The green hydrogen revolution: hydropower's transformative role

May 2021

Summary

Interest in hydrogen has risen markedly over the last two years. Governments have announced national roadmaps and strategies to scale-up hydrogen, with increasing recognition of its potential to replace fossil fuels in 'hard-to-abate' areas of the economy, such as in heavy industry and transport. Green hydrogen (H_2), produced using decarbonised electricity and water through a process called electrolysis, is a particularly attractive option and set to grow significantly in the transition to a net-zero future.

As this paper will outline, ambitious growth in green H_2 will significantly increase global demand for clean electricity. Coupling green H_2 with renewable power offers strategic advantages, particularly in locations with access to readily available and low price hydro-electricity. Indeed hydropower has long been used to produce green H_2 with large-scale electrolyser plants operated in the 20th Century situated close to low cost hydroelectric generation. Looking ahead hydropower could play a pivotal role in supporting growth in green H_2, potentially supplying at least 1,000 TWh of the additional electricity demand required in IRENA's 2050 scenario. For even more ambitious scenarios that seek to limit the increase in global temperatures below 1.5°C, the likely demand on hydropower would be correspondingly greater. However, policy and regulatory frameworks must be updated to deploy hydrogen services and infrastructure at the scale now required. As set out in the concluding section, IHA calls on governments and industry to:

- Develop enabling policies and financial incentives to stimulate demand for green hydrogen, scale-up projects and reduce technology costs.
- Support decarbonisation of power grids, and establish global certification systems that credit green H_2 produced from clean electricity sources, including hydropower.
- Recognise and support the role of hydropower capacity, alongside other renewables, for green hydrogen production. A balanced portfolio leads to a more secure and sustainable energy mix, and helps ensure high utilisation factors for H_2 electrolysis plants.
- Create markets and policy frameworks that reward flexible electricity supply and demand on the grid.
- Scale-up investment into new renewable power capacity, as soon as possible, to progress grid decarbonisation and cost reductions for green H_2.

Contents

Background

H_2 is a clean, storable and versatile energy carrier with many possible end-uses. It can be used both as an industrial feedstock and an emission-free fuel source in heat, power and transport. This means it could replace fossil-fuels in so-called 'hard-to-abate' areas of the economy.

For example, H_2 can be used as a raw material to produce chemicals such as ammonia, and potentially in manufacturing other industrial products such as iron & steel. As an energy-dense gas, H_2 can also be burned without carbon emissions to produce high temperature heat for energy-intensive industrial processes, and in modified gas boilers for space heating. Furthermore H_2 can be used as a transport fuel, either directly in fuel cell electric vehicles or via conversion into sustainable liquid fuels for use in aviation and shipping. For much of these needs, H_2 could be the only practical low carbon substitute for fossil fuels, and as such will play a crucial role in decarbonising the global economy over the long term. [1,2,3]

As H_2 does not exist freely, it requires energy to extract from natural resources. There are a number of types, or 'colours', of H_2 depending on the method of production and associated CO_2 emissions (see table below).

Today hydrogen is already supplied in large quantities every year. According to the International Energy Agency (IEA), around 74 million tonnes of pure H_2 was produced in 2018, mainly for use in ammonia production and in oil refining.[2] Of this over 95% was sourced from natural gas and coal, resulting in the emission of around 830 million tonnes of CO_2, equivalent to around 2% of the global total emitted from fossil fuels.[3,4]

Hydrogen production types

Brown H_2	Gasification of coal
Grey H_2	Steam methane reforming (SMR) typically using natural gas. Other potential methane sources include petroleum fuels and biofuels.
Blue H_2	Steam methane reforming with carbon capture and storage (CCS). Typically up to 90% of CO_2 emissions can be captured in the process.
Green H_2	Electrolysis using water and electricity to extract H_2. If electricity is sourced from renewables, then the H_2 is effectively 'green'. *It takes approximately 50-55 kWh electricity to produce a kg of green H_2.

