Analysis of the potential for development of the hydrogen economy in Poland

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INTRODUCTION

Hydrogen is a versatile energy carrier that can store, transport, and deliver energy without generating direct CO_2 emissions at the point of use, making it an attractive option for reducing greenhouse gas emissions across multiple sectors. Unlike electricity, hydrogen can provide high-temperature heat, long-duration and seasonal energy storage, and a chemical feedstock function that electricity alone cannot fulfil. These properties give hydrogen particular value for hard-to-abate industries, such as steel production, chemicals, and refineries, as well as for heavy transport modes, including shipping, aviation, and long-haul trucking, where battery electrification is currently impractical.

Hydrogen can also replace fossil-derived feedstocks (for example, in ammonia and methanol production) and thus remove a significant source of industrial emissions. The climate benefit of hydrogen depends entirely on its production pathway: hydrogen produced from renewable electricity (so-called “green” hydrogen) or fossil fuels with effective carbon capture (“blue” hydrogen) can deliver deep emissions reductions, whereas unabated fossil hydrogen perpetuates emissions.

Scaling up low-emission hydrogen, therefore, requires the simultaneous deployment of renewable generation, expanded electrolyser capacity, or robust carbon management and storage. Beyond decarbonisation, hydrogen offers strategic advantages: it can strengthen energy security by diversifying supply routes, create high-value industrial clusters and supply chain jobs, and enable cross-sector integration (sector coupling) that increases overall system flexibility. Nevertheless, realising these opportunities faces important challenges: currently high production and logistics costs, limited infrastructure for transport and storage, regulatory gaps, and public acceptance and safety considerations. Economies of scale, targeted policy instruments, and innovation in electrolysers, storage technologies, and transport logistics are key to driving down costs. Importantly, hydrogen is not a universal replacement for electrification or efficiency measures, it is a complementary tool that should be deployed where alternatives are less effective. In countries with carbon-intensive power systems, hydrogen development must be coordinated with power-sector decarbonisation to avoid simply shifting emissions upstream.

Hydrogen has strong potential to transform industrial decarbonisation pathways, but unlocking that potential requires coherent policy, sizable investment, and international cooperation across markets and infrastructure.

Main industrial sectors using hydrogen

At present, hydrogen use is dominated by a small number of industrial sectors where it plays a critical role as a feedstock or process gas. Globally, the two largest consumers are the oil refining sector and the chemical industry, particularly ammonia and methanol production [1, 2]. In oil refining, hydrogen is indispensable for hydrocracking and hydrotreating processes, which remove sulphur and other contaminants from crude oil to meet fuel quality standards and environmental regulations. This sector alone accounts for roughly one-third of global dedicated hydrogen demand [1].

The second major user in the chemical industry is ammonia production, which relies on hydrogen as a feedstock in the Haber-Bosch process. Ammonia is a primary ingredient in nitrogen fertilisers, making this use case particularly important for global food security. Ammonia production consumes about 30% of global hydrogen output [1]. A smaller but still significant share of hydrogen is used in methanol production, where it serves as a feedstock for both chemical synthesis and the manufacture of fuels and solvents [1, 2].

Beyond these dominant sectors, hydrogen is used in a variety of specialised applications:

- In metal processing, including the reduction of metallic ores and treatment of high-value alloys, where hydrogen can act as a reducing agent.
- In the glass industry and electronics manufacturing, where high-purity hydrogen is needed for controlled-atmosphere processes.
- In food processing, notably for the hydrogenation of fats and oils.

Emerging uses for hydrogen, while currently representing less than 1% of total demand, are central to decarbonisation strategies. The most prominent is direct reduced iron (DRI) production in steelmaking, where hydrogen can replace coal-based reductants, enabling near-zero-emission steel when combined with renewable electricity [3]. Another is its potential role in producing synthetic fuels (e-fuels) for shipping and aviation, where hydrogen-derived intermediates can be combined with captured CO_2 [1]. Heavy-duty transport applications, such as hydrogen fuel cell trucks, trains on non-electrified lines, and buses, are also advancing, although their hydrogen consumption remains small in absolute terms today [2].

In Poland, the structure of hydrogen use broadly mirrors the global pattern but with distinctive national features. The chemical industry, particularly ammonia production in plants operated by Grupa Azoty and Anwil, is the single largest consumer. The refining sector, led by Orlen and Lotos (now part of Orlen Group), is the second-largest. Other uses, such as metallurgy and specialised manufacturing, account for only a small share of total demand [4, 5]. This concentration of demand in large, stationary industrial facilities provides a potentially favourable starting point for the deployment of low-emission hydrogen, as it allows for economies of scale and targeted infrastructure development. This section is summed up in Table 1 [1, 6].

Table 1 Main industrial sectors using hydrogen in Europe and in Poland

Sector	**Global**	**Europe (OECD)**	**Poland (approx.)**
Refining	~43–45%	Dominant share (half of the demand)	~25–30% (Orlen, former Lotos)
Ammonia production	~34%	Significant share (chemical sector)	Largest single user → Grupa Azoty, Anwil
Methanol production	~15%	Present but smaller share	Smaller than ammonia production, mainly petrochemicals
Other chemicals/industry	~5–10%	Noticeable share	Present but limited (metals, electronics, glass)
Emerging uses (transport, DRI)	<0.1% today, growing fast	Increasing share due to EU policy	Almost 0% today, but part of the hydrogen strategy plans

Methods of Hydrogen Production

Hydrogen can be produced through a variety of pathways, each with distinct technological, economic, and environmental characteristics. Today, the overwhelming majority of global hydrogen production, around 95%, comes from fossil fuels without carbon capture, often referred to as "grey hydrogen" [1]. The dominant production method is Steam Methane Reforming (SMR), in which natural gas reacts with steam under high temperature and pressure to produce hydrogen and carbon dioxide. This process is widely deployed due to its technical maturity, relatively low cost, and large-scale output, but it is also highly carbon-intensive. In regions with abundant coal resources, notably China, coal gasification remains an important route, it is the most carbon-intensive method of all, with roughly twice the CO_2 emissions per kilogram of hydrogen compared to SMR.

To reduce the carbon footprint of hydrogen production, fossil-based methods can be combined with Carbon Capture, Utilisation and Storage (CCUS), producing so-called "blue" hydrogen. While technically proven and already operational at some facilities worldwide, "blue" hydrogen deployment remains limited due to the high costs of CO_2 capture, transport, and storage, as well as concerns over methane leakage from upstream natural gas supply chains.

The key low-carbon alternative is electrolysis, which splits water into hydrogen and oxygen using electricity. When powered by renewable energy sources such as wind, solar, or hydropower, this process produces "green hydrogen" with near-zero lifecycle emissions. Electrolysis technologies include, for example, Alkaline Water Electrolysis (AWE), Proton Exchange Membrane (PEM) electrolysis, and emerging high-temperature Solid Oxide Electrolysis (SOE).

Alkaline electrolysers represent the most mature technology, traditionally applied in the chemical industry. PEM technology, which has undergone rapid development in recent years, has achieved cost reductions and efficiency improvements, making it available globally as a commercial product. Both AWE and PEMWE operate at relatively low temperatures (<120 °C) and are therefore considered low-temperature electrolysers. In contrast, SOE electrolysers operate at high temperatures, typically between 600°C and 900°C. They remain at an early stage of commercialization but offer significant advantages, such as the ability to recover part of the input energy from heat, as well as enabling co-electrolysis of steam and carbon dioxide to produce syngas, a feedstock for synthetic fuels. In Poland, three installations based on SOE technology are currently in operation. Two of them were designed, manufactured, and integrated with industrial facilities by the Institute of Power Engineering – National Research Institute (IPE-NRI) as part of research and development (R&D) projects co-financed by the National Centre for Research and Development (NCBR). These include the Hydrogin project, featuring a 10 kW-class reversible SOE (rSOC) system, and the Vetni project, which developed a 30 kW-class SOE electrolyser.

Currently, electrolyser production capacity in Europe exceeds 1 GW per year. According to European and Polish regulatory frameworks, including the European Green Deal, the RED III Directive, and the Polish Hydrogen Strategy, the industrial sector is expected to use at least 42% renewable hydrogen by 2030 and 60% by 2035.

Methods of hydrogen storage

Hydrogen storage is a critical component of the hydrogen value chain, enabling the balancing of supply and demand, facilitating transport, and supporting grid stability, especially as renewable energy shares increase. Globally and in Europe, hydrogen is stored using various methods depending on scale, duration, and end-use requirements. The most common forms include compressed hydrogen gas stored in high-pressure tanks (typically 350–700 bar), liquefied hydrogen stored at cryogenic temperatures (around –253°C), and material-based storage using metal hydrides or chemical carriers like ammonia and liquid organic hydrogen carriers (LOHC). Underground storage in salt caverns or depleted gas fields is also gaining attention for large-scale seasonal storage, especially in regions like Germany and the Netherlands [1, 7].

In Poland, hydrogen storage infrastructure is currently very limited and mostly integrated within industrial sites. Compressed gas storage is used on a small scale, primarily for operational buffer needs in refineries and chemical plants. National plans emphasize the potential for developing salt cavern storage in areas like the Lublin or Kosakowo Basin, which are being assessed for feasibility [4]. Furthermore, pilot projects exploring the use of ammonia as a hydrogen carrier for storage and transport are underway, given Poland's strong chemical industry and export ambitions. Material-based storage technologies remain at an early research or demonstration phase.

Poland's approach to hydrogen storage is closely tied to the development of its hydrogen economy, requiring significant investments in infrastructure expansion, regulatory frameworks, and technological innovation.

In summary, Poland's current hydrogen landscape reflects the broader global challenge of transitioning from a fossil fuel-based hydrogen economy to a low-carbon, sustainable one. With a solid industrial foundation and clear strategic direction, Poland has significant potential to become a major player in the emerging European hydrogen market, contributing to the EU's climate targets and its industrial competitiveness in the coming decades.

THE HYDROGEN MARKET IN DETAIL AND NUMBERS

Poland is currently one of the largest hydrogen producers in the European Union, with an annual output estimated at approximately 1.0 million tonnes in 2022 [8]. This places the country among the top three EU producers (and the fifth in the world), alongside Germany and the Netherlands [9].

