

Research Article

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Difficulties Predicting Green Hydrogen Growth

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ABSTRACT

Very little green hydrogen is manufactured and utilized globally, making it difficult to predict the growth of low-carbon-hydrogen energy by 2030, or worse 2050. Most hydrogen in 2026 is not green yet is vital in oil refineries and other chemical factories but failing to reach consumers in the wider world. This paper explores the reasons for this problem, analyzing how some nations are progressing more rapidly than others to provide green hydrogen in new applications. For example, Asian countries have committed to hydrogen transport so are advancing faster than Western countries, where investments are susceptible to misinformation from America in recent years. A key issue is that many projects in the west are announced several years ahead of the investor funds, which fail to arrive more often than not. China differs in announcing most projects after the money is ready, making supply and demand of Green Hydrogen (GH) more stable. Most projects at present are linked to renewable electricity, depending on GH costs plus demand for ammonia, e-fuels, or heat in glass and ceramic industries, where profits and losses vary significantly. But inventions in economic electrolyzers have now proved that many innovative applications might be achieved by growing GH because of its energy storage advantages in the near future, producing a symbiotic connection between Solar power, Wind turbines and Hydrogen energy.

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Abbreviations

The following abbreviations are used in this manuscript:

GH: Green Hydrogen
Mtons: Million tons
MW: MegaWatts
GW: Giga Watts
MWh: MegaWatt hours
TWh/a: Tera Watt hours per year
Mt/a: Million tons per year
FID: Final Investment Decision
UK: United Kingdom
GWh: Giga Watt hours
£/MWh: Pounds per Mega Watt hour
HAR: Hydrogen Allocation Round

Introduction

This year 2026, an interesting diversity in Green Hydrogen (GH) technology has been defined through several sources [1-5]. More than 70 countries have expressed interest in green hydrogen projects, but only 7 countries are actually producing green hydrogen above Mega-Watt (MW) level approaching GW (Giga-Watts), while more than 60 projects out of 300 have been cancelled since 2024, losing 4.9Mtons of GH in 2025 alone.

China, Australia, Estonia, Germany, South Africa, UK and USA are 7 countries manufacturing green hydrogen at Giga-Watt (GW) scale. The 70 countries that are predicting significant green

hydrogen production by 2030 are not listed, and there is little certainty that they will reach the GW level of hydrogen production stated. During late 2024, it became clear that 70 nations had been planning more than 1500 hydrogen projects, though the final investment decisions (FIDs) had not all been confirmed [6].

The difficulty is that 2025 saw an international drop in enthusiasm for installing electrolyzers by 2030 while cutting predictions of Green Hydrogen production figures for 2030 as shown in Figure 1[7].

The purpose of this research is to define the reasons behind this sudden negative feeling about hydrogen, then to focus on the key advances that will make the Green Hydrogen prospect rise again through 2030 to 2050.

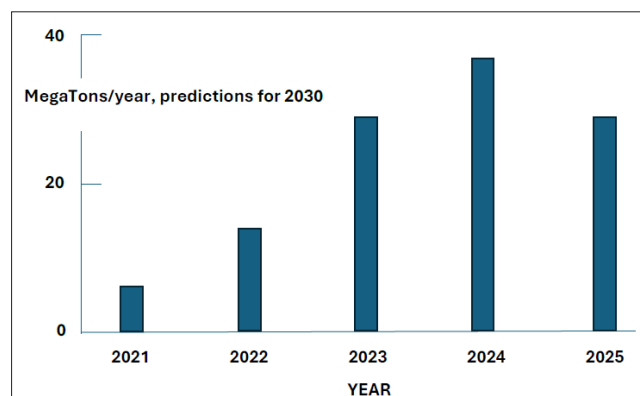


Figure 1: Green Hydrogen production by 2030, Announced Each Year, Dropped in 2025

A particular example of this 2025 pushback was evident in United Kingdom (UK) when the Climate Change Committee in Westminster UK announced that hydrogen transport was now chopped since lithium battery electric vehicles were viewed as more efficient. Consequently, several UK companies introducing hydrogen trucks went bankrupt, while major installations of 3 hydrogen refuelling stations on the M4 motorway were cancelled, and hydrogen buses were replaced by battery vehicles in Aberdeen and Birmingham [8].

The concept of 'Electric vehicle (EV) efficiency' was much used in the 7th Report from Westminster in 2025 but has long been shown to be false because vehicles essentially have zero efficiency, since all the fuel energy ends up as heat. The standard definition for comparing vehicle performance is a range test where the energy used to drive a certain distance is plotted against the weight of the vehicle. Efficiency is the the wrong description of this standard [9,10].