Note: Other types include 'Turquoise hydrogen' produced from thermal splitting of methane through pyrolysis, and 'Pink hydrogen' with electrolysis based on nuclear power. Alternative thermochemical routes for producing H_2 include partial oxidation and autothermal reforming. Gasification of biomass is another option, as well as more innovative biological routes under development. Source: Aurora Energy Research, IRENA[5].

The vision for green hydrogen

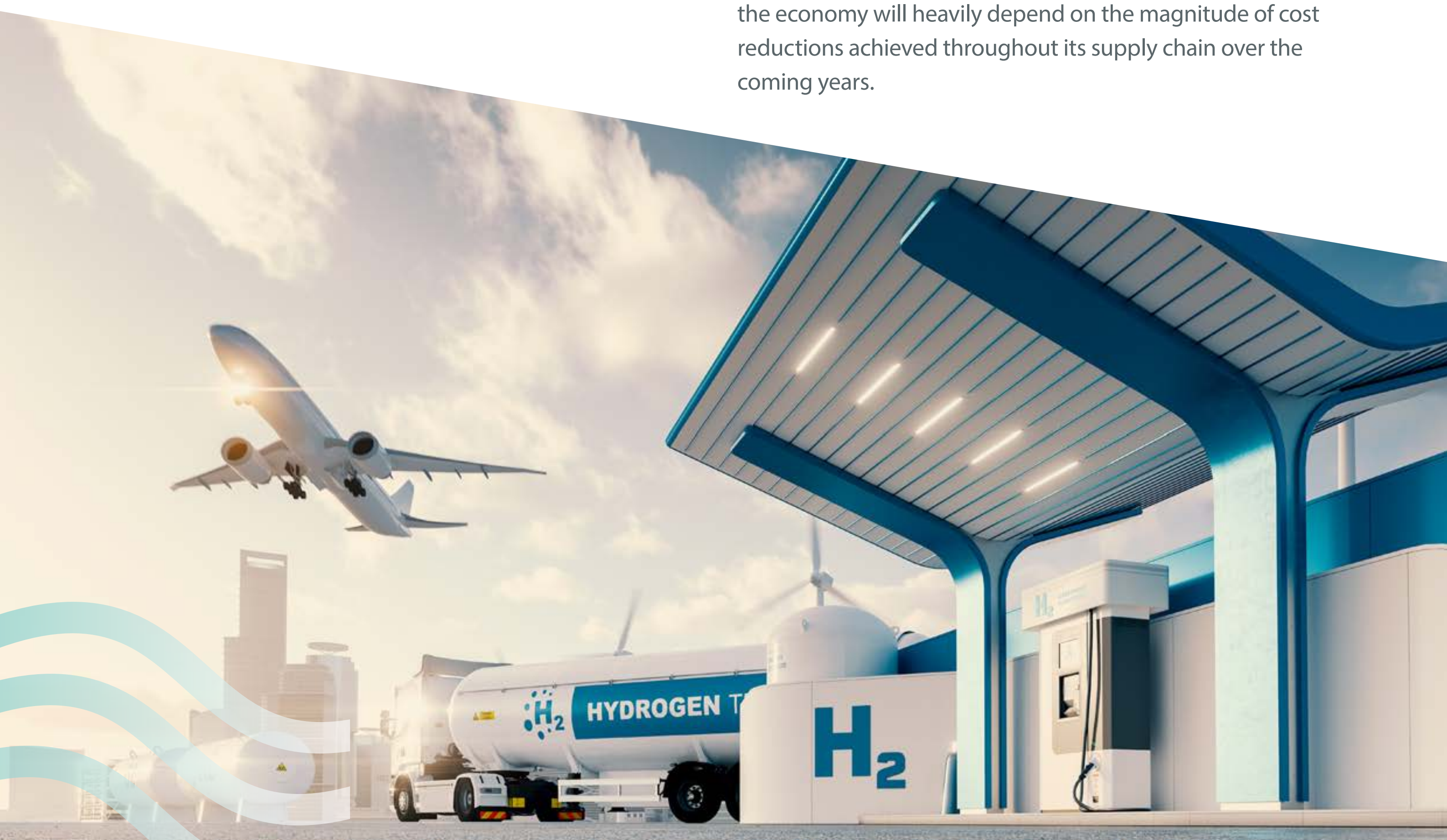
While most H_2 is currently produced from fossil fuels, projections suggest renewable and low carbon H_2 could grow dramatically and play a key role on the path to net-zero. In its Transforming Energy Scenario published in its Global Renewables Outlook in 2020, the International Renewable Energy Agency (IRENA) says H_2 could supply up to 8% of overall global energy demand by 2050, with more recent studies suggesting it could be even higher. The industry-led Hydrogen Council have envisioned up to 18% could be possible, saving 6 gigatonnes of annual emissions and potentially creating a US$ 2.5 trillion per annum industry.[6,7]