In Poland, hydrogen production is almost entirely fossil-based, with over 99% derived from natural gas reforming and refinery off-gases, and a smaller share from coke oven gas in steel and chemical plants [4]. In Poland in 2023, 1158 kt hydrogen was produced using steam reformate, 23.3 kt as by product and 0.04 tk by electrolysis, making Poland one of the top three hydrogen producers in the European Union, after Germany and the Netherlands. Poland's hydrogen production is strongly tied to its traditional heavy industries, especially the chemical sector (notably ammonia and methanol production) and oil refining, which consume hydrogen directly on-site as a raw material or in refining processes. Focusing on Poland, the largest hydrogen producers are primarily industrial conglomerates deeply integrated into the country's chemical and refining sectors. The main producers include [4, 5]:

- PKN Orlen, Poland's largest oil refining and petrochemical group, operates major hydrogen production units at its refineries in Płock and Gdańsk. Hydrogen produced here is mostly used internally for refining processes and as feedstock.
- Grupa Azoty, Poland's leading chemical producer, especially in ammonia and fertilizers, with hydrogen production facilities at plants in Puławy, Police, and Kędzierzyn. These plants are the country's biggest consumers of hydrogen and also the largest producers, as hydrogen is produced on-site mainly from natural gas reforming to supply ammonia synthesis.
- Other industrial users include steelmakers and smaller chemical companies, but their hydrogen consumption is relatively limited compared to the giants in refining and ammonia production.

When compared with other European countries, Poland's hydrogen output is significant but still behind leaders like Germany, which produces between 1.5 and 2 million tonnes annually, fuelled by a diverse industrial base and increasing investment in electrolyser capacity [1]. The Netherlands also produces close to 1 million tonnes of hydrogen annually, supported by a strong refining and chemical industry, as well as significant imports and exports of hydrogen derivatives [10]. Across the European Union as a whole, annual hydrogen production is estimated at 10 to 12 million tonnes, predominantly "grey" hydrogen, although this balance is shifting as member states implement policies to scale up "green" and "blue" hydrogen production.

Overall, Poland's hydrogen production landscape reflects the global challenge, such as a mature, large-scale "grey" hydrogen base that is carbon-intensive, alongside emerging but still small-scale low-emission projects. The transition to "green" and "blue" hydrogen will require significant investment in renewable generation, grid infrastructure, CO_2 storage capacity, and supportive market mechanisms to make low- and zero-emission hydrogen cost-competitive.

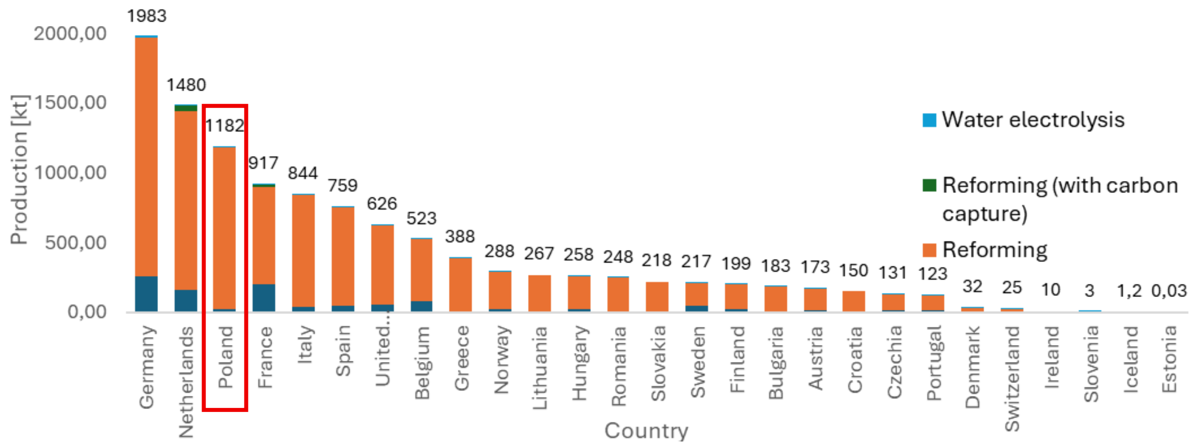

Figure 1 Hydrogen production capacity in Europe in 2023 [11]

On the market, there are available a rage of methods for hydrogen production. They differ primarily in their carbon intensity, technological readiness level (TRL) and production costs. The following table gives an overview of selected hydrogen production methods.

Table 2 Hydrogen production methods [12]

Method name	Description	Emission [kg CO_2/kg H_2]	Cost (LCOH) [EUR/kg]	TRL
Coal gasification	Emissions-intensive method of producing hydrogen. It consists in the conversion of lignite or hard coal under high pressure and temperatures of 800 - 1000°C. The reaction products are hydrogen and carbon monoxide. The method is fully commercially developed.	15-20	3-5	9
Steam methane refoming	Emissions-intensive method of producing hydrogen. It consists in conversion of natural gas using process steam and catalyst at high temperature (700-1100°C). This method is commercially available.	8-12	2-4	9
Electrolysis powered by grid	The method is based on the decomposition of water under the influence of a voltage coming from the power grid. The final emissivity of this method depends on the carbon footprint of the energy mix.	30-35	3-4	7-9
Waste processing	Decomposition of waste into synthetic gas at high temperature (700-800°C)	7-9	7-9	5-7
Termochemical processes	Method based on the water decomposition. The most developed methods include the Sulphur-Iodine cycle and the Copper-Chlorine cycle. Emissions of the process depend on the type of heat supplied. Technologies are in the research phase.	10-15	3-7	5-6

Natural gas pyrolysis	Methode based on thermal decomposition of methane. The process requires the use of nickel as a catalyst. Methane conversion is carried out at temperature of around 500-700°C. The method does not generate CO_2 emissions but its by-product is carbon. Methode is not fully commercially available, but first demo projects were completed.	0	5-7	4-5
Biogas steam reforming	Method base on conversion of biogas using process steam and catalyst at high temperature (700-1100°C). Method is in the initial stage of commercialisation. Process has low net emissions compared to other methods for hydrogen production.	2-3	6-7	5-7
Biomass gasification	Biomass gasification is a mature technology. The process uses heat, steam and oxygen to convert biomass into hydrogen and other products, without combustion.	2-3	4-6	6-8
Electrolysis powered by wind farm	Production method involving the decomposition of water into hydrogen and oxygen using electrical voltage generated from a wind farm. Product of this method is low-emission hydrogen.	0-0,2	4-6	7-9
Electrolysis powered by PV	Production method involving the decomposition of water into hydrogen and oxygen using electrical voltage generated from PV. Product of this method is low-emission hydrogen.	0-0,2	5-7	7-9
Nuclear powered electrolysis	Production method involving the decomposition of water into hydrogen and oxygen using electrical voltage generated from nuclear power plant.	0-0,2	5-7	6-7
Other methods	Other methods include membranes for hydrogen separation, photolysis, biological processes, dark phase fermentation or water deoxidation. Methods are still being developed, and it is difficult to determine when they will be commercialised.	Very low	>10	2-3

Several factors influence the price of hydrogen produced by steam reforming. These include the purchase price of natural gas, the costs associated with the purchase of CO_2 emission rights and other costs such as electricity. CAPEX decomposition is also included in the production costs. The cost structure for producing 1 kg of hydrogen in 2021 is shown below.

Hydrogen production by steam reforming, despite its economic viability (production cost of around 3 €/kg in 2021), is sensitive to fluctuations in natural gas prices. This phenomenon could be observed in the period July-September 2022. During this period, the price of hydrogen was in the range of 10-15 €/kg. The increase in hydrogen production costs has directly resulted in a reduction and in some cases the cessation of chemical production in Europe (mainly ammonia and its derivatives). Another factor directly influencing the increase in the price of hydrogen was the increase in the price of emission allowances.

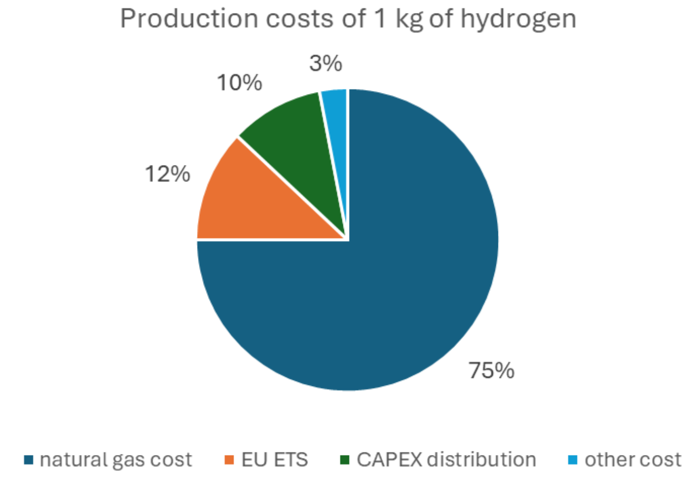

Figure 2 The cost structure for producing 1 kg of hydrogen in 2021 [12]

Based on the data compiled in the table, the cost in Poland of producing 1 kg of hydrogen using steam reforming in 2025 was 4,32 EUR. In turn, the cost of hydrogen produced using electrolysis powered by grid is estimated at 11,3 EUR. The disproportion is large but the continuous increase in the EU ETS price and RED III directive is putting increasing pressure on the implementation of clean technologies contributing to the decarbonisation of operational processes. Below scheme show how the cost of the EU ETS/CBAM system will rise with time. As a result of it the cost of producing hydrogen from natural gas (SMR) will increase as well.