A second example is the cutting of hydrogen projects in USA during 2025 as the new President deleted federal funds for a range of GH applications. While China, India, Saudi Arabia and United Arab Emirates were pumping \$billions into hydrogen, President Trump was cutting \$7.5 billion by slashing clean energy projects approved by the previous president. Much concern has emerged in the USA as these hydrogen projects have died, though renewable energy infrastructure has continued to rise across America as the individual states recognise the importance of wind and solar. China power in reducing global warming. This paper examines the spread of GH speculations, then defines more reliable forecasts that are based on proven profitable innovations instead [11,12].

Background

This year 2026 will be remembered for two landmarks: First, total global hydrogen production based on fossil fuels has reached 100Mt/a; Second, GH production worldwide has risen past 1Mt/a, rising exponentially, and predicted to overtake fossil hydrogen by 2045, though pessimism is now becoming visible. Predictions are delicate because USA, UK and other nations have reduced their 2022 decarbonization ambitions, while the once popular idea of Carbon Capture, Utilization and Storage (CCUS) has been dropped by the major fossil fuel companies which have reverted to natural gas making higher profits.

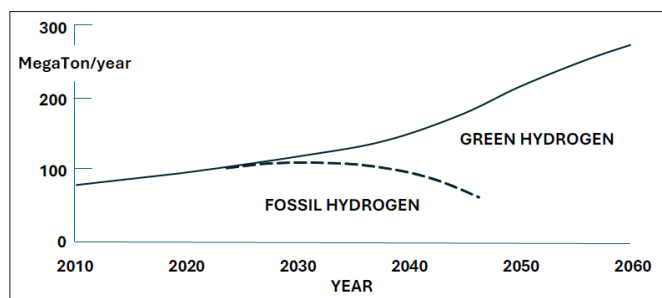


Figure 2: Present Prediction of Changes in Global Production of Hydrogen, Combining Fossil and Green [13].

Despite this present blip in confidence, the target for 100Mt/a of GH remains near 2050 with CAPEX investments expected around \$3trillion in that period. Figure 2 shows a typical growth space for green hydrogen, slower than expected 5 years ago, but reaching 100Mt/a as predicted previously [13]. The main problem has been the cutting of the \$8bn hydrogen hubs in USA since Donald Trump took over in 2025. Just as UK decided to stop hydrogen vehicles, killing a major innovation built in Britain

since 2000, Americans folded numerous GH projects around USA [11,12]. Thus, China moved further ahead as the GH leading nation, while Italy and Brazil began to order electrolysis systems from Asia. Fortunately, UK has ITM Power as a major electrolyzer manufacturer with two giga factories growing in Sheffield, so that the planned supply of renewable energy can be utilized to make GH in Britain. A typical advance by Envision Energy [13] was the certification of the huge 500MW inner Mongolian Chifeng factory using green hydrogen to manufacture green ammonia at 300,000t/a industrial scale, with full volume expected in 2026. For comparison, NEOM in Saudi Arabia expects its 1Mt/a ammonia plant to be running by 2027. In both projects, the largest on the planet, the green electricity infrastructure required is dependent on renewable energy installations, as shown in section 3, together with the GH price being sufficiently low in section 4, to incentivize demand in substantial applications described in section 5.

Renewable Electricity in Leading Nations

Table 1 shows that renewables accounted for a third of global electric generation in 2025, mainly hydro, wind and solar. China is the leading nation by far with 37% of world capacity for green electricity on the supply side, still rapidly expanding its solar and wind manufacturing. Only 4 of the world's present major GH producers appear in this table, suggesting that the need for hydrogen is not widely accepted, possibly because the demand for products is low and electrolyzer supply is limited [14].

This growth of renewable electric energy is the first criterion, followed by the price of GH in various countries, then profit-making products on the demand side, without which investment decisions fail, as shown in the next sections.

Table 1: Renewable Electricity Capacity in TWh/a for 12 Leading Countries in 2025 [14].