The scenarios rely on scaling up production mainly via green H_2 linked to renewable electricity, or blue H_2 based on natural gas using carbon capture and storage technology. IRENA's Transforming Energy Scenario for example involves a massive increase in green H_2 production: up to 1,700 GW of electrolyser capacity by 2050, and requiring over 7,500 TWh of clean electricity, equivalent to almost one third of current global electricity generation. Such ambitious targets would clearly have major impacts on electricity demand, given there is less than 1 GW electrolyser capacity installed today.[8]

Hydropower could play a transformative role in supporting growth in green hydrogen, providing at least 1,000 TWh (13%) of the required additional demand for emission-free electricity, when considering its share in IRENA's 2050 scenario for decarbonised electricity.[9] As understanding of the potential for hydrogen increases, new analysis projects even higher levels of hydrogen electrolysis. This in turn suggests hydropower's contribution could be much greater as part of a much higher demand for low carbon electricity. For example, IRENA's 1.5°C scenario, previewed in their World Energy Transitions Outlook, indicates as much as 5,000 GW of hydrogen electrolysers by 2050.[10,11]

Expanding the infrastructure to transport, store and use H_2 will also be needed to realise these growth figures. Transporting H_2 in existing or dedicated gas pipelines, by road and sea tankers, are all approaches being explored, as well as the option of storing H_2 in underground salt caverns for longer periods. There is also an opportunity to convert green H_2 into other tradable commodities, such as synthetic fuels or ammonia.[12,13] As explained later, the role and applicability of green hydrogen across different sectors of the economy will heavily depend on the magnitude of cost reductions achieved throughout its supply chain over the coming years.

* Global carbon emissions in 2019 were estimated at 33 gigatonnes (IEA)



Recent developments

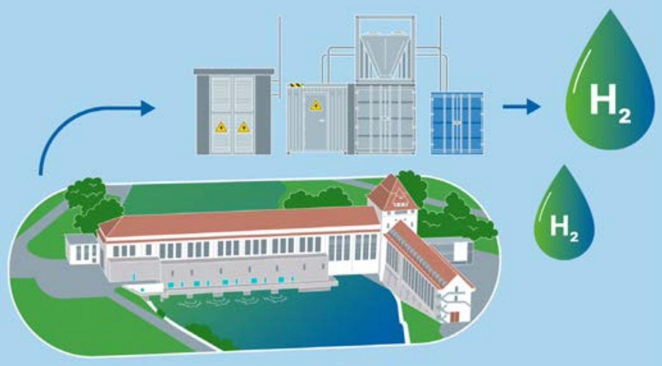
IEA, IRENA, the Hydrogen Council and countless other media reports over the past year highlight the "growing momentum" behind hydrogen. 2020 saw hybrid renewable energy & electrolysis plants open, concepts released for H_2-powered aircrafts, and even pilot schemes to produce fossil-free steel, all based on green hydrogen. Successive governments around the world have launched roadmaps and strategies to develop hydrogen, including South Korea, Japan, Chile, Russia, Australia, Canada and countries in Europe, with others like the US, home to one in three H_2-powered fuel cell electric vehicles (FCEVs), investing into R&D. As the leading hydrogen producer today, primarily from coal, China is a major player in hydrogen and has supported development of H_2 technologies including fuel cell vehicles. Interest is also growing in expanding green H_2, in line with the government's commitment to reach net-zero by 2060. [14,15,16,17,18,19]