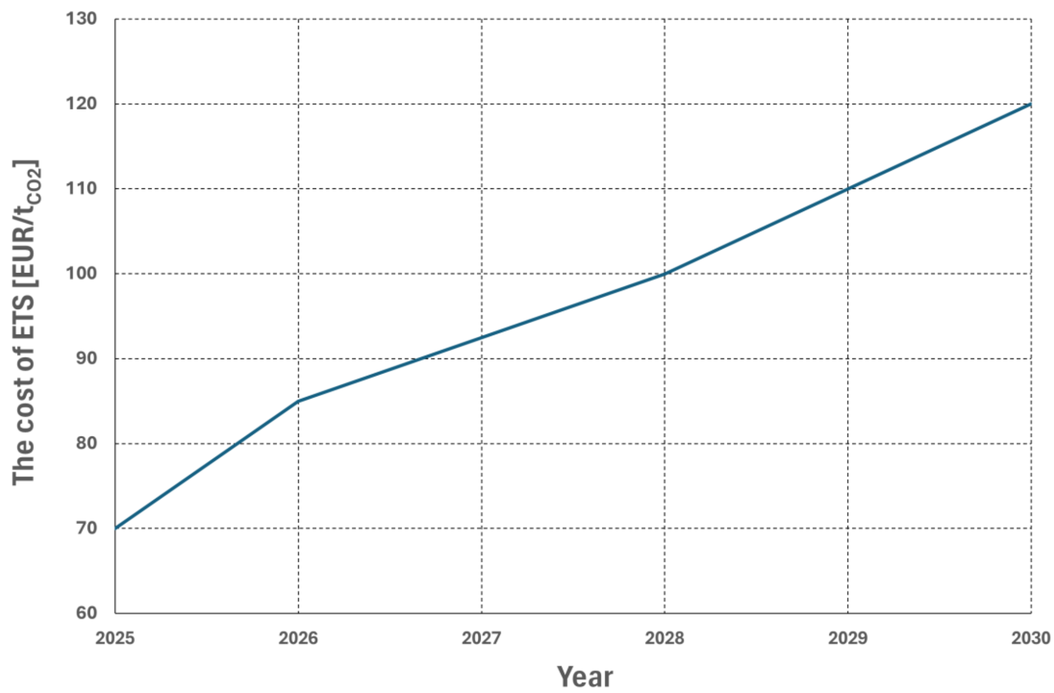

Figure 3 The prediction of increasing the ETS cost in Poland [13]

gas price	63 EUR/MWh [14]
EU ETS	73 EUR/t CO_2 [15]
energy	230 EUR /MWh [16]
CAPEX	0,4 EUR/kg H_2
water	0,01 EUR/kg H_2 [17]

In the last decade (except for 2022), the largest producer and consumer of hydrogen in Poland has been the fertiliser sector. Hydrogen was used in the Haber-Bosch process to produce ammonia. This sector accounts on average for about 374 kt of hydrogen production and consumption. In turn, the chemical sector (excluding ammonia production) was responsible for the production and, at the same time, auto consumption of about 14 kt of hydrogen. Hydrogen was used to produce chemicals such as toluene, vinyl chloride and cyclohexane.

After the fertiliser industry, another sector that plays a key role in production and consumption is the refining and petrochemical industry. The sector is responsible for the production and consumption of approximately 381 kt of hydrogen. Hydrogen is used for crude oil treatment.

Production of hydrogen as a by-product in Poland was at the level of 23,3 kt [F18]. It was generated in coking plants in the form of coke oven gas.

Other sectors, among which the industrial gases sector, food industry and use of hydrogen as a coolant accounted for about 6 kt of hydrogen production and consumption.

As mentioned earlier, hydrogen production using electrolysis accounts for only a small share of total production in Poland.

The first system in Poland integrating renewable energy production with hydrogen production was created in Gaj Oławski on behalf of Promet-Plast.

A 5 MW (1000 Nm^3/h) electrolyser is part of the trigeneration installation. The entire system includes components such as [19]:

- hydrogen compressor (50 kg/h),
- hydrogen storage tank with a capacity of 35 m^3 at a pressure of 500 bar,
- hydrogen reduction station (two-stage – 500/40 bar and 40/5 bar),
- hydrogen cogeneration engine with an electrical power of 1 MWe and a thermal power of 1.2 MWt,
- absorption unit with a cooling capacity of 0.85 MWt,
- closed cooling tower,
- external installations for heating water, ice water and cooling water, hydrogen and nitrogen.

As mentioned previously, hydrogen production in Poland is based on steam reforming. The largest hydrogen production facilities are located in Płock, Gdańsk, Puławy, Police, Włocławek, Kędzierzyn-Koźle and Jedlicze. Despite the small share of electrolysis in hydrogen production, a number of projects are ongoing in Poland aimed at accelerating economic development. Green H2 and Hydrogen Eagle are two Orlen Group programs that have received funding for hydrogen projects from the National Recovery Plan (KPO). Hydrogen Eagle involves the construction of diversified sources of renewable and low-emission hydrogen. Hydrogen will be produced both through electrolysis using renewable energy sources and from municipal waste using waste-to-hydrogen technology. The goal of second co-financed project – Green H2 is to produce renewable hydrogen for use in refinery processes for fuel production in Gdańsk. This project involves the commissioning of a 100 MW electrolyzer combined with an energy storage facility.

Table 3 List of production capacities at selected the biggest facilities in Poland (2022).

Localization	Owner	Process type	Capacity [t/y]
Płock	Orlen Group	Steam Methane Reforming	232 836
Puławy	Azoty Group	Steam Methane Reforming	214 620
Gdańsk	Orlen Group	Steam Methane Reforming	168 809
Kędzierzyn- Koźle	Azoty Group	Steam Methane Reforming	139 024
Police	Azoty Group	Steam Methane Reforming	105 120
Włoclawek	Orlen Group	Steam Methane Reforming	92 327
Tarnów	Azoty Group	Steam Methane Reforming	50 602

There is still no dedicated pipeline for hydrogen transport in Poland, but initiatives are being taken to develop hydrogen transportation infrastructure. One such initiative is PSG obtaining a Technical Assessment Certificate for its the new gas pipeline between Jelenia Góra and Piechowice in the field of natural gas transmission with hydrogen blends. Due to the lack of standards and technical specifications at both EU and national level, in July 2023, Polska Spółka Gazownictwa (Polish Gas Company) launched a project in Lower Silesia in cooperation with the Oil and Gas Institute – National Research Institute and the company 'GAZ'. Its aim was to build the first gas pipeline in Poland to obtain a technical assessment certificate confirming its ability to distribute natural gas with hydrogen blends.

Based on the assessment of the products used, construction technology and quality of work performed, it was confirmed that the Jelenia Góra-Piechowice gas pipeline can transport a mixture of natural gas and hydrogen up to 20 per cent of its volume. As part of an investment worth over PLN 11 million, a medium-pressure gas pipeline with a length of approx. 7 kilometres was constructed.

The hydrogen produced will also power hydrogen refuelling stations which network is being developed in Poland. Currently, there are 7 stations operating in Poland, located in Kraków, Konin, Poznań, Rybnik, Warszawa, Solec Kujawski and Wałbrzych but this number will increase to 24 as a result of H2 Program "Clean Cities – Hydrogen mobility in Poland" realized by PKN Orlen S.A. and subsidized under the CEF Blending Facility [20].

DETERMINANTS OF THE DEVELOPMENT OF THE HYDROGEN ECONOMY

The development of the hydrogen economy is shaped by a combination of technological, economic, and policy factors that together determine its pace and direction. In Poland, the transition from conventional hydrogen production towards low- and zero-carbon alternatives is closely linked to national strategies, regional decarbonisation initiatives, renewable energy potential, and the role of key industrial actors. At the same time, opportunities for new applications, storage solutions, and the emergence of dedicated hydrogen valleys highlight the growing importance of hydrogen as both an energy carrier and an industrial feedstock. Understanding these determinants is crucial for assessing the prospects and challenges of building a competitive hydrogen economy.

National and regional strategies for hydrogen development

At the national level, Poland has been steadily developing a comprehensive framework that aligns energy, climate, industrial, and transport policies to enable a hydrogen economy. Key among these is the Polish Hydrogen Strategy (PHS, 2021), which sets a target of 2 GW of electrolyser capacity by 2030, supports the emergence of hydrogen hubs, and foresees widespread deployment of hydrogen refuelling stations and fleets. Complementing that, the government's Energy Policy until 2040 (PEP2040) embeds hydrogen as a primary lever for decarbonisation in industry, transport, heating, and power generation. The National Energy and Climate Plan (NECP) (2021–2030) and its recent draft update (2024) reinforce these goals, particularly through strengthened renewable energy deployment, which is essential to supplying low-carbon electricity for electrolysis [21].

In addition, the government has introduced legislative and regulatory initiatives to reduce barriers and provide clarity. A draft legislative package defines "renewable and low-emission gases", establishing quality and certification rules, and assigning operators for hydrogen transmission, distribution, and storage systems. Funding schemes under the National Recovery and Resilience Plan (KPO) allocate €640 million for hydrogen technologies covering production, storage, transport, and related infrastructure [22].

Regionally, multiple hydrogen valleys are being established or developed, often aligned with regions having strong industrial bases, renewable energy potential, and research capacities. Examples include:

- The Lower Silesian Hydrogen Valley, a partnership involving KGHM Polska Miedź S.A. and regional authorities, focusing on industrial, scientific, and technological ventures [23]. The green hydrogen production facility located in Gaj Oławski, developed by Promet-Plast, is the first commercial green hydrogen installation in Poland. It utilises renewable energy from nearby wind turbines (22 MW), an agrivoltaic farm (9.1 MW), and a rooftop photovoltaic system (1 MW) to power a 5 MW electrolyser [24].
- The Silesian-Lesser Poland Hydrogen Valley, linking heavy industrial areas in Silesia and Małopolska, aiming at decarbonisation of industry, transport, and heating [25].
- The Central Hydrogen Valley covering Łódzkie, Mazowieckie and Świętokrzyskie voivodeships, built on the cluster under Industria (Świętokrzyska Grupa Przemysłowa), seeking to combine green hydrogen production, industrial applications, and transportation uses [26].
- The Mazovian Hydrogen Valley / HySPARK project, which aims to build a replicable hydrogen ecosystem in the Masovian region, targeting transport (airport ground handling, buses, trucks), infrastructure (refuelling stations), and industry [27].
- The Amber Hydrogen Valley in the Pomerania Region, which aims to develop a hydrogen value chain from production to storage and distribution to mobility, industry, and energy [28].

Recent survey data further sharpen the understanding of how strategy translates into potential. According to GAZ-SYSTEM's "Hydrogen Map of Poland" (2024), the declared domestic hydrogen production potential is projected to grow after 2030 and reach about 1.11 million tonnes/year by 2040, although many projects are at early stages. In that same survey, hydrogen consumption is forecasted to increase from ≈ 1.27 million tonnes in 2030 to ≈ 2.62 million tonnes in 2040, with the highest demand concentrated in central and south-west provinces [29].

Electrolyser capacity targets are also being updated: survey respondents declared planned electrolyser capacity in 2030 of around 5.6 GWe, and a target of 9 GWe by 2050—significantly higher than the 2 GW target in PHS for 2030, indicating both ambition and the recognition of the scale needed [30].

Moreover, policy documents aim to ensure infrastructure is not left behind. The strategy identifies creation of a north–south hydrogen pipeline feasibility study by 2025, formal investigations into using existing gas networks for hydrogen or hydrogen-gas blends, and large-scale salt cavern storage R&D by 2030 [31].

These regional strategies serve multiple purposes: they concentrate investment, reduce logistical challenges (proximity of producer/user), build up local technical / R&D capacity, and promote social acceptance by locating projects in identifiable regions.

Renewable energy potential and hydrogen production potential

The potential for hydrogen production in Poland is closely tied to the availability and growth of renewable energy sources, which provide the low-carbon electricity required for electrolysis. Expanding wind, solar, and other renewables, therefore, directly determines the scale at which green hydrogen can be produced, while planned projects in offshore wind and photovoltaic capacity offer significant opportunities for future development.

