St Fergus terminal, one of the UK's main gas terminals and store it in the North Sea. Additionally, a redundant offshore gas pipeline will be converted to carry CO2 to the licensed region for the Acorn CO2 Storage Site.

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The lead developer of the Acorn projects is **Storegga** an independent UK-based decarbonisation development business previously known as Pale Blue Dot. Storegga's expertise lies in carbon capture and storage technology, with experience in the UK and internationally. **Shell UK** are the technical developer providing oversight of transport and storage. Additionally, **Harbour Energy** the largest UK-listed independent oil and gas company and North **Sea Midstream Partners** (NSMP) are both partners in the Acorn CCS project. Both Harbour Energy and NSMP operate and own production and processing facilities in the North Sea, such as the St. Fergus gas terminal. In summary, both Acorn and Liverpool Bay Project show how UK expertise and companies are managing ambitious CCS projects on a vast scale.

Bioenergy Carbon Capture and Storage (BECCS)

BECCS can also be combined with bio-based hydrogen pathways, as those described above: this is typically referred to as Hydrogen BECCS. The UK government has supported a **Hydrogen BECCS Innovation Programme**, and the first round of the funding has been awarded to 22 companies with up to £250,000 of funding per project. Below are the project introduction from their website.

Producing hydrogen fuel feedstock from compost oversize led by **Biowise Ltd**. Biowise are an experienced composting and waste management company operating across the north and Midlands. Biowise are proposing, with Hydrogen BECCS innovation funding, to develop an exciting project that will process a waste compost oversize to produce a biogenic feedstock source for hydrogen gasifiers. The innovation will use sorting, grading and material handling techniques to produce a fuel that meets a hydrogen gasification feedstock specification, thereby addressing the current challenges associated with compost oversize, and also providing a fully biogenic feedstock for hydrogen BECCS supply chains.

Bluegen - Utilisation of Biorefinery Residues for Blue Hydrogen Production led by **University of Hull**. With the growing use of bio-fuels produced through fermentation and digesters (removal of sugars), the project produce more bio-refinery waste through the conversion of lignocellulosic biomass. These sludge-based materials are an untapped supply of hydrogen, a future net-zero fuel. Project Bluegen will produce hydrogen through gasification of these sludges. This project will focus on cost effective treatment of bio-refinery waste for use as a gasifier feedstock, which will also have process efficiency benefits. Bluegen will take a holistic approach to the use of sludge-based solid fuels by carrying out cradle-to-grave techno-economic and life-cycle assessments, resulting in the design of an integrated system, sugar removal and hydrogen production that can be coupled with carbon capture and storage (CCS), thus eliminating CO2 emissions and preventing the release of waste to landfill.

Development of Biomass Gasification Tar Reformation and Ash Removal led by **Advanced Biofuel Solutions Ltd** (ABSL). ABSL and UCL will collaborate to enhance and improve biomass gasification. Fluidised bed oxy-steam gasification is a key pathway to produce BECCS biohydrogen. However, biomass contains ash components that can bind the fluidised bed and impair the gasification process. This means that gasification takes place at low temperatures resulting in the formation of tars. The ash and tars foul equipment making the gas produced from biomass very difficult to work with. This pro-

ject will explore novel solutions to deal with these contaminants.

Micro-hydrogen hub utilising biogenic feedstock for hydrogen and CO2 production Led by **Compact Syngas Solutions Limited**. Compact Syngas Solutions has brought together proven technology and expertise in gasification / gasifier processes, with support from sub-contractors in chemical and process engineering and design. Project objectives include exploring the technical, economic, and commercial feasibility of using water, replacing amines, as a scrubbing material, for CO2 removal and capture in a form that can be transported and sold to end-users, using biogenic feedstock from syngas streams.

Bio-hydrogen Produced by Enhanced Reforming (Bio-HyPER) is a collaboration between **Cranfield University, Helical Energy, Bioenergy Infrastructure Group, GTI Energy, Petrofac**, and **Origen Power** looking to demonstrate a state-of-the-art hydrogen BECCS process. The project will undertake a feasibility study on the production of biomass-derived hydrogen with carbon capture. This feasibility study will assess the potential for integrating advanced gasification technologies and biogas feedstocks with the HyPER process. The clean hydrogen production technology is based on Sorption Enhanced Reforming, and the Phase 2 project will demonstrate the technology in the HyPER pilot plant at Cranfield University.

Rising Pressure Reformer (RiPR) **using Super Critical Water Gasification** (SCWG) led by **Helical Energy Ltd**. The project is looking to demonstrate this state-of-the-art novel hydrogen-BECCS process. The innovation is a disruptive technology changing the current order of thinking on gasification. RiPR processes biogenic fuels by gasification and water-gas-shift at extremely high pressure and temperature. At these conditions the fuel is rapidly converted to Hydrogen, Methane and CO2. Besides being net-negative when using biogenic fuels, the key advantages are that little or no fuel preparation is required, and the product gas is delivered at high pressure requiring no further expensive and energy intensive compression.

Enhancement of KEW biomass gasification technology performances through optimisation of the H2/CO2 separation process stage Led by **Kew Projects Ltd**. KEW's innovative pressurised Advanced Gasification Technology converts biomass into a hydrogen-rich Syngas and is demonstrated at commercial-scale at its plant in Wednesbury. KEW is adding process steps based on proven technologies to produce high-purity Hydrogen for transport or industry as well as CO2 ready for sequestration. This Project will evaluate innovative processes which can reduce the capital and operational costs of the H2 / CO2 separation stage as well as improve the overall energy efficiency. A demonstrator will be designed with the aim of being tested in phase 2 in a modular configuration ready for commercial applications.