Another factor driving interest in green H_2 is its capacity to support growth and intermittency of variable renewable energy on the electricity grid. Wind, solar and hydropower can be used to produce electrolytic H_2; meaning that, during periods of excess output, renewable energy can be stored as green H_2 for later use and help reduce curtailment of renewables when demand on the grid is low.

Taking this into account, the European Commission announced an ambitious Hydrogen Strategy alongside its Energy System Integration strategy: outlining plans to build 40 GW of electrolyser capacity across the EU by 2030, plus 40 GW in partner countries and reaching up to 10 million tonnes of renewable hydrogen production over the next decade. Estimates suggest €180-470 billion investment will be required from now until 2050 covering electrolysers and additional infrastructure for hydrogen, including an additional 80-120 GW of wind and solar PV to power the green H_2 producers. European countries are also publishing national strategies to invest into green H_2 in line with the EU, for example Germany announced a €9 billion hydrogen acceleration plan as part of its post-Covid stimulus package in 2020, alongside France and others. [20,21,22]

Coupling green H_2 with hydropower and other renewables

Hydropower has played a significant role in green H_2 production for the last 100 years. Operated in the 20th Century, the 167 MW Rjukan and 135 MW Glomfjord electrolyser facilities in Norway produced hydrogen from locally-sourced hydropower, supplying H_2 for ammonia production used in fertilizers. Other large-scale electrolysers built last century included sites at Trial in British Columbia in Canada (commissioned in 1939), at Nangal in India (1958), and at Aswan in Egypt (1960), among several others; all situated near low-cost hydroelectric generation and available water supply.[23,24]



Principle of coupling hydropower plants with H2 production. Diagram extracted from video credit: Hydrospider (www.hydrospider.ch).

More recent coverage has focused on coupling green H_2 with wind and solar power sources, noting a 10 MW electrolyser opened at a solar PV farm in Fukushima, Japan in 2020. Larger-scale green H_2 projects are also in development, for example plans to generate green H_2 from GWs of new offshore wind energy in the North Sea. Other proposals include the Asian Renewable Energy Hub in Western Australia, aiming to build up to 26 GW of wind and solar power mainly for green H_2 production for domestic and export markets. [12,25,26,27,28]

Gösgen run-of-river hydropower plant in Switzerland, where a 2 MW green H2 electrolyser was commissioned in 2020. Photo credit: Alpiq.

New projects are also emerging in locations benefitting from hydropower resources. In 2020, a 2 MW electrolysis plant was opened in Switzerland at the Gösgen hydropower plant under the 'Hydrospider' joint venture, and this follows South East Asia's first integrated H_2 production and vehicle refuelling station commissioned in Sarawak, Malaysia, which includes a 500 kW electrolysis plant based on hydropower supply.[29,30] Further green H_2 projects are also under development in regions such as Iceland, Tasmania and Canada where hydropower plays a leading role. Annex A presents examples of green H_2 and hydropower projects by country.