A key enabler for green hydrogen is the scale and rate of growth of renewable energy sources (RES) in Poland. As of early 2025:

- Photovoltaic (PV) capacity had surpassed 22 GW, and wind farms (onshore) were nearing ~10.9 GW [32].
- Solar PV saw about 4 GW of new capacity in 2024 alone [33].

In parallel, Poland's Transmission System Operator (PSE) in its 2023–2032 development plan projects a substantial RES potential: new onshore and offshore wind farms, large expansions of solar, plus connection conditions already granted for many RES projects. This could lead to over 100 TWh/year from renewables by 2030, meeting more than 50% of Poland's projected electricity demand [34].

Translating this into hydrogen production potential depends on electrolyser efficiency, capacity factor (how often the electrolyser is actually operating), grid integration, and curtailment. While there is no single definitive published number yet in Polish sources for total green hydrogen production with this RES potential, initiatives like ORLEN are planning to reach ~1 GW electrolysis capacity by 2030 within its hydrogen projects, producing over 130,000 tonnes/year of renewable hydrogen in its strategies, combining both renewables + municipal waste feedstocks [35].

Thus, the country's renewable energy trajectory appears strong enough that, with sufficient investment, grid flexibility, and favourable regulation, significant green hydrogen production is technically feasible. The gap lies in ensuring RES growth aligns with hydrogen infrastructure, regulatory certainty, and financial incentives.

Key investors, component producers, and institutional leaders

The establishment of a hydrogen economy in Poland is strongly influenced by the activities of key investors, technology providers, and institutional leaders who drive innovation and coordinate large-scale projects. Their involvement not only accelerates the deployment of hydrogen production and infrastructure but also helps shape supply chains, create regional hydrogen ecosystems, and foster cooperation between industry, research institutions, and public authorities.

Major industrial and energy companies are leading the hydrogen economy in Poland. Notable among them:

- PKN Orlen S.A. (combined with its subgroup LOTOS Green H2) is a champion: under its "Hydrogen Eagle" and other programmes, Orlen secured over PLN 1.7 billion in non-repayable funding (National Recovery Plan) for hydrogen projects. It aims to develop ~0.9 GW of electrolyser capacity by 2035, about 0.7 GW of which will be in Poland. Also, to build a hydrogen refuelling station network (over 100 stations across Poland, the Czech Republic, and Slovakia) by 2030 [36].
- Polenergia S.A., a private renewable energy company, won ~€143 million from the Recovery and Resilience Facility to build its "H2Silesia" green hydrogen production project in Upper Silesia, which could significantly shift the industrial region away from coal [37].
- ArcelorMittal Poland, in cooperation with Linde Gaz Polska, is investing over PLN 100 million to build a hydrogen production plant at the Kraków facility, intended to supply cleaner hydrogen for steelworks and to replace ammonia in some processes. The project should be operational by late 2026 [38].

On the technology side, component producers (electrolyser manufacturers, hydrogen purification, compression, fuelling station technologies) are often part of consortia in hydrogen valleys, involving both Polish firms and international partners. Examples include ORLEN's investment via its venture capital fund into a manufacturer of high-efficiency PEM electrolysers.

Public agencies also play key roles: the Industrial Development Agency (ARP), the Institute of Power Engineering – National Research Institute (IPE-NRI), regional governments, universities, and R&D institutions are founding partners in many hydrogen valley projects. Their involvement improves local capacity, risk sharing, and helps secure public funding.

Emerging applications and new users

The expansion of Poland's hydrogen economy depends not only on production and infrastructure but also on the identification of new applications and users that can absorb growing hydrogen supplies. Beyond traditional industrial use, hydrogen is increasingly being explored in transport, energy systems, and public services, creating opportunities for decarbonisation, innovation, and the development of integrated regional hydrogen ecosystems. Understanding these emerging applications is essential for assessing potential demand, guiding investment, and ensuring the long-term sustainability of the hydrogen market.

While industry remains the main driver of hydrogen demand in Poland, several emerging applications and new users are beginning to shape the broader hydrogen ecosystem.

Transport is one of the first sectors to experience significant hydrogen deployment. Cities such as Warsaw and other regional centres are introducing hydrogen-powered buses as part of efforts to decarbonise public transportation, while airport ground handling vehicles and hydrogen trucks are also being piloted. These early projects demonstrate the versatility of hydrogen in applications where battery-electric solutions may face limitations due to weight, range, or operational constraints [39].

In heavy industry, companies like ArcelorMittal Poland are exploring the use of hydrogen to replace coal in steel production processes, while fertiliser and chemical producers are considering hydrogen as a substitute for natural gas or ammonia feedstock. These initiatives not only provide substantial volumes of demand for hydrogen but also serve as critical levers for reducing CO_2 emissions in sectors that are otherwise difficult to decarbonise [40].

Similarly, refineries, including projects by PKN Orlen, are integrating hydrogen into operations and production of synthetic fuels, creating synergies between industrial processes and clean energy goals [41].

Public services and municipal applications are also emerging as important new users of hydrogen. Pilot projects are exploring the use of hydrogen for buses, service fleets, and municipal vehicles, as well as for local heating solutions and other energy services. Additionally, hydrogen is being considered as a flexible energy carrier within the power system, offering opportunities for grid balancing, seasonal storage, and blending with natural gas networks. These applications highlight hydrogen's potential to complement an increasingly renewable-based electricity system while supporting industrial and transport decarbonisation.

The combination of industrial, transport, municipal, and energy-related applications illustrates how hydrogen is beginning to diversify beyond its traditional industrial use. By creating opportunities for a wide range of users, Poland can gradually expand the hydrogen market, strengthen infrastructure networks such as refuelling stations and storage facilities, and support the emergence of regional hydrogen ecosystems, including the so-called hydrogen valleys. This broadening of potential applications will be crucial for scaling up production, attracting investment, and embedding hydrogen as a key component of Poland's low-carbon economy.

Potential of hydrogen storage in salt caverns

The development of a robust hydrogen economy requires not only production and distribution infrastructure but also reliable storage solutions. Salt caverns offer one of the most promising options for large-scale hydrogen storage in Poland, providing the capacity to balance seasonal variations, support grid stability, and secure reserves for industrial and transport applications. Assessing the potential of these geological formations is therefore critical for understanding how hydrogen can be integrated effectively into the national energy system.

Poland's geological conditions present significant opportunities for large-scale hydrogen storage, particularly through the use of salt caverns. These natural formations, primarily found in the Polish Lowlands, offer several advantages for hydrogen storage, including high structural integrity, low permeability, and the ability to store gases under pressure without significant leakage. The suitability of these caverns for hydrogen storage has been a subject of various studies. For instance, research indicates that salt domes such as Rogóźno, Damasławek, and Łeba are among the most promising sites for developing hydrogen storage caverns due to their favourable geological characteristics [42].

The potential storage capacity of these salt caverns is substantial. Studies have estimated that the average hydrogen storage potential in Polish salt domes ranges from 125.7 TWh after the first filling to 83.8 TWh after 30 years of operation, depending on factors like cavern volume, depth, and geological structure [43]. This capacity is particularly valuable for balancing the intermittent nature of renewable energy sources such as wind and solar power, enabling the storage of excess energy produced during periods of high generation for later use.

Furthermore, advancements in technology and methodology are enhancing the feasibility of utilising salt caverns for hydrogen storage. Recent studies have employed artificial intelligence and machine learning techniques to assess the suitability of various salt deposits for hydrogen storage, leading to more precise identification of optimal sites [44]. Additionally, geomechanical simulations are being used to understand the long-term behaviour of salt caverns under cyclic hydrogen injection and withdrawal, ensuring the structural integrity and safety of these storage facilities [45].

While there is not yet large-scale operational hydrogen storage in salt caverns in Poland on an industrial scale, these studies suggest that several salt deposits (especially in central and northern Poland) could host such caverns. The legal and regulatory framework for underground gas storage (for natural gas) provides precedents, and knowledge from CO_2 storage / natural gas storage helps inform potential hydrogen storage site selection. The development of practical projects will depend on demonstrating safety (leakage, embrittlement, etc.), economic viability, and integration with demand/production cycles.

In conclusion, the development of hydrogen storage in salt caverns in Poland holds significant promise for supporting the country's transition to a low-carbon energy system. By leveraging its favourable geological formations and advancing technological methodologies, Poland can establish a robust infrastructure for large-scale hydrogen storage, facilitating the integration of renewable energy sources and enhancing energy security.

Summary

To sum up, Poland has significant positive determinants in place: strong strategic policy, increasing RES capacity, active large firms and consortia investing in hydrogen projects, regional hydrogen valleys, and geological potential for storage. However, several challenges remain.

BARRIERS TO THE DEVELOPMENT OF THE HYDROGEN ECONOMY

The development of the hydrogen economy in Poland is confronted with multifaceted and interlinked barriers spanning legal, economic, environmental, technical, and infrastructural domains. These obstacles constrain financing, deployment, and scalability, demanding coordinated policy and industrial responses to unleash the sector's full potential.

Legal and Regulatory Gaps

One of the primary challenges hindering the growth of hydrogen technologies in Poland has been the lack of a dedicated and comprehensive legal framework. Until recently, hydrogen was not formally recognized as a distinct energy carrier, leading to regulatory ambiguity in areas such as market access, infrastructure development, safety standards, and certification procedures. This legal vacuum increased investment risks and discouraged private sector involvement. To address these barriers, Poland introduced the Hydrogen Law in early 2025, which marks a significant step toward regulatory clarity. The law defines hydrogen as a separate energy vector, distinct from natural gas, establishes licensing regimes for hydrogen production, storage, and distribution, introduces hydrogen system operators, and enables the development of dedicated infrastructure, as well as simplifies permitting procedures for hydrogen-related investments, including amendments to construction law. The introduced regulations align national regulations with EU directives, particularly the Hydrogen and Decarbonised Gas Market Package and RED III. Additionally, Poland has implemented mechanisms for guaranteeing the origin of renewable hydrogen, issued by the Energy Regulatory Office (URE), and is integrating with EU-wide certification systems such as CertifHy.

These measures aim to reduce regulatory uncertainty, enhance investor confidence, and accelerate the deployment of hydrogen technologies in line with the EU's climate and energy goals. Nevertheless, there are not enough, among the legislative barriers, the following can be distinguished:

Despite the introduction of Poland's Hydrogen Law in 2025, which marked a significant step toward establishing a legal framework for hydrogen activities, several critical regulatory gaps remain. These gaps continue to impede the full-scale deployment of hydrogen technologies and the creation of a competitive hydrogen economy.