North East Waste Wood Hydrogen Demonstrator (NEW2H2) led by **Northumbria University**. This project will determine the techno-economic viability of a scalable, modular, demonstration plant that generates biohydrogen out of waste wood gasification. The system is designated the 'North East Waste Wood Hydrogen Demonstrator' – NEW2H2. The demonstrator will be located in South Tyneside at the Holborn site in South Shields. It will form part of the Holborn Renewable Energy Network (HREN) that aims to generate renewable energy by scavenging waste energy resources. This is a collaborative effort between local authorities (South Tyneside Council and the North East Local Enterprise Network), academia (Northumbria University) and industry (Driver Global

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Construction Consultancy and Buro Happold).

Novel plasma reforming technology for tars reduction in BECCS led by **Queen Mary University of London**. Gasification is the underpinning technology for biohydrogen and BECCS. The syngas produced from gasification of biomass contains not only the useful CO and hydrogen, but also tars, mixed ash-char particles, and inorganic contaminants. The key challenge for implementing BECCS systems globally is delivering an integrated, engineered system reducing problematic components to a manageable level cost-effectively. QMUL and UCL will explore the feasibility of a novel solution to remove these contaminants from syngas by employing a novel self-powered plasma catalytic system for particles and tars removal and develop a costed plan for implementing this solution in an existing gasification plant.

Hydrogen production via Biomass gasification Integrated with innovative one-step Gas shift reforming and separation (BIG-H2) led by T**ranslational Energy Research Centre - The University of Sheffield**. BIG-H2 investigates the integration of biomass/bio-waste gasification with innovative gas cleaning/upgrading and novel membrane-based separation to produce high-purity hydrogen and CO2, a BECCS--to-hydrogen solution with potential to deliver long-term net negative emissions for a range of industries. Focusing on technologies, feedstocks, techno-economics, product markets, sustainability and demonstration/development, the project will ultimately produce an initial FEED study of the integrated system. Along with systems modelling and validation of the demonstration plant, these feasibility studies will develop the concept and identify a forward development plan to take into Phase 2 – a large-scale industrial demonstration to prove the technology in real operational environments.

Hydrogen from Cyanobacteria - a biological route to zero-carbon or carbon--negative hydrogen led by **17Cicada Ltd**. 17Cicada is a UK start-up established to develop, scale up and commercialise a range of "products from bacteria" technologies. The company's CTO, Dr Samantha Bryan, is an academic researcher based at Nottingham University. In this project isusing cyanobacteria for the biological production of hydrogen. Cyanobacteria are photosynthetic organisms that use light energy and CO2 as a carbon source under ambient conditions offering a low energy, zero/negative-carbon approach for the direct production of hydrogen from solar energy. This approach has the potential to complement other hydrogen production methods and associated carbon capture and storage (CCS) technologies.

Eco Dark Fermentation led by **Alps Ecoscience UK Ltd**. Alps Ecoscience's hydrogen BECCS project seeks to produce hydrogen from waste using Dark Fermentation to deliver a sustainable, low carbon energy supply. This novel technology will enable anaerobic digestion plants to produce hydrogen in conjunction with their existing biogas production. The process enables economies of production in heat and electricity and greater waste to energy conversion through biological process efficiency. Resulting in more energy per tonne, reduced carbon emissions and the diversion of organic material from landfill or incineration. The work is delivered by Alps Ecoscience, a biological engineering consultancy specialising in the development of green fuels from organic waste.

Production of biohydrogen from waste biomass led by **CATAGEN Limited**. As a net-zero business known for highly innovative, new technology solutions, CATAGEN is

applying its proprietary recirculating-gas reactor technology to develop a cost-effective method of producing low-carbon biohydrogen. This approach can facilitate the early adoption of low-carbon hydrogen and greatly accelerate the route to a Net Zero hydrogen economy. The production of hydrogen from sustainable biomass is a key challenge in the realisation of a hydrogen economy. The proposed CATAGEN solution has the potential to produce renewable bio-hydrogen and bio-CO2 from waste biomass via an energy efficient approach. At current market price this would allow production of low--carbon bio-hydrogen compared to the cost of green hydrogen.

Pure Pyrolysis Refined led by **Environmental Power International (UK R&D) Limited**. Environmental Power International has developed a unique Pure Pyrolysis technology which converts almost any type of organic matter into high quality fuel gas and carbon-rich char. This unique process has no combustion, therefore zero emissions. The process has been developed in the UK and successfully trialled at full scale over more than 20 years. Focus to-date has been on production of electricity, but this programme brought together two other unique UK technologies, to demonstrate production of green hydrogen and carbon sequestration with zero emissions. Carbon Life Cycle assessments already indicate carbon negative performance from this unique British technology.

HAROW – Hydrogen by Aqueous-Phase Reforming of Organic Wastes led by **ICMEA-UK Ltd**. HAROW - a consortium project with partners ICMEA-UK, **Olleco** and **Aston University**, focusses on hydrogen production from organically contaminated wastewater. Based on research at Aston, ICMEA-UK will lead engineering of a reactor to utilise various organic wastes in water available at Olleco. The objectives of this project are to demonstrate that the process will work effectively, producing high yields of biogenic hydrogen. Using a laboratory rig, the reaction kinetics with different feedstocks will be established, allowing design parameters, capital/operating costs as well as hydrogen yields for the Phase 2 demonstrator to be determined, targeting ~5kg/hr of hydrogen.