COUNTRY	RENEWABLES	HYDRO	WIND	SOLAR
China	3913	1396	1135	1175
USA	1159	242	464	389
Brazil	650	389	118	89
India	501	178	104	196
Canada	417	345	51	10
Germany	296	20	136	90
Japan	243	74	13	101
Russia	207	200	4	3
Spain	161	33	59	63
Norway	159	145	14	1
Turkey	153	57	39	37
UK	152	6	86	19

Figure 3: shows that china has overtaken EU since 2020, rising to almost 2TW capacity in solar and wind by 2025, by far the largest renewable electricity infrastructure. Meanwhile, USA has doubled its renewables from 2020 to 2025, similar to Brazil and Japan, ahead of Spain, Germany and UK. The most impressive feature of China policy is the doubling of renewable resources every 3 years whereas UK has been doubling every 8 years. However, this British renewable infrastructure has now been accelerated to double by 2030, so should soon begin to compete with the China progress. Clearly, China has decided to replace its huge coal-fired energy power stations with mainly solar by 2060. UK in contrast is focusing on offshore wind as the best source of cheap renewable electricity, utilizing the North Sea as the extensive area required

years [15].

Converting this green electricity into GH is an urgent requirement now as recognition of numerous hydrogen applications is accepted by policy makers. In the Prime Minister in Britain decided that £1 billion would be applied to producing 10GW of hydrogen by 2030, sufficient to replace all the fossil hydrogen now produced in British refineries. In 2026. The idea was to this prediction looks weak because the tens of projects subsidized by the government have not been as successful as planned. Also, the CCUS (carbon capture) 5GW has been dropped and is unlikely to be replaced by GH since prices in UK are not as low as the fossil competition.

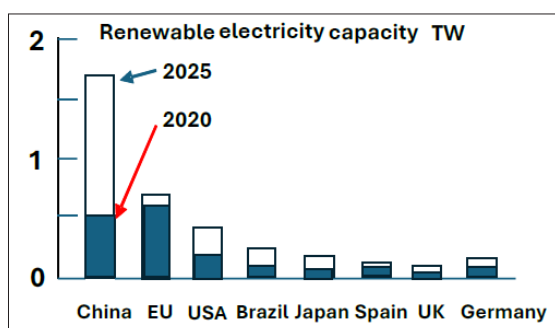


Figure 3: Growth of Renewable Energy Capacity from 2020 to 2025 in Leading Countries

Present pricing of Green Hydrogen

A major worry is the price of GH which varies widely around the planet, depending on the cost of making renewable electricity and converting it to hydrogen by electrolyzing water. The price also depends markedly on the application. Four major snags are obvious but vary from nation to nation: a) Present GH price (Figure 4) is between \$2.5 and \$7.0 per kg, much higher than the cost of fossil hydrogen which can be as low as \$1.5/kg; b) Electrolyzer costs are still high because mass production is not yet here; c) Thermodynamic cost because 20% heat losses are typical during electrolysis while making ammonia adds an extra 11% penalty; d) WACC (Weighted Average Cost of Capital) which affects every company finance.

Two UK examples of high retail prices for GH illustrate some difficulties. The 2024 retail price of filling a hydrogen car in Birmingham UK rose from £12/kg to £23/kg whereas the China price is near £4/kg due to subsidies, which can then compete with fossil fuels depending on taxes and carbon penalties. A similar surge in the hydrogen price around Los Angeles happened in 2024 when it more than doubled to near \$35/kg. Such a gap in GH prices must be avoided or buyers will vanish [16].

Another typical UK example is retail price for GH used to generate heat and power replacing diesel generators with hydrogen gensets. The company GeoPura has daily numbers, two levels: one for GH around £38/kg and another for Low Carbon Hydrogen near £20/kg. These prices look rather high except in niche areas like TV filming or music festivals but are meant to compete with diesel generators while cutting emissions to zero [17].

Contrasting with these high numbers are the prices of GH in regions where the renewable electricity is cheap, around \$2/kg which was the target figure in future for the USA. Such prices are essential if ammonia is to be made from GH and shipped to compete with fossil fertilizers. Only by resolving these cost and price differences across nations will the global picture make sense. UK is difficult because it has the highest prices globally

for Grid Electricity, typically approaching £400/MWh that cannot compete with Saudi or Nigeria at a factor 15 times less. This cost of renewable electricity then is paramount, best from hydro power used in Norway and second-best with solar + wind, commended by NEOM in Saudi Arabia [18].

A graph of global GH prices for 2026 is in Figure 4.