- lack of a unified legal definition of hydrogen as an energy carrier

While hydrogen is now partially recognized in sectoral legislation, Poland still lacks a clear and unified definition of hydrogen as a distinct energy carrier within the core Energy Law. This omission creates ambiguity in how hydrogen is treated across various energy regulations, complicating its integration into national energy planning and market structures.

- absence of a mandatory guarantee of origin system

Poland has begun issuing guarantees of origin for renewable hydrogen through the URE, but the system is not yet mandatory or fully harmonized with the EU's CertifHy framework. Without a robust and standardized certification system, producers and consumers face uncertainty regarding the environmental credentials of hydrogen, which undermines market transparency and investor confidence.

- incomplete regulation of hydrogen infrastructure operators

The current legal framework does not fully define the roles and responsibilities of hydrogen transmission and distribution system operators. Although recent legislative drafts propose the establishment of such entities, there is still no comprehensive regulation governing their operation, access rights, or tariff structures. This gap hinders the development of dedicated hydrogen networks and the conversion of existing gas infrastructure.

- fragmented licensing and permitting procedures

Hydrogen-related activities such as production, storage, and distribution are subject to inconsistent licensing requirements. For example, trading hydrogen may require a license only if the annual turnover exceeds €1 million, leaving smaller operators in a legal grey zone. Moreover, technical certification standards for hydrogen equipment and installations are still underdeveloped, creating barriers for technology deployment and safety assurance.

- lack of support for local and distributed hydrogen systems

Current regulations do not adequately support localized hydrogen systems, such as microgrids or regional hydrogen valleys. These systems are essential for integrating hydrogen into industrial clusters and transport hubs. The absence of tailored legal provisions for geographically limited networks restricts innovation and regional development.

- weak integration with spatial and environmental planning

Hydrogen infrastructure projects often face delays due to complex environmental and spatial planning procedures. Although the Hydrogen Law introduces some simplifications, there is still no dedicated fast-track process for hydrogen investments. Moreover, hydrogen installations are not prioritized in local zoning plans, which limits site availability and increases administrative burdens.

Environmental Permitting Challenges

Environmental permitting rules represent a significant bottleneck in the rapid build-out of hydrogen infrastructure in Poland. The permitting regime for renewable energy installations, hydrogen production plants, and associated infrastructure requires multiple layers of environmental impact assessment and local government approvals. These procedures contribute to delays averaging from several months to over a year, depending on project scale and location. The stringent assessment necessary to address potential ecological impacts on land use, water resources, and air quality while complying with EU standards adds to project lead times and costs. Public consultations and potential local opposition can amplify procedural burdens, creating tension between environmental protection aims and developmental pace (CMS Expert Guide, 2024).

Economic and technical barriers to CAPEX and OPEX of hydrogen production

The economic viability of green hydrogen production in Poland is significantly influenced by the capital and operational costs associated with electrolysis technologies. These costs vary depending on the type of electrolyser used, with Proton Exchange Membrane (PEM), Alkaline Water Electrolysis (AWE), and Solid Oxide Electrolysis Cells (SOEC) representing the most prominent technologies. Each presents distinct advantages and challenges, but all face economic hurdles that must be addressed to enable large-scale deployment.

PEM electrolysers are widely regarded for their high efficiency, rapid response times, and compatibility with intermittent renewable energy sources such as wind and solar. However, they are also among the most expensive options. In Poland, the capital expenditure (CAPEX) for PEM systems typically ranges between €700 and €1,000 per kilowatt of installed capacity. For instance, a 10 MW PEM electrolyser facility may require an upfront investment of €7–10 million. Operational expenditure is also substantial. Fixed OPEX is estimated at 3–5% of CAPEX annually, but the dominant cost driver is electricity, which accounts for approximately 60–70% of total operating expenses under current Polish energy pricing. Additional variable costs include water purification and stack replacement, both of which are essential for maintaining system performance. According to NESO data from 2024, CAPEX for PEM electrolysers is expected to decline to around £450/kW by 2030, driven by technological improvements and economies of scale. The average plant lifetime is estimated at 25 years, although stack components may require replacement every 7–10 years, depending on usage intensity.

Alkaline electrolysers represent the most mature and commercially available electrolysis technology. They are characterized by lower CAPEX and simpler system architecture, making them attractive for large-scale hydrogen production. In Poland and across the EU, CAPEX for AWE systems typically ranges from €500 to €600/kW, with projections suggesting a reduction to €300–400/kW by 2030.OPEX for alkaline systems is generally lower than for PEM, with electricity consumption averaging around 54 kWh per kilogram of hydrogen produced. Material costs are also more favorable, as AWE systems rely on abundant and inexpensive materials such as nickel and nickel-coated steel. Stack lifetimes are longer—often exceeding 80,000 hours—and maintenance requirements are less frequent. However, the lower efficiency and slower dynamic response of AWE systems make them less suitable for integration with variable renewable energy sources.

SOEC technology is still in the early stages of commercialization, but offers promising advantages in terms of efficiency and integration with high-temperature heat sources. These systems operate at elevated temperatures (typically 700–900°C), which allows for significantly higher electrical efficiency—up to 90–100% in optimal conditions. Despite their potential, SOECs currently face high CAPEX due to the complexity of ceramic stack manufacturing and limited production volumes. OPEX is comparatively lower, especially in terms of electricity consumption, but stack degradation under thermal cycling remains a major technical challenge. Stack lifetimes are still being evaluated, with early estimates suggesting replacement intervals of 5–9 years depending on operating conditions. Material costs are lower than PEM, but manufacturing scalability remains a barrier.

Critical Raw Materials for electrolyser manufacturing

The production of electrolysers depends on access to critical raw materials such as platinum, iridium, nickel, and rare earth elements. According to the European Commission's Electrolyser Factsheet (2023), demand for platinum is expected to reach 9–34 tons globally by 2050, with 3–9 tons allocated to European production. Iridium demand could exceed 200% of global supply without significant reductions in catalyst loading. Poland lacks domestic sources of these materials and relies heavily on imports, primarily from China, India, and the United States. Advanced materials such as fluoropolymers and titanium fiber mesh also face supply risks. The Critical Raw Materials Act (CRMA) and Net-Zero Industry Act (NZIA) aim to strengthen European supply chains, but their impact on Poland's hydrogen sector remains to be seen.

Infrastructure retrofitting costs and challenges

One of the most pressing non-legislative barriers to the development of a hydrogen economy in Poland is the inadequacy of existing infrastructure to support hydrogen production, transport, storage, and distribution. While strategic plans and pilot projects are underway, the current state of infrastructure remains insufficient to meet the needs of a scalable and integrated hydrogen market. As of mid-2025, Poland has fewer than 20 operational hydrogen refuelling stations, primarily located in urban centers and pilot regions. This number is expected to grow to 32 stations by the end of 2025, and 57 by 2030, according to national infrastructure development plans. However, this pace of expansion is modest compared to the needs of a nationwide hydrogen mobility network. For comparison, Germany already operates over 100 stations, with plans to reach 300 by 2030. The limited availability of refueling infrastructure poses a significant challenge for the adoption of hydrogen-powered public transport, freight vehicles, and passenger cars. Municipalities and fleet operators are hesitant to invest in hydrogen vehicles without guaranteed access to refueling points, creating a chicken-and-egg dilemma that slows market uptake.

Poland's electricity transmission grid is another bottleneck in hydrogen infrastructure development. Over 40% of high-voltage lines are more than 40 years old, which limits the grid's capacity to integrate new renewable energy sources and support large-scale electrolysis. Electrolysers require stable and high-capacity connections to renewable electricity, and grid congestion or outdated infrastructure can delay or restrict project deployment. Moreover, the lack of smart grid technologies and energy storage systems further complicates the integration of intermittent renewables with hydrogen production. Without grid modernization, Poland risks underutilizing its renewable potential and failing to meet its hydrogen production targets.

Poland currently lacks dedicated hydrogen pipelines, and existing natural gas infrastructure is not yet adapted for hydrogen transport. While feasibility studies and planning efforts are underway, construction has not yet begun on major pipeline projects. Two key international initiatives aim to address this gap the Nordic-Baltic Hydrogen Corridor, which will connect Finland, the Baltic States, and Poland with Central Europe, and the Central European Hydrogen Corridor, linking Poland with the Czech Republic, Slovakia, and Hungary. These corridors are expected to facilitate cross-border hydrogen trade and improve regional energy security. However, their implementation depends on complex regulatory harmonization, funding, and technical coordination across multiple countries.

Distribution systems—whether via pipelines, trucks, or rail—also require significant investment and standardization. The absence of a national hydrogen logistics strategy means that producers and consumers must rely on ad hoc solutions, which increases costs and reduces efficiency. Repurposing existing natural gas pipelines for hydrogen transmission presents both opportunities and challenges. According to ACER (2021), retrofitting costs range from €0.5 to €2 million per kilometer, depending on pipeline age, diameter, and condition. Hydrogen embrittlement poses technical risks, requiring inner coatings and material compatibility assessments. The levelized cost of hydrogen transportation by pipeline is estimated at €0.09 to €0.17 per kg per 1,000 km. Poland's Hydrogen Map initiative by GAZ-SYSTEM outlines plans for a national hydrogen transmission network, with feasibility studies underway for repurposing selected pipeline sections.

Hydrogen storage infrastructure in Poland is still in its infancy. Most existing facilities are small-scale and designed for demonstration purposes. Large-scale underground storage, such as salt caverns or depleted gas fields, has not yet been developed, although geological assessments are ongoing.

Market uncertainty and strategic prioritization

Despite growing interest and investment in hydrogen technologies, Poland's hydrogen market continues to face significant uncertainty regarding long-term demand, sectoral prioritization, and commercial viability. This uncertainty stems from a lack of binding policy instruments, insufficient demand-side coordination, and limited visibility into future hydrogen consumption across key sectors. Currently, hydrogen use in Poland is heavily concentrated in traditional industrial applications—primarily in fertilizer production (ammonia synthesis) and oil refining. These sectors rely on grey hydrogen derived from natural gas, with limited incentives or mandates to transition to low-emission alternatives. In contrast, hydrogen penetration into transport, power generation, and residential heating remains minimal, despite its inclusion in strategic planning documents. The Polish Hydrogen Strategy identifies transport, industry, and energy as priority sectors for hydrogen deployment. However, the strategy lacks binding quotas, mandates, or sector-specific targets that would compel adoption. For example, there are no legal requirements for public transport fleets to transition to hydrogen-powered vehicles, nor are there obligations for industrial emitters to substitute grey hydrogen with green alternatives.