Biohydrogen from Dark and Photo Fermentation led by **Phoebus Power Limited**. Phoebus Power has joined with Grassroots Energy to develop an innovative production process for Bio-Hydrogen to produce nearly 100% Hydrogen from organic feedstocks like straw, grass, food waste and energy crops. The feasibility study will work on the design of, first-of-its-kind, biphasic dark and photo fermentation system using novel and proprietary microbes while capturing the CO2 generated. The BEIS funding of the Phase 1 feasibility study will enable the development of a demonstration project in Phase 2 to showcase the biorefinery concept to produce Bio-Hydrogen from organic feedstocks that are widely available in the UK and globally.

Thermal Catalytic Conversion of Syngas to Carbon Nanotubes led by **The Cool Corporation Ltd**. The collective project between Cool, Kew and Petrofac aim to convert syngas derived from RDF to Biohydrogen and Carbon Nanotubes (CNTs). The project aims to simultaneously reduce CO2 emissions, produce clean hydrogen and CNTs, a high value nanomaterial with wide ranging applications. The consortium will build a pilot plant to demonstrate the commercial feasibility and emissions reduction potential of Cool's technology. Kew and Petrofac are part of the consortium preparing the technical, costs and execution definition of the project.

The Sustainable Biogas, Hydrogen, Graphene LOOP led by **United Utilities Water**. The project will provide a completely sustainable feed source to produce hydrogen and graphene using the Levidian LOOP process. By adopting biogas from the treatment of

wastewater as the feed material to the LOOP, it provides a continuous supply of a fuel source, hydrogen, and a means of carbon capture and storage, graphene. By using this continuously available and sustainable feed material the project is opening up opportunities for multiple industries to become carbon neutral and supporting the UK government in achieving a viable and sustainable hydrogen economy and their targets for net zero carbon.

Hydrogen from organic waste with an integrated biological-thermal-electrochemical process led by **University of Aberdeen**. The project aims to develop an innovative and sustainable process to obtain hydrogen from the organic matter present in many types of waste using a combination of biological, thermal and electrochemical processes. Project partners are University of Aberdeen, **University of Cranfield** and **University of Verona**. Phase 1 is a feasibility study of the process. Phase 2 will be aimed at building and operating the pilot plant that will be used to demonstrate the process. The pilot plant will be used for functional and performance testing and will allow the measurement of the hydrogen yield and of the energy consumption.

H2-Boost led by **University of Leeds**. The H2-Boost project aims to produce biohydrogen for the UK transport sector in an environmentally sustainable and commercially viable manner. The proposed multi-step process uses organic waste readily available as feedstock (farm waste, manures, etc.), which is initially pre-treated using a novel oxidation process (advanced wet oxidation) to increase biodegradability and hydrogen yields in a subsequent biological process (dark fermentation), using fermentative microorganisms to transform organic compounds into hydrogen gas and other valuable by products. The project will conduct a comprehensive feasibility study to assess the potential of this technology and produce a business case for implementation at full scale.

BIOHYGAS led by **University of South Wales**. BIOHYGAS is a two-stage biohydrogen / biomethane AD system which can increase energy recovery from sewage biosolids by up to 37% compared with existing processes. This project will demonstrate this process at full scale using USW's innovative 2-stage digestion system, stage one produces hydrogen directly from sewage biosolids, the output from the biohydrogen reactor (stage 1) is then fed to a conventional methane digester which operates nearly twice as fast as a conventional methane digester resulting in higher yields of methane which is then converted to fuel cell grade hydrogen whilst the CO2 co-produced in both stages is used in food packaging.

Bio Hydrogen Demonstrator led by **Wood Group UK Ltd**. Wood has created a hydrogen production technology that benefits from Wood's market leading SMR (steam methane reformer) efficiency but is fed and fuelled by renewable biological liquid feedstocks. The proprietary process allows production of carbon neutral or, when coupled with carbon sequestration, carbon negative, hydrogen. Under the BEIS Hydrogen BECCS Innovation Programme, Wood will assess the feasibility of deploying its innovative biohydrogen production technology at an industrial demonstrator scale. The site for the demonstration of the technology will be integrated with an innovative UK Hydrogen infrastructure project.

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Carbon Credits and CCS

Carbon credits are market-based mechanism which incentivise the reduction of greenhouse gas emissions. In a carbon credit system, such as the European Union Emissions Trading System (EU ETS) and UK ETS. CCS and carbon credits could create a market that financially incentivises entities to reduce their emissions and invest in CCS technology. The use of carbon credits can also help to ensure that emissions reductions are achieved at the lowest cost, as entities can choose the most cost-effective methods for reducing emissions, including CCS. Currently, the UK does not have a system to maximise this potential. However, a consultation launched by the UK Government in 2022 has started the process of considering how CCS could be built into the UK ETS [25] and similar discussions are also being carries out at the EU level.