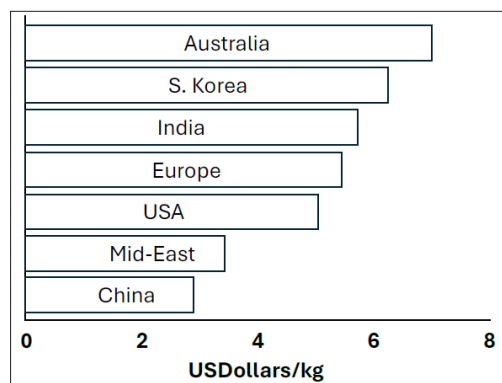


Figure 4: Range of 2026 Green Hydrogen prices world-wide, Sources: IRENA, IEEFA, Dristi IAS, NREL

Products requiring Green Hydrogen demand

GH continues to be interesting because numerous novel applications are plausible, leading to massive change-over from current fossil hydrogen, which is utilised largely on refineries. GH is now moving to ammonia or methanol production, e-fuels for aviation sustainability, adding to gas pipelines that heat most buildings in winter across the globe, heating glass or ceramics, creating new processes for steel or cement, powering buses, trucks and aircraft, replacing diesel generators with zero emission, and storing energy in pipes, lightweight cylinders or salt caverns. Britain is an interesting example of the issues caused by this range of possibilities Eleven projects took 5 years to get moving in Hydrogen Allocation Round (HAR) 1, followed by 27 in HAR 2, possibly with more in round 3. But it has taken 6 years to approach 1GW of GH, well below 10GW the original 2030 UK target. UK hydrogen transport was killed in 2025 by Westminster, contrasting with China which regards transport as the most significant application to cut carbon emissions from taxis, buses and trucks.

An unexpected delay in China was the large GH plant operating at 0.26GW at the Kuqa plant run by Sinopec, the Chinese state-owned petroleum and chemicals company, the biggest global project planned to start production in 2023 but only now running in 2026. The idea was to install 3 alkaline electrolyzers from different suppliers, using mainly solar power to drive water electrolysis. The problem was that the solar power dropped in voltage so much that hydrogen crossed the diaphragm to mix with oxygen, potentially causing an explosive situation. The answer was to switch off the electrolyzers when the voltage was too low, causing an 80% drop in product output, making the project uneconomic for 3 years [19].

Five failures to achieve FID are illustrated in Figure 5. The Australian project BP-AREH is the largest GH project ever to be cancelled because local 26GW renewable electricity was too expensive and the ammonia produced could not be shipped profitably in 2025. In the same month of July 2025, another smaller Australian project at 2.9GW was dropped when the desired \$1bn investment was rejected by the government [20].

Earlier, in Norway during September 2024, the Shell-Aukra project was dumped because the off-takers were insufficient and the EU pipeline infrastructure was not satisfactory, cutting the planned 2.5GW of hydrogen production. Air Products had a similar failure in November 2024 because off-takers were lacking and capital costs had risen too far. Plug power in New York was much smaller at 80 tons per day of GH in early 2023 but failed because loan conditions were not acceptable.

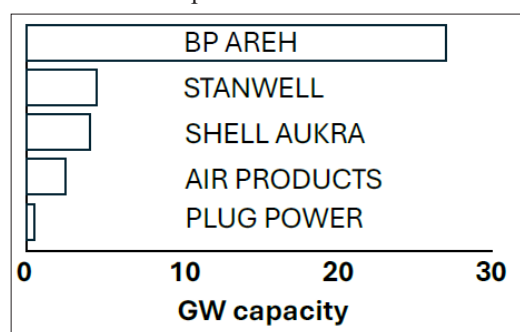


Figure 5: Five large GH Projects that Failed to Reach the Final Investment Decision (FID)

Seven smaller projects also failed in 2025 because the EU Hydrogen auction with a £1bn fund could not support the low finance offers around £0.4/kg, too low to interest the off-takers required to join the 1.88GW of projects out of 2.33GW total.

The remarkable conclusion was that 520GW of projects were proposed worldwide but only about 5% reached the final investment decision (FID) point needed for success. This very poor acceptance rate is the main reason explaining Figure 1 that illustrates how unpredictable the Western investors are when compared with Asian. More discretion in announcing premature projects is required.

Such discretion has been observed in the UK Green Village innovation which started during 2023 but has yet to be defined in terms of investments. Similarly, the production of salt caverns for UK storage of GH at scale has been significant for 3 years but held back by the companies involved [21].

Innovative Green Hydrogen Applications

An obvious need for green hydrogen in Scotland is the present wastage of renewable wind power because the National Grid cannot often accept the huge amounts of electrical wind-power generated. Refusal of Scottish wind electricity by the Grid in 2025 cost around £350million with added cost over £1billion to bring in natural gas generators instead. From April 2025 to February 2026, Britain lost £1.8billion as the Grid network had to be balanced across the country, while lacking energy storage capacity [22].