One of the most critical barriers to market development is the absence of long-term offtake agreements—contracts that guarantee hydrogen producers a stable buyer base. Without these agreements, investors face high risks related to demand volatility and price uncertainty. This is particularly problematic for large-scale projects, such as 100+ MW electrolyser installations, which require multi-year planning and financing. Moreover, Poland has not yet introduced carbon contracts for difference (CCfDs) or hydrogen purchase guarantees, which are increasingly used in other EU countries to de-risk investments and stimulate demand. The lack of such mechanisms makes it difficult for hydrogen producers to secure financing and scale operations. While various ministries and agencies are involved in hydrogen-related initiatives, Poland lacks a centralized governance structure to coordinate hydrogen policy across sectors. This fragmentation leads to inconsistent messaging, overlapping responsibilities, and delays in regulatory implementation. For example, there is no national hydrogen demand forecast or roadmap that quantifies expected uptake by sector and region. This absence of strategic planning makes it difficult for stakeholders to align investments with future market needs.

LEGAL CONDITIONS

In recent years, Poland has been strongly involved in climate issues through the ratification of international agreements and EU regulations introducing a legislative framework to support environmentally friendly technologies. The United Nations Framework Convention on Climate Change (UNFCCC) in 1992 played a key role in this regard, as it laid the global foundations for cooperation to reduce greenhouse gas (GHG) emissions responsible for global warming. Poland has been actively participating in its implementation since 1994 [46, 47]. This led to the adoption of the Kyoto Protocol (1997), the first pact requiring industrialized nations, including Poland, to meet predetermined targets for GHG emissions that are on average 5% lower than those of 1990. When Poland joined this agreement in 1998, it pledged to keep GHG emissions between 2008 and 2012 at 6% below the base year of 1988 [48]. In the following years, the 2015 Paris Agreement, adopted during the 21st Conference of the Parties (COP21, UNFCCC), also had a significant impact on national policy. At that time, Poland, as part of the European Union, declared its commitment to achieving common climate goals. The aim of this agreement was to limit the global average temperature increase to below 2°C, with a target of 1.5°C compared to the pre-industrial era, and to achieve climate neutrality in the second half of the 21st century. The agreement influenced Poland's long-term energy and climate policy, forcing numerous modernizations of the energy sector through the development of RES and the search for new low-emission technologies.

The pursuit of climate neutrality among EU member states has progressed with the ratification of new documents setting out long-term climate strategies. One of these was the announcement in 2019 of the European Green Deal, a comprehensive plan for a profound transformation of the EU economy (energy, transport, agriculture, industry, and construction) towards sustainable development. The goal is to make Europe a climate-neutral continent by 2050 by reducing GHG emissions by at least 55% by 2030 (compared to 1990), intensifying the development of RES and energy efficiency. Although the far-reaching vision for climate transformation at the EU level does not include a detailed plan for the hydrogen economy, its key strategic objectives are conducive to the development of hydrogen technologies. These goals include using low-carbon gases to decarbonize the gas sector, minimizing the use of raw materials in line with the principles of the circular economy, promoting clean, innovative industrial technologies, such as energy storage or the zero-emission hydrogen production, and lowering emissions in the whole transportation sector by the implementation of sustainable, alternative fuels [49]. Poland formally participates in the European Green Deal, although it did not initially declare its full support for this regulation at the European Council summit, citing the high costs of energy transition and dependence on coal. Nevertheless, in the following years, Poland gradually joined the implementation of the plan, including through the National Energy and Climate Plan, mining region transformation programs, and participation in EU funds (e.g., the Just Transition Fund). The legal basis for the European Green Deal is the European Climate Law, which obliges all member states, including Poland, to implement the strategy's objectives. This means continuing to move away from coal, developing RES, investing in energy efficiency, and green technologies [50].

The multiple applications of hydrogen - as a feedstock, a fuel, and an energy carrier and storage medium – combined with the drive to achieve climate neutrality, have contributed to its growing importance as a factor that could revolutionize industry, transport, energy, and construction sectors. In response to these prospects, in 2020, the European Commission presented a document supporting the development of the hydrogen economy - Hydrogen Strategy for a Climate-Neutral Europe. The strategy sets specific targets for 2050, divided into three stages. The first stage, covering the period up to 2024, provided for the installation of electrolysers powered by RES with a total capacity of at least 6 GW. The second stage, up to 2030, envisages increasing this capacity to at least 40 GW. The final stage, covering the years 2030–2050, anticipates the full maturity of renewable hydrogen production technologies and their widespread use in high-emission sectors [51].

On June 21, 2021, the Polish Ministry of Climate and Environment published and submitted for public consultation a draft of the Polish Hydrogen Strategy until 2030 with a perspective until 2040 [5]. The document presents a comprehensive approach covering the entire hydrogen value chain, with a particular focus on three priority areas for its future use in Poland: energy, transport, and industry. The main objective of the strategy is to create a national hydrogen industry and develop it towards climate neutrality while maintaining the competitiveness of the Polish economy. This strategy identifies 6 objectives that must be achieved. These objectives include the introduction of hydrogen technologies into the energy sector, which is to be facilitated by an increase in the share of RES in the energy mix and the use of hydrogen as an alternative fuel for transport, which will require the construction of appropriately adapted storage and refuelling infrastructure for the new fuel. Furthermore, according to the Polish strategy, hydrogen is to play a key role in the decarbonization of industry, which will be aided by the creation of special energy areas/regions near energy-intensive industrial consumers, known as hydrogen valleys, around which a coordinated hydrogen transmission chain will be concentrated. According to data from the Industrial Development Agency JSC, there are currently 11 hydrogen valley projects operating in Poland [52]. Under current EU law, there is no precise definition of the term “hydrogen valley.” However, it should be assumed that such initiatives can be classified as a form of decentralized energy communities, falling within the broader category of structures such as energy clusters, the definition of which is contained in Article 2 of the Directive of the European Parliament and of the Council on the promotion of the RES use [53].

One of the most active and best-funded hydrogen valleys in Poland is the Mazovian Hydrogen Valley. It was officially established in 2022 under the leadership of PKN ORLEN S.A., at the head of 16 experienced partner entities. The initiative covers an area corresponding to administrative regions where hydrogen projects are implemented according to set objectives. The valley aims to develop a regional hydrogen market covering activities from production to consumption, the creation of hydrogen technologies correlated with RES, the use of hydrogen in transport, energy, heating, and aviation, the construction of hydrogen transmission infrastructure (hydrogen refuelling stations, distribution networks), the transfer of knowledge and innovation through cooperation between science and industry, and finally the decarbonization of the Mazovia region. As part of the Mazovian Hydrogen Valley, an international project called HySPARK (*Hydrogen Solutions for euroPean Airports & Regional Kinetics*) was launched, with the Institute of Power Engineering – National Research Institute (IPE-NRI) acting as the leader. The project brings together 14 consortium members from 4 countries: Poland, Italy, Ireland, and the United Kingdom. The initiative supports the decarbonization process in the public transport sector, at Warsaw Chopin Airport, and in energy-intensive industries. There are plans to launch a hydrogen refuelling station near the airport. Another aspect of the project involves testing tractors used to transport hydrogen and ammonia production with the use of hydrogen [54].

The remaining objectives of the Polish Hydrogen Strategy are: producing hydrogen from new low- and zero-emission sources, building a safe and convenient hydrogen distribution system, and developing appropriate standards and legal regulations governing the functioning of the market based on clean hydrogen [5, 49].

In July 2021, the European Commission presented a comprehensive legislative package called "Fit for 55," comprising 13 draft legal acts aimed at regulating key areas of climate and energy policy, including: the emissions trading system (EU ETS), RES (Renewable Energy Directive, RED III), energy efficiency (EED), and alternative fuels infrastructure (AFID). The proposed legislative changes are currently the subject of negotiations and further legal work aimed at finalizing their exact wording. The ultimate goal of the package is a systemic shift away from fossil fuels and the intensification of pro-environmental measures as part of the EU member states' goal of achieving climate neutrality by 2050 [55].

The development of RES is the foundation for building a modern hydrogen economy, and these two areas are closely linked. A key condition for their harmonious development is to ensure a transparent and stable legal framework for the renewable energy sector. In response to this need, Directive (EU) 2018/2001 of the European Parliament and of the Council, known as RED II, was adopted in 2018. The new regulation replaced the previously applicable legal acts, i.e., Directive 2009/28/EC, Directive (EU) 2015/1513, and Council Directive 2013/18/EU, creating a uniform system for promoting RES in EU member states. RED II sets sectoral targets for the minimum share of energy from renewable sources in specific areas of the economy: in transport (at least 14% by 2030), in the heating and cooling sector (an average increase in the share of RES of approximately 1.3% annually until 2030 compared to 2020 levels), and in electricity production. In the overall energy balance, the target share of renewable energy is at least 32% of total gross energy consumption by 2030. In addition, the directive introduced harmonized sustainability criteria for biofuels, bioliquids, and biomass, requiring them to achieve, among other things, a minimum 50% reduction in greenhouse gas emissions compared to fossil fuels. Obligations have also been established for tracking the origin of renewable energy and certifying its production, taking into account environmental requirements, including the special protection of biodiversity and forest resources.

As a result of the implementation of the RED II provisions into national law, Poland has amended the Renewable Energy Sources Act (the so-called RES Act). The legislative changes included, among other things, the abolition of the obligation to obtain a building permit for photovoltaic installations with a capacity of up to 150 kW (previously the limit was 50 kW), as well as the introduction of provisions defining biomethane and formalizing the functioning of energy clusters as local prosumer structures. In addition, a National Contact Point for Renewable Energy Sources was established to simplify administrative procedures for entities investing in the renewable energy sector. These measures resulted in a dynamic increase in installed capacity in RES - according to data from the end of June 2023, the total capacity of renewable energy installations in Poland reached 25 GW, which corresponded to approximately 40% of the total installed capacity in the national power system [56].

Directive (EU) 2023/2413 of the European Parliament and of the Council, known as RED III, is the third iteration of the EU policy regulating the development of RES. It was adopted in October 2023 as part of the implementation of the European Green Deal objectives. This amendment tightens existing climate and energy requirements, introducing more ambitious targets for the share of renewable energy and strengthening criteria for the sustainable use of natural resources. RED III sets a new EU-wide target of at least 40% of RES in gross final energy consumption by 2030. In addition, the directive sets more restrictive conditions for the use of biofuels and bioliquids - a minimum 65% reduction in GHG emissions compared to fossil fuels is now required [49].