Globally, one market that shows overlap with carbon markets and CCS is California, USA. Annual carbon intensity (CI) benchmarks are set by the California Low Carbon Fuel Standard (LCFS). The number of credits or deficits a fuel produces are determined by the difference between its CI and the benchmark CI. Entities that generate deficits by producing or supplying high CI fuels then purchase credits. In 2018 CCS Protocol, which has made it possible for developers of CCS projects to generate and trade credits under the LCFS program. The protocol applies to both new and existing CCS projects, with additional eligibility criteria that the carbon dioxide must be stored onshore in saline formations or depleted oil & gas fields. Some of the UK companies that provide services on carbon trading are **Redshaw Advisors Ltd**, **Carbon Neutral Britain** and **Carbon Trading Limited.**

25 https://www.gov.uk/government/consultations/developing-the-uk-emissions-trading--scheme-uk-ets

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9. Appendix – list of companies based in the UK

Appendix - list of companies based in the UK

Report - Mapping hydrogen supply chains in Poland and the UK

Company name	Product and services	Website	Contact
17Cicada Ltd	A UK start-up established to develop, scale up and commercialise a range of "products from bacteria" technologies.	https://www.17cicada.com/	enquiries@17cicada.com
Acorn Bioenergy	Acorn Bioenergy is a developer of anaerobic digestion sites and producer of biomethane.	https://www.acornbioenergy.com/	info@acornbioenergy.com
AcrEnergy	AcrEnergy is an developer and operator of biogas plants.	http://www.acrenergy.com/	Tel: 020 7243 1625 info@acrenergy.com
Adapt Biogas	Pioneers within the field of green gas injection into the National Grid NTS pipeine; producer of biomethane.	https://www.adaptbiogas.com/	lets.adapt@adaptbiogas.com
Advanced Biofuel Solutions Ltd (ABSL)	ABSL aims to lead the development of advanced biofuel projects around the world as a project owner and supplier of technology to other organisations.	https://absl.tech/	info@absl.tech
AFC Energy	The company provided zero-emissions operations through its H-Power Towers hydrogen fuel cell system to generate clean power.	https://www.afcenergy.com/	Tel: +44 (0)1483 276726 info@afcenergy.com
Agrivert	Consultancy and technical solutions for organic waste management. Concentrating in anaerobic digestion facilities and infrastructure assets in the UK.	https://www.agrivert.co.uk/	Tel: +44 (0)330 1340 070
Air Liquide	French multinational corporation that supplies hydrogen fuel and operates hydrogen refuelling stations in various countries, including the UK.	https://www.airliquide.com/	IRTeam@airliquide.com
Alps Ecoscience UK Ltd	Alps Ecoscience offer a fully managed service for all aspects of the anaerobic digestion (AD) & biogas production lifecycle.	https://www.alpsecoscience.co.uk/	online inquiry form
Alstom	A global leader in the transportation sector, in the digital age.	https://www.alstom.com/	
Amalyst	Producer of fuel cell and water electrolysis catalyst	http://www.amalyst.com/	david.hodgson@amalyst.com
AMP Clean Energy	Biomass heat installations. AMP Clean Energy is a distributed energy company which funds and develops low carbon heat and power solutions including biomass heat installations, solar PV and flexible energy plants.	https://www.ampcleanenergy.com/about-us	Tel: 0800 157 7331 hello@ampcleanenergy.com
AMS Fleet Management	Hydrogen fleet management software providers in the UK	https://www.amsfleet.co.uk/	Tel: 07850 591391 / 07968 071890 andrew@amsfleet.co.uk
Anglo American Platinum	A subsidiary of the UK-based multinational Anglo American, is the global leader in platinum production, accounting for 40% of the world's platinum group metals (PGMs).	https://www.angloamericanplatinum.com/	online inquiry form
AqualisBraemar LOC	ABL Group is a leading independent global energy and marine consultancy, working in energy and oceans to de-risk and drive the energy transition.	https://abl-group.com/	Tel: +44 (0)20 7264 3250

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Arup	The company provides rail engineering consultancy services for technical concepts, high-level design, and safety strategies	https://www.arup.com/	Tel: +44 (0)117 976 5432 bristol@arup.com
AssetWorks	Hydrogen fleet management software providers in the UK	https://www.assetworks.com/	Tel: 0161 266 1050
Ballard Motive Solutions	Ballard Motive Solutions is a leading specialist in hydrogen and fuel cell technologies	https://www.ballardmotivesolutions.com/	Tel: +44 (0) 20 7503 1386
BHP Group	A UK/Australian multinational mining company headquartered in London, primarily mines iron ore and copper, which are both essential ingredients in the production of catalysts used in electrolysis.	https://www.bhp.com/	online inquiry form
Bioenergy Infrastructure Group	A renewable energy provider that is developing one of the UK's largest portfolios of biomass and waste-to-energy facilities.	https://bioenergyinfrastructure.co.uk/	info@bioenergyinfrastructure.com
Bioenergy Infrastructure Group (BIG)	An independent power producer specialising in energy-from-waste and biomass, is pleased to announce that one of its largest assets in the UK.	https://bioenergyinfrastructure.co.uk/site/ince-bio-power/	info@bioenergyinfrastructure.com
Biogas Heating Solutions Limited (BHSL)	An Irish agricultural and technology that focuses on the conversion of untreated poultry manure into energy.	https://www.bhsl.com/	Tel: +353 (0) 69 85926 sales@bhsl.com
Biogen	UK's leading operator of anaerobic digestion plants	https://www.biogen.co.uk/	Tel: 01234 827249 info@biogen.co.uk
Biowise Ltd.	Biowise are a leading composting and waste management company operating across the north and Midlands.	https://www.wastewise.co.uk/	Tel: +44 (0) 1482 325221 info@wastewise.co.uk
BOC	A subsidiary of The Linde Group, BOC provides hydrogen production and dispensing equipment, as well as hydrogen fuel, for HRS in the UK and around the world.	https://www.boconline.co.uk/en/index.html	online inquiry form
Cadent Gas	The UK's largest gas distribution network, managing a network of more than 82,000 miles of pipes, most of them underground, which transport gas throughout the North West, West Midlands, East Midlands, South Yorkshire, East of England and North London.	https://cadentgas.com/	online inquiry form
Cadent Gas	Facilitates new entry connections to existing gas distribution network that will enable biomethane producers to inject their renewable gas into Cadent Gas's network.	https://cadentgas.com/services/gas-producers/biomethane	Tel: 0800 074 5788
Caledonian Maritime Assets Limited (CMAL)	Caledonian Maritime Assets Limited owns ferries, ports and harbours and infrastructure necessary for vital ferry services serving the west coast of Scotland and the Clyde Estuary, and the Northern Isles.	https://www.cmassets.co.uk/	info@cmassets.co.uk
Calvera	An international group that manufactures compressed gas trailers for Hydrogen, being leader in the sector for this range of product.	https://www.calvera.es/	calvera@calvera.es
Carbon Neutral Britain	Carbon trade services	https://carbonneutralbritain.org/	partnerships@carbonneutralbritain.org
Carbon Trading Limited	Carbon trade services	https://ctxglobal.com/	Tel: +44 203 598 5890 info@ctxglobal.com