Locating projects in these countries can provide access to reliable, low cost and clean electricity with high availability year-round. This can not only help guarantee supply of renewable and hence 'green' power for H_2 producers, but also reduce cost of production. Currently green H_2 is on average two to three times more expensive than grey or brown H_2 produced from fossil fuels, according to IEA figures for 2018, meaning cost remains a key challenge to overcome.[2]

The main cost driver for green H_2 is the price of electricity, with other key contributors being the capital cost of electrolyser plant and the utilisation factor, a measure of how often the electrolyser runs throughout the year.[4] Targeting countries with low price and readily-available hydropower could clearly help improve the economics for green H_2 producers, especially where there is strong government support for scaling up green H_2. As a dispatchable and flexible electricity source, hydropower can also work together with wind and solar power to supply firm capacity, which further supports high utilisation of H_2 electrolysis plants compared to intermittent operation.[31] Moreover run-of-river hydropower can have high utilisation factors where there is a continuous water flow all year round, so could be particularly suitable for hydrogen production.

In terms of capital cost, while still relatively expensive, the costs for both Alkaline electrolysers and Polymer Electrolyte Membrane (PEM) technologies have fallen over the last 10 years; and reductions are expected to continue as manufacturing ramps up. Overall, cost outlooks suggest green H_2 could be competitive at or around US$ 2 per kg by 2030 in the best locations, according to studies published by BloombergNEF and IRENA.[32,33]

H2 vehicle refuelling station in Sarawak, Malaysia. Photo credit: Sarawak Energy.

Opportunities for hydropower

There are clearly ambitious plans to develop green hydrogen. Governments are releasing roadmaps to scale up production as part of decarbonisation commitments, and trends show reducing technology costs. IRENA energy outlooks illustrate the potential scale and impact on grid systems: requiring 1,700 GW of H_2 electrolyser capacity in the Transforming Energy Scenario by 2050, and more than double this capacity stated in IRENA's latest 1.5°C Scenario. The additional renewable electricity generation needed for green H_2 production would also be significant , of which upwards of 1,000 TWh could be supplied by hydropower.

To deliver this vision, IHA recognises the opportunities in coupling hydropower with green H_2 and supports partnerships to promote development:

- As the market for H_2 grows, hydropower generators can integrate electrolysers at or nearby hydropower sites, to produce green H_2 as a zero-carbon product and revenue option. Green H_2 can also make use of surplus hydropower supply where it may be available, and especially if it can support high utilisation factors for electrolysis plants.
- Green H_2 producers and users could develop commercial partnerships with hydropower generators through power purchase agreements (PPAs), possibly together with wind and solar generators. Targeting countries with readily-available hydropower resources and policies to scale-up green H_2, could help reduce costs, guarantee access to green electricity and support much greater annual utilisation factors.
- Green H_2 production also provides (a) a firm market for hydropower when the electricity demand is temporarily low, enabling fuller utilisation of existing hydropower assets; and (b) a new market and zero carbon product, which could facilitate implementing new hydropower plants in some regions of the world.
- In general, a drive for green H_2 will broadly rely on decarbonisation of the power sector and significantly increased demand for clean electricity. As the leading source of renewable and reliable electricity, this further supports the case for hydropower capacity and its critical role alongside other renewables in the transition to net-zero.

Recommendations

Scaling up green hydrogen will require continued investment to address barriers and promote wider uptake over the long term. With clear synergies between growth in green H_2 and decarbonisation of electricity, IHA calls on both governments and industry to:

- Prioritise development of green hydrogen through enabling policies and financial incentives. This will help upscale technology, stimulate growth in demand, and accelerate cost reductions in green H_2 infrastructure.
- Support increased decarbonisation of power grids to ensure electricity used for hydrogen is green. Global certification systems should be introduced to appropriately credit green H_2 and derived products, sourced from clean electricity sources including hydropower.
- Recognise and support the role of hydropower capacity, alongside other renewables, in green hydrogen supply. A balanced portfolio of low carbon generation leads to a more secure and sustainable energy mix, and will also help ensure high utilisation factors of H_2 electrolysis plants.
- Create markets and policy frameworks that reward flexible electricity supply and demand on the grid. This 'no regrets' approach would incentivise green hydrogen producers, as well as other flexible technologies and service providers including hydropower.
- Scale-up investment into new zero carbon generation capacity, as soon as possible. This will bring down the cost of renewable electricity and help green H_2 to become cost-competitive.