Although Poland expressed its opposition to RED III during legislative work at the EU Council, citing concerns about the pace of energy transition and the dominant role of coal in the national energy mix, the directive came into force on May 21, 2025. Therefore, on the 27^{th} of May, 2025, the Polish Council of Ministers adopted a draft energy-sector deregulatory law (UDER29), raising the licensing threshold for RES installations from 1 MW to 5 MW, enabling smaller projects to use streamlined registration instead of full licensing. As a response to the problems arising so far, hydrogen was defined as “another type of combustible gas” and regulated only in the case of its distribution via the gas network, while in other respects it was regulated by the Energy Act, this Act has been changed. The amendment to the Energy Law was passed on November 21, 2024, and came into force on January 20, 2025. Under this amendment, hydrogen was formally recognized as a separate type of fuel, alongside solid, liquid, and gaseous fuels. Three categories of hydrogen were also introduced: low-emission, renewable, and renewable non-biological origin (RFNBO). The Act also defines new concepts that are key to the hydrogen market, such as hydrogen transmission network, distribution network, hydrogen system, hydrogen storage, and specifies the roles of operators (transmission, distribution, storage, interconnected networks). Simplifications have been introduced, among others, in construction law, allowing, for example, notification instead of a permit for hydrogen networks up to 0.5 MPa and electrolysers up to 10 MW. The new regulations also introduce the obligation to obtain a license for activities related to the trade and storage of hydrogen up to specified capacity limits, with a deadline for applications of July 20, 2025.

Additionally, Poland is working on a national legislative package on the hydrogen economy, referred to as the Hydrogen Act. It is a colloquial, non-standard name for a set of legal regulations concerning hydrogen, mainly those introduced by the amendment to the Energy Law and related regulations (e.g., construction and environmental regulations). The act will accelerate the development of the hydrogen economy in Poland, where its estimated added value is as high as EUR 870 million in 2040. As the 3rd largest producer of hydrogen in Europe and the 5th largest in the world, Poland has the potential to become an important link in the European hydrogen value chain in the coming years and an attractive destination for investors interested in zero-emission technologies [57].

The National Recovery Plan will also play a significant role in achieving the RED III targets, with approximately €640 million earmarked to support investments in hydrogen technologies, including the development of electrolysers, the expansion of the transmission network, and the implementation of solutions for heavy industry. Despite structural challenges related to the dominance of fossil fuels (coal still accounts for approximately 57% of the energy mix), Poland is seeing record growth in the share of RES in the electricity sector. In 2024, RES accounted for 28.8% of electricity production, which is a significant step towards the EU's climate targets. The photovoltaic and wind energy segments are showing particularly dynamic growth. The implementation of RED III may markedly accelerate investments in modern energy sources, the modernization of the national transmission infrastructure, and the development of private energy initiatives, such as long-term Power Purchase Agreements (PPAs).

SUPPORT INSTRUMENTS FOR THE DEVELOPMENT OF THE HYDROGEN ECONOMY

Qualification of Support Instruments

The Polish government has introduced several financial instruments aimed at supporting the development of the hydrogen economy, especially in the areas of hydrogen production, storage, and transport. These instruments primarily target medium- and large-scale projects with defined technological thresholds. The main support programs are financed from both national and European funds:

1) Strategic Investment Program: Projects eligible for support must involve hydrogen installations with a capacity of at least 20 MW. However, it includes additional support for entrepreneurs to modernize and reduce emissions in their companies. Due to this, there is support for low-emission transport such as hydrogen cars or bikes. Among the others, one of the purposes of the program is the transformation of the Polish hydrogen economy by building RFNBO hydrogen production and low-emission hydrogen production facilities in Poland with a total capacity of at least 315 MW.
2) Modernisation Fund: Funding is available for investments involving installations of minimum 1 MW. Support will be provided in the energy sector, industry, buildings, and transportation, as well as in the area of replacing coal-based electricity generation with less carbon-intensive fuels. It therefore considers the implementation of alternative methods of energy production, which include hydrogen and its synthetic derivatives. Under the Modernization Fund, support will be provided for investment projects in the areas of electricity generation from renewable sources, modernization of energy networks, and energy efficiency in the energy sector, industry, buildings, and transport, as well as in the area of replacing coal-based electricity generation with less carbon-intensive fuels.
3) Innovation Fund: Auction-based support targets entities with hydrogen production projects of at least 5 MW capacity. The fund is financed by revenues from the auctioning of allowances under the EU Emissions Trading System and could amount to around €10 billion, depending on the price of CO2 emissions.
4) Other National Centre for Research and Development (NCBR, pl. Nardowe Centrum Badań i Rozwoju) programs funded or co-funded by the Polish Government or European Union: e.g., Swiss-Polish fund, Feng program, Polish-Taiwan fund, Neon, IPCEI (Important Projects of Common European Interest)

5) Horizon Europe – funds can be used to support research, innovation, and demonstration projects aimed at integrating hydrogen into the power sector. The funding facilitates collaboration on developing new hydrogen production methods, storage, and distribution infrastructure, as well as deploying pilot projects to showcase hydrogen's role in decarbonizing electricity generation. By participating in Horizon Europe calls, Polish organizations can access financial resources, foster international partnerships, and accelerate the adoption of green hydrogen solutions in the energy transition.
6) Alternative Fuels Infrastructure Facility. The qualification of support instruments centers on a blend of EU grant funding and leveraged financing; while hydrogen refuelling infrastructure is explicitly eligible, applicants must demonstrate readiness and financial backing to ensure implementation and impact. In 2025, an update to the call notably clarified eligibility for hydrogen (and ammonia/methanol) refuelling infrastructure for maritime and inland waterway vessels, reinforcing AFIF's alignment with broader clean-fuel strategies
7) Regional Operational Programmes (pol. Regionalne Programy Operacyjne) – Eco-Energy Loan Program (pol. Ekoenergetyczna pożyczka) implemented in the Wielkopolska Province voivodeship. It is a financial instrument that targets investments that contribute to a low-emission economy—this includes hydrogen technologies such as hydrogen production, storage, transport, or usage ("Hydrogen Direction" initiative). Projects must align with environmental sustainability goals and energy efficiency improvements.

Level of Subsidizing/Funding

Strategic Investment Program as a part of the National Recovery Plan (KPO, pl. Krajowy Program Odbudowy) is focused on the reduction of greenhouse gas emissions, including carbon dioxide (CO2) into the atmosphere and reduction of emissions, primarily in sectors that are difficult to decarbonize, such as industry and transport, by implementing building RFNBO hydrogen production and low-emission hydrogen production facilities in Poland.

Funding details:

- Budget: €640 million distributed by BGK (pl. Bank Gospodarstwa Krajowego), EU funds
- Support type: Non-repayable grants, funds are allocated as direct grants for large-scale, strategic projects with high potential for impact on the national hydrogen infrastructure
- Focus: investments in hydrogen technologies, hydrogen production, storage, and transport.

Modernisation Fund (pl. Fundusz Modernizacyjny) - founding entity National Fund for Environmental Protection and Water Management (NFOŚiGW pl. Narodowy Fundusz Ochrony Środowiska i Gruntów Wodnych):

- Budget: Approx. PLN 5 billion
- Support type: Grants for investment projects, support targeting smaller-scale projects and encouraging business sector participation
- Focus: the production and use of electricity from renewable sources, including renewable hydrogen, heating and cooling using renewable energy sources; reducing overall energy consumption through energy efficiency, including in industry, transport, construction, agriculture, and waste management; energy storage and modernization of energy networks, including demand management, pipelines belonging to local heating systems,

electricity transmission networks, and increasing interconnections between Member States and expanding infrastructure for zero-emission mobility; support for low-income households, including in rural areas and remote regions, to address energy poverty and upgrade their heating systems.

Innovation Fund (pl. Fundusz Innowacyjny) – founding entity CINEA (European Climate, Infrastructure and Environment Executive Agency), Polish responsible unit NCBR (pl. Narodowe Centrum Badań i Rozwoju):

- Budget: €1.2 billion
- Support type: non-repayable grants up to 60% of eligible project costs for large-scale, small-scale (CAPEX < €7.5 million) Pilot and pre-commercial projects. Grants are distributed in stages.
- Focus: Support for cost-efficient and innovative technologies

Alternative Fuels Infrastructure Facility – The AFIF is a rolling call for proposals under the EU's Connecting Europe Facility (2021–2027), launched on 29 February 2024, with three submission deadlines—24 September 2024, 11 June 2025, and 4 March 2026—aimed at promoting deployment of alternative fuels infrastructure across the TEN-T network, including hydrogen refuelling stations

- Budget: €1.0 billion - €780 million under the general envelope and €220 million under the cohesion envelope
- Support type: EU contributes a percentage of total eligible costs—up to 50%, and occasionally up to 70% in outermost regions
- Focus: It targets hydrogen refuelling stations for road transport (including heavy-duty vehicles), ensuring alignment with the EU's AFIR regulation. It also supports hydrogen supply infrastructure for airports and for maritime and inland waterway vessels, complementing broader goals under ReFuelEU Aviation and FuelEU Maritime.

Regional Operational Programmes (pol. Regionalne Programy Operacyjne) – it is a program that defines the development strategy for a given region, financed by the European Union under its cohesion policy.

- Budget: €12 632 000 PLN
- Support type: Loan up to PLN 1 200 000 for micro, small, and medium-sized enterprises
- Focus: Targets investments in a low-emission economy—this includes hydrogen technologies such as hydrogen production, storage, transport, or usage.

The expected level of subsidizing and funding from various programs in Poland for hydrogen projects generally ranges from 50% to 70% of eligible costs, depending on the specific program, project scope, and innovation level. Programs such as NCBR and Horizon Europe are more focused on development and require work in consortia. They support not only entrepreneurs but also scientific institutions. However, the Strategic Investment Program, Innovation Fund, and the Modernisation Fund typically offer grants that can cover a significant portion of investments in hydrogen production, storage, and infrastructure, aimed at reducing emissions in hard-to-decarbonize sectors. Support levels may vary based on project size and technological advancements, with larger or more innovative projects potentially receiving higher support rates. The Innovation Fund's support is more variable, as it is tied to competitive auctions based on hydrogen production costs, often favoring the most cost-efficient and cutting-edge technologies. Overall, Polish entities can expect substantial financial assistance to promote hydrogen development, significantly lowering the financial barriers associated with large-scale deployment. This support aims to accelerate the energy transition, enhance energy security, and promote sustainable industry growth in Poland.

HYDROGEN ECONOMY DEVELOPMENT SCENARIOS AND RECOMMENDATION

Economic and regulatory aspects

The coming decade will bring profound changes across the energy, transport, and industrial sectors, driven primarily by regulatory pressure, cost dynamics, and infrastructure constraints. Increasing stringency of EU climate policies, notably the EU Emissions Trading System (EU ETS) and the Carbon Border Adjustment Mechanism (CBAM), will systematically raise the cost of grey hydrogen and other carbon-intensive products. This will effectively force industrial players to initiate and accelerate their transition toward low- and zero-emission alternatives, even in the absence of short-term cost competitiveness.