CATAGEN Limited	As a net-zero business known for highly innovative, new technology solutions, CATAGEN is applying its proprietary recirculating-gas reactor technology to develop a cost-effective method of producing low-carbon biohydrogen.	https://catagen.com/	Tel: +44(0)2890455100 info@catagen.com
C-Capture	C-Capture has patented a unique, solvent-based technology which offers a safe, low-cost way to remove carbon dioxide from emissions using a post-combustion capture approach.	https://c-capture.co.uk/	Tel: + 44 (0)113 245 0418 info@c-capture.co.uk
Centrica	A UK energy services and solutions company, now operating Rough field, the UK's largest natural gas storage facility.	https://www.centrica.com/	media@centrica.com
Ceres Power	A British clean energy technology company that specializes in the development of hydrogen fuel cell technology. The company has developed a unique solid oxide fuel cell (SOFC) technology that enables highly efficient and durable fuel cells for a range of applications, including stationary power generation, transportation, and combined heat and power (CHP) systems.	https://www.ceres.org/homepage	Tel: info@ceres.org
Clean Power Hydrogen Group (CPH2)	Manufacturer of the unique Membrane-Free Electrolyser Model	https://www.cph2.com/	info@cph2.com
CLM Fleet Management Services	Hydrogen fleet management software providers in the UK	https://www.clm.co.uk/	info@clm.co.uk
Compact Syngas Solutions Limited	Compact Syngas Solutions Limited (CSS) is developing non power applications for synthesis gas utilising waste biomass and prepared SRF fuels as feedstock.	https://www.syngas-solutions.co.uk/	Tel: +44 (0) 1244 529589 paul@syngas-solutions.co.uk
Corre Energy	Corre Energy is a leader in the development and operation of Long Duration Energy Storage (LDES) projects and products, accelerating the transition to net zero and enhancing the security and flexibility of energy systems.	https://corre.energy/	info@corre.energy
Dennis Eagle	A leading manufacturer of waste collection vehicles which specialises in OEM designed and fully integrated refuse collection vehicles.	https://www.dennis-eagle.co.uk/	Tel: +44 (0)1926 458 500 contact.us@dennis-eagle.co.uk
DNV	A recognized advisor for the maritime industry. The company delivers world-renowned testing, certification and technical advisory services to the energy value chain including renewables, oil and gas, and energy management. DNV lands 3-year contract in UK for safe use and conversion of pipelines to transport 100% hydrogen.	https://www.dnv.com/	Ulrike.Haugen@dnv.com Peter.Lovegrove@dnv.com
Drax	Drax group specialise in the production of sustainable biomass. It is the UK's largest source of renewable electricity. The company also operates a global bioenergy supply business with manufacturing facilities at 13 sites in the United States and Canada, producing compressed wood pellets for its own use and for customers in Europe and Asia.	https://www.drax.com/biomass/	Tel: +44(0)1757 618381

Ecotricity Group Ltd.	British energy company providing 100% green electricity. The company seeks to increase the amount of renewables in Britain by researching and developing newer, bigger and more efficient ways of generating green electricity.	https://www.ecotricity.co.uk/	business@ecotricity.co.uk
EDF Renewables	In England, Ireland, Scotland and Wales, EDF Renewables is a major renewable energy company, specialising in wind power, solar power, battery storage and EV power infrastructure technology.	https://www.edf-re.uk/	lindsey.southworth@edf-re.uk
Element 2	UK's leading hydrogen refuelling business	https://element-2.co.uk/	hy@element-2.co.uk
Energas	Subsidiary of Air Liquide, provides a variety of gas and hydrogen cylinders	https://www.energas.co.uk/	online inquiry form
ENGIE UK	Global energy player with UK investments in renewable energy and storage, whilst supplying gas and electric energy to organisations of all sizes.	https://www.engie.co.uk/	customer.service@energysupply.engie.co.uk
Eni	A global energy company, active at every stage of the value chain: from natural gas and oil to co-generated electricity and renewables, including both traditional and bio refining and chemicals.	https://www.eni.com/en-IT/home.html	ufficio.stampa@eni.com
Equinor	International energy company, major gas supplier to the UK for many decades and global leader in CCS. Collaborating in "H21 North of England"report, in the aim to convert natural gas to hydrogen	https://www.equinor.com/	irpost@equinor.com
Eversholt Rail	The company has a history of innovation and play an integral role in the growth and modernisation of the UK rail sector by introducing new products, technologies and manufacturers into the market.	https://eversholtrail.co.uk/	Tel: +44 (0) 20 7380 5040
Exelby Services	In partnership with Element 2 to develop hydrogen refuelling stations	https://exelbyservices.co.uk/	online inquiry form
First Bus	UK's leading bus operator providing services in the city and the surrounding area.	https://www.firstbus.co.uk/	Tel: 0345 646 0707
Fleetinsight	Hydrogen fleet management software providers in the UK	https://www.fleetinsight.com/fiportal/public-a/contact-us	Tel: (844) 426 - 4555
Fluxys	Fluxys is an independent energy infrastructure group active in gas transmission & storage and liquefied natural gas terminalling, and working on hydrogen storage and transportation infrastructures.	https://www.fluxys.com/#/	online inquiry form
Future Biogas	A highly experienced developer and operator of AD plants across the UK, and able to provide full service capabilities of development, construction, operations, ongoing compliance and asset management.	https://www.futurebiogas.com/	Tel: +44 (0) 1483 375 920 info@futurebiogas.com
Gascade	Expertise in energy, gas transport and pipelines, also supports using the existing gas infrastructure for hydrogen. The company provides service in transporting hydrogen with the existing infrastructure.	https://www.gascade.de/en/	https://www.gascade.de/en/hydrogen