About IHA

The International Hydropower Association (IHA) is a non-profit organisation that works with a vibrant network of members and partners active in more than 120 countries. Our mission is to advance sustainable hydropower by building and sharing knowledge on its role in renewable energy systems, responsible freshwater management and climate change solutions.

Authors: David Samuel, IHA Senior Analyst, and Alex Campbell, IHA Head of Research and Policy.

Annex A – Green H_2 and hydropower projects

Country	Projects
Norway	Historically has produced green H_2 from hydropower. In 1927, Norsk Hydro opened a 167 MW electrolyser plant to supply H_2 for ammonia production at Rjukan, which used hydropower from plants along the Måna river. A later 135 MW hydro-powered electrolyser plant was opened at Glomfjord in 1953, near a hydropower plant of the same name, now owned by Statkraft. This experience developed into NEL Hydrogen, a leading electrolyser supply today.[34]
Switzerland	Hosts the 'Hydrospider' project – a joint venture between Alpiq, H2 Energy and Linde Gas to produce 100% renewable H_2 for fuel cell heavy-duty trucks, in partnership with Hyundai Hydrogen Mobility and the H_2 Mobility Switzerland Association. A 2 MW electrolysis plant was opened at the 51 MW Gösgen run-of-river hydro plant in 2020, producing up to 300 tons green H_2 per year, enough to supply 40-50 trucks or 1700 passenger cars.[26]
Iceland	In 2020, Landsvirkjun announced plans for development of a 10 MW electrolyser project at the Ljósifoss hydropower plant, which could help replace use of fossil fuels for example in heavy transport.[35]
Sarawak, Malaysia	Sarawak Energy unveiled South East Asia's first integrated H_2 production plant and vehicle refuelling station in 2019, supporting H_2-powered vehicles in Kuching. The electrolyser unit produces green H_2 based on hydropower.[27] In 2020 Sarawak have also signed Memorandum of Understandings (MOUs) with Japanese companies to export and scale-up green H_2 production.[36]
Canada	Air Liquide Canada has recently installed a 20 MW electrolyser for low carbon H_2 at its facility in Bécancour, Québec, making use of the abundant and low cost hydropower available in the region.[37] In its 2020-2024 Strategic Plan, Hydro Québec also identifies green hydrogen as a key development opportunity, and has recently announced plans to develop a 90 MW electrolyser plant for green H_2 for biofuels production.[38,39] Proposals in other Provinces include for example Renewable Hydrogen Canada (RH2C) in British Columbia which would make use of wind resource and BC Hydro firming capacity.[40]
Tasmania, Australia	Hydro Tasmania released a 2019 Whitepaper subsequently followed by the State Government's release of the Tasmanian Renewable Hydrogen Action Plan, identifying green hydrogen as a competitive advantage for the State. [28,41] Critical advantages include readily-available renewable power from wind energy and flexibly operated hydropower, to support high capacity-factor and cost-competitive green H_2. The Tasmanian Government is providing \$2.6 million to support three feasibility studies investigating large-scale renewable hydrogen projects in Tasmania (projects scaled at 500 MW, 100 MW and 90-100 MW in size). The Tasmanian Government has also committed \$50 million over 10 years to help develop the Tasmanian hydrogen industry.
Russia	In the far east of Russia, RusHydro is developing a pilot plant to produce liquified hydrogen at the 310 MW Ust-Srednekanskaya hydropower station, in partnership with Japanese Kawasaki Heavy Industries.[42,43]