Despite this pressure, the cost gap between renewable hydrogen (including RFNBOs) and conventional hydrogen is expected to remain substantial until at least 2035, unless a rapid and sustained decline in renewable electricity costs materializes [12]. Similar dynamics apply to downstream products such as green ammonia or green steel, where the price differential compared to “grey” alternatives is likely to persist until around 2040, unless hydrogen production costs fall significantly and carbon prices increase faster than currently anticipated. As a result, market uptake will depend less on pure economics and more on targeted policy intervention and structural advantages.

Key enablers of early RFNBO commercialization include access to low-cost renewable energy, dedicated support schemes for RFNBOs, direct power lines connecting generation with electrolysis, and relief from network charges. These conditions are most likely to be met first in sectors with concentrated demand and limited substitution options, such as refineries, the chemical industry (particularly ammonia and methanol production), and segments of road transport, especially collective and long-distance applications. In these areas, hydrogen can be integrated at scale, allowing learning effects and partial cost reductions.

It is being assumed that the sectors currently using grey hydrogen (including chemical and refinery plants) will be the first sectors in Poland to use RFNBO fuels in the economy. This assumption is confirmed by the fact of construction of large-scale pilot projects. Following sectors for transformation are ferrous and non-ferrous metallurgy, as well as petrochemicals. However significant changes in technological processes and relatively high CAPEX/OPEX expenditures will be required.

Commercial application of RFNBO in the energy sector may occur in particular in the model of decarbonization of gas units (and later also in the model of using hydrogen as seasonal/large-scale storage for the purposes of grid/industrial balancing (Power to X).

In transport three main groups are being distinguished. The light road transport is predisposed to be the first in terms of usage of RFNBO. However, the potential competition with battery drives may hinder the development. The bus sector, railways (non-electrified routes), and possibly selected commercial vehicles (e.g., long-distance trucks) are following sectors. After 2030-35, commercialization of RFNBO use in maritime and aviation transport should occur (mainly in the form of synthetic hydrocarbon fuels, e-fuels).

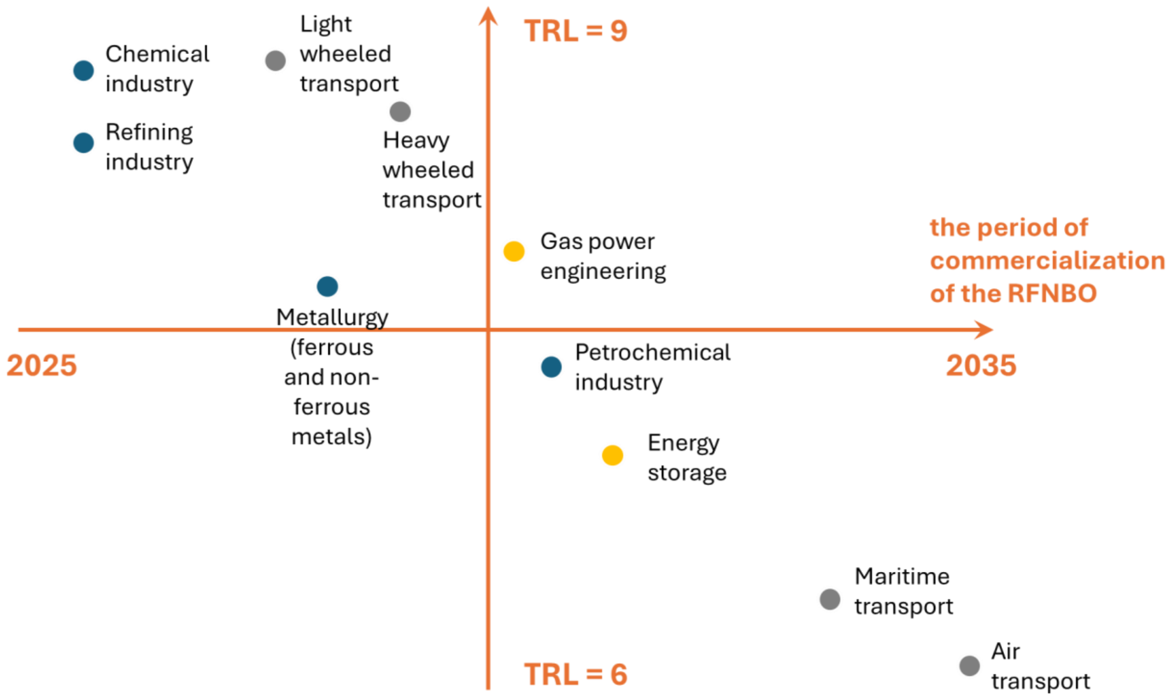

Figure 4 TRL and commercialization periods of RFNBO applications – sector comparison [12]

From a demand perspective, regulatory frameworks such as RED III, AFIR, and ReFuelEU will act as the primary drivers for hydrogen and hydrogen-derived fuels in both transport and energy. Their effectiveness, however, will depend on the speed and coherence with which national strategies and implementing measures are adapted. Delays or regulatory uncertainty could significantly slow investment decisions and infrastructure development.

Infrastructure remains a critical bottleneck, particularly hydrogen storage. Large-scale storage options are limited, with salt caverns emerging as the most cost-effective solution due to their high capacity and relatively low unit costs, while pressurized tanks will play a complementary role for smaller and more decentralized applications. Liquid hydrogen and hydrogen carriers such as ammonia or methanol involve high costs and energy losses related to liquefaction and reconversion, and should therefore be used primarily in maritime transport, where alternatives are scarce.

For hydrogen transport, pipelines offer the most economical solution for large volumes over short distances, but the technical potential for retrofitting existing gas networks is constrained. Imports of hydrogen or its derivatives will require substantial investment in port infrastructure and dedicated support mechanisms, such as auction-based models similar to H2Global. Ultimately, one of the most critical challenges may be last-mile distribution: delivering hydrogen reliably to end users will require the development of local hydrogen hubs and valleys that integrate production, storage, transport, and consumption within coherent regional ecosystems.

Recommendations

The development of a competitive hydrogen economy in Poland will depend to a large extent on the timely deployment of production and storage solutions supported by coherent regulatory and financial frameworks. In the area of hydrogen production, a key conclusion is the urgent need to launch a dedicated support system for renewable hydrogen and its derivatives, in particular RFNBOs. Without targeted support mechanisms, renewable hydrogen production will remain economically uncompetitive compared to conventional alternatives, significantly slowing down market uptake and investment decisions. A stable and predictable support framework would reduce investor risk, enable project bankability, and create the conditions necessary for scaling up domestic hydrogen production.

Equally important is enabling the realization of industrial-scale renewable energy investments connected through direct lines to hydrogen production facilities. Direct connections between renewable electricity sources and electrolyzers represent one of the most critical enablers of cost-effective hydrogen production, as they reduce exposure to network charges, congestion risks, and regulatory uncertainty related to grid access. Facilitating such solutions should be treated as a strategic priority for the development of the hydrogen economy in Poland, as it directly links the expansion of renewable energy capacity with industrial decarbonization and strengthens energy security. In addition, an in-depth analysis of potential reductions or exemptions in regulatory and network fees for hydrogen producers is recommended. Even partial relief from these charges could materially lower the levelized cost of hydrogen, improving competitiveness and accelerating early-stage deployment.

In the field of hydrogen storage, economic considerations clearly indicate that gaseous storage technologies—namely salt caverns and pressurized tanks—offer the lowest unit costs (LCHS), while storage in chemical carriers such as ammonia or methanol is associated with the highest costs. These higher costs stem mainly from the substantial energy required for dehydrogenation, and they increase significantly with longer storage durations. As a result, the economic viability of certain technologies is limited in seasonal storage applications. Among the most mature solutions, long-term storage in salt caverns emerges as the most cost-effective option, particularly when considering Poland's favorable geological potential. In this context, the development of pilot projects and targeted programs for hydrogen storage in depleted gas fields would also be beneficial, as it could prepare these assets for large-scale seasonal storage in the future.

A key recommendation is to align storage technologies with their specific role in the energy system. Expensive carriers such as ammonia and methanol should be avoided in seasonal storage applications. At present, the hydrogen storage market remains at an early stage of development, characterized by high demand uncertainty and a relatively low share of projects reaching final investment decisions. This lack of market maturity acts as a significant barrier to investment and underscores the need for public support, risk-sharing instruments, and clear long-term signals regarding the role of hydrogen in the energy system.

Storage infrastructure can also play a strategic role in supporting hydrogen imports, particularly in scenarios where salt caverns are located close to coastal areas and ports. Such configurations could enhance supply security and flexibility while enabling integration with international hydrogen supply chains. Looking ahead, hydrogen storage costs are expected to decline toward 2050, although the pace of cost reduction will vary significantly across technologies. Policymaking and investment strategies should therefore remain adaptive, prioritizing scalable and cost-effective solutions while maintaining technological optionality to respond to future market and system needs.

Scenarios

Due to the dynamically changing economic and geopolitical environment, the development of scenarios for the development of a hydrogen economy in Poland focused on two economic sectors that are obliged to transform first due to legal regulations: the industrial and transport. According to publicly available data, Poland produces approximately 1 million tons of hydrogen annually [18]. The calculation of the required amount of hydrogen production was carried out in accordance with the objectives of the RED III Directive and the REFuelEU Aviation Regulation:

- the share of RFNBO in the hydrogen used in industry should be at least 42% in 2030 (Article 22a of RED III),
- a 1% share of RFNBO in the final energy consumption of transport in 2030 (Article 25 of RED III),
- a 1.2% share of RFNBO in the final energy consumption of maritime transport by 2030 (Article 25 of RED III),
- a 0.7% share of synthetic aviation fuels in the final fuel consumption of air transport in 2030 (REFuelEU Aviation).

According to the calculations, achieving the RFNBO industrial target (Article 22a of RED III) will require the production and use of between 161 kt (minimum scenario) and 192 kt (maximum scenario) of RFNBO hydrogen in both existing and new industrial sectors. The fertilizer sector (ammonia) will play a leading role (or bear the greatest burden) in achieving the RFNBO industrial target. Most of the RFNBO transport target in Poland can be achieved at the refinery level, where the hydrogen will be used in conventional fuel/biofuel production processes, rather than as a fuel for zero-emission hydrogen vehicles. The minimum and maximum scenarios assume hydrogen use at levels between 39.7 kt and 36.7 kt.

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