To cut this renewable energy curtailment, Kintore Green Hydrogen project has received planning permission in Aberdeenshire, installing a 3GW plant converting excess wind power to green hydrogen, funded by the government department DESNZ (Department for Energy Security and Net Zero) aiming for full deliver by 2030 with the company Worley, supplying 200,000 tons of green hydrogen per year. The project shown in Figure 6 has been running since 2023 and is completing phase 1 at 500MW, resisting the hype of hydrogen premature publicity [23].

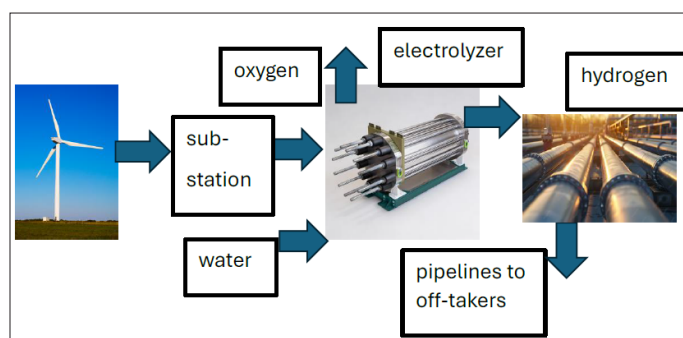


Figure 6: Schematic Plan of the Kintore GH Project, the Biggest in UK

Other smaller British green hydrogen projects include Eastington Humber with 1GW planned for commissioning in 2029 by Equinor and Centrica, and Stanlow Hydrogen project to be commissioned in 2027 by ESSAR Oil and Progressive Energy producing 0.35GW.

Another UK hydrogen project discussed since 2023 is progressing quietly and is also hoping to see delivery by 2030 depending on local renewable power around private wire sites that can cut energy bills by a big margin, including heating and transport as well as electricity. The message is that local power can beat the UK Grid on delivery and pricing, making very significant savings and profits. An ITM electrolyser at 5MW is installed to utilise excess 5MW wind and 10MW solar electricity while composite cylinders on trailers store the gas at pressures near 500 bar. Feeding the hydrogen gas into pipes that drive fuel cells can then produce Combined Heat and Power (CHP) when wind and sun go down. Shipping any surplus hydrogen product can also be beneficial to the energy market [24].

Looking ahead to 2040, as local UK energy at MW scale expands, it is plausible that 10,000 such sites, each with a wind turbine and large solar installation, could produce 50GW of new energy, far more than the 34GW produced by the whole UK National Grid in 2026. The estimated cost of such investment is £100 billion but the profits saved from the Grid will be an order of magnitude higher because UK Grid electricity is most expensive, while local green power is 3 times more economic.

Conclusions

The main conclusion is that the predictions of Green Hydrogen production from renewable electricity have dropped in 2025 and are likely to fall further in 2026, since the demand appears lower in transport, buildings, industries and city applications. Major exceptions are the application of hydrogen gas energy storage near offshore wind farms to save Grid curtailment, plus local energy from onshore wind/solar on private rural sites, and the production of new UK salt caverns for massive hydrogen energy stores around 100TWh.

A significant factor is the present price of green hydrogen in countries like UK, where typical costs are much larger than the £2/kg thought to be acceptable by 2050. Some off-takers have been satisfied as government subsidies have ensured, but major industries like steel, cement, ceramics, are not happy with the research needed and the financing required.

The UK government has succeeded in stopping coal used for energy and is looking to GH for new energy stores as the electricity grid becomes carbon-free in 2030 but failing in stored energy now. But There are two problems that are nowhere near fruition: First, the

idea that heat pumps can replace natural gas for heating buildings in winter has not been proved, while efforts to manufacture and install heat pumps is only 1% in UK; Second, UK's major fossil fuel combustion around 50% total energy emissions is due to petrol/diesel in vehicles, not yet declining as desired. Battery electric vehicles running on Grid Electricity are near 5% of the 40 million vehicles in current use and are slowing below the plan in 2026. 79% of UK major emissions issues remain to be proved by 2050 or sooner.

Three innovations in UK: Offshore wind curtailment; Green villages using onshore Wind/Solar/Green Hydrogen; and Salt caverns for GH energy storage have emerged over 3 years to be running by 2030-2035 These has been growing discreetly but now should become more public as the investments are revealed.

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