References

1 www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php
2 www.iea.org/reports/the-future-of-hydrogen
3 www.irena.org/publications/2019/Sep/Hydrogen-A-renewable-energy-perspective
4 www.carbonbrief.org/in-depth-qa-does-the-world-need-hydrogen-to-solve-climate-change
5 www.irena.org/publications/2020/Nov/Green-hydrogen
6 www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020
7 hydrogencouncil.com/en/study-hydrogen-scaling-up/
8 www.irena.org/newsroom/pressreleases/2020/Dec/Making-Green-Hydrogen-a-Cost-Competitive-Climate-Solution
9 www.irena.org/remap
10 irena.org/publications/2021/March/World-Energy-Transitions-Outlook
11 hydrogencouncil.com/en/hydrogen-decarbonization-pathways/
12 about.bnef.com/blog/liebreich-separating-hype-from-hydrogen-part-one-the-supply-side/
13 about.bnef.com/blog/liebreich-separating-hype-from-hydrogen-part-two-the-demand-side/
14 www.linkedin.com/pulse/helping-world-move-closer-realising-hydrogens-clean-energy-birol?trk=portfolio_article-card_title
15 fuelcellsworks.com/news/worlds-largest-hydrogen-plant-in-fukushima-opens/
16 www.airbus.com/innovation/zero-emission.html
17 www.reuters.com/article/us-sweden-steel-hydrogen-idUKKBN25R1PI
18 www.irena.org/publications/2020/Nov/Green-hydrogen
19 www.power-technology.com/features/will-china-do-for-hydrogen-what-it-did-for-solar-power/
20 ec.europa.eu/commission/presscorner/detail/en/ip_20_1259
21 ec.europa.eu/commission/presscorner/detail/en/FS_20_1296
22 www.reuters.com/article/us-health-coronavirus-germany-stimulus-idUSKBN23B10L
23 deepresource.wordpress.com/2019/01/14/largest-hydrogen-electrolyser-plant-in-the-world-135-167-mw/
24 www.routledgehandbooks.com/pdf/doi/10.1201/b10789-6
25 www.itm-power.com/news/industrial-scale-renewable-hydrogen-project-advances-to-next-phase
26 orsted.co.uk/media/newsroom/news/2020/02/gigastack-phase-2
27 www.rechargenews.com/wind/shell-unveils-worlds-largest-offshore-wind-plan-to-power-green-hydrogen/2-1-763610
28 asianrehub.com/
29 hydrospider.ch/en/the-green-hydrogen-ecosystem-has-been-launched-hydrospider-delivers-first-container-to-st-gallen/
30 www.sarawakenergy.com/media-info/media-releases/2019/sarawak-launches-south-east-asias-first-integrated-hydrogen-production-plant-and-refueling-station-unveils-hydrogen-buses
31 www.hydro.com.au/clean-energy/hydrogen
32 irena.org/publications/2021/March/World-Energy-Transitions-Outlook
33 data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf
34 nelhydrogen.com/about/#timeline
35 www.landsvirkjun.com/news/green-hydrogen-is-an-environmentally-friendly-energy-carrier
36 www.spglobal.com/platts/en/market-insights/latest-news/electric-power/102320-japans-eneos-sumitomo-malaysian-sedc-energy-mull-green-hydrogen-supply-network
37 www.rechargenews.com/transition/worlds-largest-green-hydrogen-plant-inaugurated-in-canada-by-air-liquide/2-1-952085
38 www.hydroquebec.com/about/strategic-plan.html
39 news.hydroquebec.com/en/press-releases/1667/hydro-quebec-to-operate-one-of-the-worlds-most-powerful-electrolyzers-to-produce-green-hydrogen/
40 www.renewableh2canada.ca/
41 www.stategrowth.tas.gov.au/__data/assets/pdf_file/0003/207705/Draft_Tasmanian_Hydrogen_Action_Plan_-_November_2019.pdf
42 www.eng.rushydro.ru/investors/IR_news/88827.html
43 www.spglobal.com/platts/en/market-insights/blogs/agriculture/032420-russias-hydrogen-bet-sets-up-contest-with-australia-for-japanese-market