GHD	GHD's strategic and commercial experience includes: transactions due diligence, hydrogen related strategy development and techno-economic modelling. This is complemented by technical and design expertise across the entire supply chain including environmental permitting and planning, production, storage, distribution and end use application.	www.ghd.com/hydrogen	Andrew Winship, Future Energy Lead – Hydrogen andrew.winship@ghd.com +44 (0) 20 81877988
GTI Energy	GTI Energy is a leading research and training organization focused on developing, scaling, and deploying energy transition solutions.	https://www.gti.energy/	https://www.gti.energy/contact/pr-media-contact/
H2GO Power	Product: Zero-emission solid-state hydrogen storage and hydrogen AI solutions	https://www.h2gopower.com/	online inquiry form
Harbour Energy	The largest UK-listed independent oil and gas company.	https://www.harbourenergy.com/	Tel: +44 (0)207 730 1111; +44 (0)207 660 5555 info@harbourenergy.com
Helical Energy	Helical Energy is the world's leading innovator of heat recovery systems for gas turbine exhausts and other waste gas streams, as well as combustion and gasification systems for biomass and waste fuels based on fluidised bed technology.	https://www.helical.energy/	Tel: +44 (0)203 545 1075 richard.storti@helical.energy
Holman Fleet Services	Hydrogen fleet management software providers in the UK	https://www.holman.com/uk/	Tel: 0844 8000 700
Iberdrola	A global copmany specialized in clean energy.	https://www.iberdrola.com/home	comunicacioncorporativa@iberdrola.es
ICMEA-UK Ltd	An innovative Engineering consultancy company, and work in partnership with a range of other organisations to provide innovative, bespoke solutions to problems where an Engineering solution is required.	https://www.icmea.uk/	Tel: +44 (0)7380 629 476 info@icmea.uk
IMI Critical	Turbine bypass and feedwater pump control valves for biomass plants. IMI Critical provides its industry-leading turbine bypass and feedwater pump control valves to this growing industry.	https://www.imi-critical.com/global-contacts/	Tel: +44 121 327 4789 imitm.sales@imi-critical.com
INFINIS	Renewable baseload Captured Landfill Methane (CLM). Infinis is the UK's leading generator of low carbon power from captured methane.	https://www.infinis.com/about#	Tel: +44 (0)1604 662400 companysecretary@infinis.com
Intelligent Energy	UK-based company that specializes in the development and commercialization of hydrogen fuel cell technology.	https://www.intelligent-energy.com/	Tel: +44 (0) 1509 271 271 sales@intelligent-energy.com
ITM Power	The only electrolyser provider in the UK for hydrogen production at greater than 1 MW capacity. The company manufactures market-leading PEM electrolysers from small to large size.	https://itm-power.com/	chp@itm-power.com
JCB	A British multinational corporation and one of the world's largest manufacturers of construction and agricultural equipment. The company plans to develop hydrogen fuel cell technology for use in its heavy machinery but is also an active player in wider fuel cell technology.	https://www.jcb.com/en-gb	Tel: 0800 083 8015

Johnson Matthey	UK-based company that specializes in hydrogen fuel cell technology. One notable example of their work in this field is the development of hydrogen production catalysts and components for fuel cells.	https://matthey.com/	Tel: 44 20 7269 8000
Johnson Matthey	Manufacturing CCS-enabled (blue) hydrogen	https://matthey.com/products-and-markets/energy/hydrogen/ccs-enabled-blue-hydrogen	Robert.Jolly@matthey.com sam.french@matthey.com Robert.Jolly@matthey.com
Kew Projects Ltd	An innovative renewable energy business, currently constructing a first of a kind advanced thermal conversion plant, which will accept a range of waste and biomass types and convert them into a range of energy vectors, including electricity, heat, renewable diesel and Hydrogen.	https://kew-tech.com/	Tel: +44 (0) 7534 839093 MJohnson@kew-tech.com
LAVO	An Australian company driving the green energy transition with long duration energy storage (LDES) solutions and a digital platform to unlock the full potential of renewable energy.	https://www.lavo.com.au/	online inquiry form
Linde	Global engineering company that provides hydrogen production and dispensing equipment for HRS.	https://www.linde.com/	contactus@linde.com
Logan Energy	UK company based in Scotland that provides storage and compression facilities, also delivers hydrogen refuelling stations ranging from 300-700 bar delivery.	https://www.loganenergy.com/	info@loganenergy.com
Luxfer Gas Cylinders	Luxfer Gas Cylinders develops virtual pipeline solutions to support hydrogen expansion, H2 storage across rail, road and sea essential in reaching net zero targets.	https://www.luxfercylinders.com/	Tel: +44 (0)115 980 3800; online inquiry form
MWH Treatment	MWH Treatment is a sector leading solution provider operating across the UK water industry.	https://mwhtreatment.com/	info.treatment@mwhtreatment.com
Nexterra Systems Corp	Nexterra Systems Corp. is a global leader in the development and supply of community scale gasification systems that convert non-recyclable organic waste into clean, renewable heat and power.	http://www.nexterra.ca/	inquiries@nexterra.ca
North Sea Midstream Partners (NSMP)	North Sea Midstream Partners focuses on the ownership and commercial development of large-scale midstream oil and gas infrastructure assets in and around the North Sea.	https://nsmp-limited.com/	Tel: +44 (0) 203 9628610
Nothern Gas Network	The company delivers gas to 2.7 million homes and businesses in the North East, Northern Cumbria and much of Yorkshire, transported through a vast	https://www.northerngasnetworks.co.uk/	customercare@northerngas.co.uk; stakeholder@northerngas.co.uk
Octopus Energy	One of Europe's largest investors in renewables, managing 400+ green generators, predominantly wind and solar farms	https://octopus.energy/	hello@octopus.energy
Olleco	Olleco serves the UK food and hospitality industry, helping you to operate more sustainably.	https://www.olleco.co.uk/	Tel: +44 (0)808 169 4441 enquiries@olleco.co.uk
OMNI Conversion Technologies	Waste Conversion Systems. OMNI CT is a leader in conversion of waste to value for any type of feedstock.	https://omnict.com/	

Origen Power	Origen is a climate tech company with groundbreaking technology to enable lime-based carbon dioxide removal (CDR).	https://origencarbonsolutions.com/	enquiries@origencarbonsolutions.com
OVO Energy	Powering over 4 million homes with 100% renewable electricity. OVO provides.a range of energy product and services from solar panels and smart meters to energy efficient tool.	https://www.ovoenergy.com/	letter: 1 Rivergate Temple Quay Bristol BS1 6ED call: 0330 303 5063 (Mon-Fri 9am-5pm)
Peel NRE Environmental	An infrastructure developer in the waste, mineral and environmental technology sectors.	https://peellandp.co.uk/what-we-do/natural-resources-and-energy/peel-nre/	kdavison@peellandp.co.uk (Katy) egreen@peellandp.co.uk (Emma)
Petrofac	A UK leading energy services company.	https://www.petrofac.com/	alex.haynes@petrofac.com
Phoebus Power Limited	Phoebus provides engineering, project management and business development consultancy in the clean technology sector for IPPs, infrastructure funds, commercial and Industrial clients to implement projects that accelerate the path towards Net Zero emissions.	https://www.phoebuspower.com/	online inquiry form
Porterbrook	The company offers a comprehensive range of tailored and attractive rail leasing solutions.	https://www.porterbrook.co.uk/	Tel: +44 (0)20 7380 4560 enquiries@porterbrook.co.uk
Progressive Energy Ltd	Progressive Energy develops, and implements, low-carbon projects to support the decarbonisation of the energy sector. The hydrogen economy is at the centre of their thinking.	https://www.progressive-energy.com/	Tel: +44 1453 791565 info@progressive-energy.com
Promethean Particles	Technology: Continuous Flow Hydrothermal Synthesis (CFHS) and patented reactor systems. The company is delivering the materials and technology to meet these demands via MOF (metal–organic frameworks)-based carbon capture.	https://prometheanparticles.co.uk/	Tel: +44 (0)115 967 8119 info@proparticles.co.uk
Redshaw Advisors Ltd	Carbon trade services	https://redshawadvisors.com/	Tel: +44 20 3637 1055 info@redshawadvisors.com
Renewable Energy Systems Ltd. (RES)	RES is the world's largest independent renewable energy company, active in 11 countries working across onshore and offshore wind, solar, energy storage and transmission and distribution.	https://www.res-group.com/en	+44 (0)1923 299 200 (no email found)
RheEnergise Ltd	RheEnergise Ltd will receive £8.24 million to build a demonstrator near Plymouth of their 'High-Density Hydro®' pumped energy storage system.	https://www.rheenergise.com/	online inquiry form
Riversimple	Fuel cell provider.	https://www.riversimple.com/	Tel: +44 (0)1597 821060 info@riversimple.com
Roadgas	On site biomethane refuelling station infrastructure.	https://www.roadgas.co.uk/services/	Tel: +44 115 822 5530 info@roadgas.co.uk
Ryze Hydrogen	Ryze supplies clean hydrogen and hydrogen infrastructure for transport, industry, domestic heating and other applications. The company provides a complete hydrogen solution including hydrogen transportation, hydrogen distribution and hydrogen infrastructure.	https://ryzehydrogen.com/	info@ryzehydrogen.com
Ryze Hydrogen	The company manages the transportation of fuel to the fuelling station.	See above	See above
Scottish Hydrogen & Fuel Cell Association (SHFCA)	SHFCA promotes and develops Scottish expertise in fuel cells and hydrogen technologies.	http://www.shfca.org.uk/	online inquiry form

Scottish Power	Large provider of 100% green electricity using wind farms in the UK.	https://www.scottishpower.co.uk/	contactus@scottishpower.com
Severn Trent Green Power	Food wate recycling that is converted to renewable energy. 12% of UK commercial food waste is collected and sent to Severn Trent Green Power's anaerobic digestion facilities.	https://www.stgreenpower.co.uk/	Tel: 01608 677700 commercial@stgreenpower.co.uk
SGN	Gas supplier for the south of England and across Scotland.The Local Transmission System (LTS) is the backbone of theirenergy network, delivering gas from National Transmission System (NTS) offtakes to towns and cities across the country.	https://www.sgn.co.uk/	customer@sgn.co.uk; WhatsApp: 07490 077 649
Shell UK	The technical developer providing oversight of transport and storage of the Acorn CCS project in the UK.	https://www.shell.co.uk/	Tel: +44 (0) 20 7934 1234
Siemens UK	Siemens's contribution to the UK renewable energy industry is provided by two of theirthree sectors: Energy and Industry. Their financial services arm also offers flexible finance packages for all aspects of renewable energy projects.	https://www.siemens.com/uk/en.html	online inquiry form
SSE Thermal	The company operates an industry-leading fleet of flexible generation and energy storage assets, based in the UK and Ireland.	https://www.ssethermal.com/	ir@sse.com
Storegga	The company is developing a green hydrogen project in Comarty, north of Inverness.	https://storegga.earth/hydrogen	online inquiry form
Storengy UK	Storengy owns and operates the Stublach Gas Storage Facility located in Cheshire. Its subsidiary, ENGIE UK, produces green hydrogen to supply the hydrogen station.	https://www.storengy.co.uk/	online inquiry form
StorTera Ltd	Based in Edinburgh, will receive £5.02 million to build a prototype demonstrator of their sustainable, efficient, and high energy-dense single-liquid flow battery (SLIQ) technology.	https://www.stortera.com/	Tel: +44 (0)131 5690727 info@stortera.com
Suez Recycling and Recovery UK Ltd	Waste management, recycling services, collection services and resources management consulting. Drawing on a wide-ranging expertise and services to manage waste more cost-effectively and comply with all regulations, Suez aims to turn waste into new resources and contribute to a circular economy.	https://www.suez.co.uk/en-gb	Tel: 0800 049 5832
Sunamp Ltd	Sunamp designs and manufactures space-saving thermal storage that makes homes, buildings and vehicles more energy-efficient and sustainable, while reducing carbon emissions and optimising renewables.	https://sunamp.com/	Tel: +44 (0)1875 610001 info@sunamp.com
SuperCritical Solutions	The company is developing the world's first high pressure, ultra-efficient electrolyser.	https://www.supercritical.solutions/	online inquiry form
Symbio Fcell	Symbio FCell is a pioneering company in fuel cell technology and inventors of the first range extender for hybrid (combined electricity and hydrogen) vehicles.	https://www.symbio.one/en/#!	contact@symbio.one
TFP Hydrogen	Products of the company: PEMWE component coatings, coated electrodes, catalysts, GDL substrate, electrochemical materials.	https://www.tfphydrogen.com/	enquiries@TFPhydrogen.com

The Cool Corporation Ltd	Cool is a CO2 utilisation startup that begun at the University of Cambridge, with their unique technology is permanently carbon negative, profitable and scalable.	https://www.thecoolcorporation.co.uk/	info@thecoolcorporation.com
The London Bullion Market Association (LBMA)	A UK-based trade association, facilitates platinum trading by setting standards and providing a framework to trade.	https://www.lbma.org.uk/	Tel: +44 (0) 20 7796 3067 mail@lbma.org.uk
The Wrightbus	Northern Ireland based company, manufactured the buses, leading to the creation of new job opportunities.	https://wrightbus.com/	enquiries@wright-bus.com
Tomtom Telematics Fleet	Hydrogen fleet management software providers in the UK	https://www.tomtom.com/solutions/fleet-management-logistics/	online inquiry form
Transport for London (TFL)	In 2021 TFL launched 20 new hydrogen fuel cell double decker buses which joint the fleet of over 500 eclectic buses.	https://tfl.gov.uk/corporate/publications-and-reports/bus-fleet-data-and-audits	Tel: 0343 222 1234
UK Oil & Gas PLC	UKOG focusses primarily on oil and gas assets located in the Weald Basin in southern England.	https://www.ukogplc.com/	info@ukogplc.com
United Utilities Water	United Utilities provides water and wastewater services in the North West of England, leading the Sustainable Biogas, Hydrogen, Graphene LOOP project.	https://www.unitedutilities.com/	Tel: +44 207 197 0197
Urenco	Urenco is an international supplier of enrichment services and fuel cycle products for the civil nuclear industry. The company provides EDF with depleted uranium for hydrogen storage.	https://www.urenco.com/	enquiries@urenco.com
Whites Recycling	Waste management services.	https://whitesrecycling.co.uk/about/	info@whitesrecycling.co.uk
Wood Group UK Ltd	Wood has created a hydrogen production technology that benefits from Wood's market leading SMR (steam methane reformer) efficiency but is fed and fuelled by renewable biological liquid feedstocks.	https://www.woodplc.com/	online inquiry form
Xodus Group	A global energy consultancy to solve the energy industry's problems.	https://www.xodusgroup.com/	online inquiry form
ZeroAvia	ZeroAvia enables scalable, sustainable aviation by replacing conventional engines with hydrogen-electric powertrains.	https://www.zeroavia.com/	

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