TRENDS
HYDROGEN

Boosted by the Recovery, the "Hydrogen Economy" Gains Credibility

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Largely unknown to the general public a few years ago, hydrogen now enjoys strong public support, based on the hope that it will become a strategic energy vector in a low-carbon world. But where do things actually stand? Are today's hydrogen projects really centred on decarbonization? Have the numerous announcements been followed up by numerous investments? With carbon neutrality acting as the new international climate barometer, oil and gas companies concerned by the need to diversify have rapidly positioned themselves on the hydrogen market. The hydrogen boom also brings new hope for sectors that seemed to be unable to reduce their emissions, i.e., heavy industries.

DATA OVERVIEW

Still in its nascent stage, low-carbon hydrogen garners the support of several States

Cars and planes that only emit water vapor, "zero-carbon" steel, heating for buildings, storage of electricity produced from intermittent renewable energy: recent years have seen multiple discussions about the promising ways in which hydrogen can be employed to shift to a low-carbon economy.

Current hydrogen production is nevertheless far from being low-carbon: in 2018, it was responsible for emitting about 830 megatons (Mt) of CO_2.[1] In fact, 98% of current production is qualified as "gray",[2] which means that it comes from processes that use fossil fuels (methane reforming or coal gasification) (**fig. 1**), generating around 10 kgCO_2e for every kilogramme of hydrogen produced.[3] The remaining 2% is produced from the electrolysis of water, a process that operates on electricity, most of which comes from fossil fuels. The share of "green" hydrogen, in other words produced by electrolysis from renewable electricity, is no more than 0.3%, while "blue" hydrogen, produced at sites equipped with Carbon Capture, Utilization and Storage (CCUS),[4] represents barely 1.1% of global production. As a result, only 1.4% of the hydrogen currently produced is "low-carbon", due to its relatively uncompetitive production costs compared to high-carbon alternatives (**fig. 2**).

Additionally, low-carbon hydrogen applications are still few and far between. In 2018, the IEA estimated that about 120 Mt of hydrogen was produced in the world: 75 Mt of "pure" hydrogen, mostly used in oil refining (38.2 Mt) and ammonia production (31.5 Mt); and 45 Mt of hydrogen that is "mixed" with other gases to produce synthetic gases, used for example to produce methanol (14 Mt), an intermediate product in plastic production among other things, or in industrial processes (e.g. steelmaking).[4, 5] The Covid-19 pandemic caused a drop in this production. In Europe, demand for pure hydrogen decreased by about 10%, while demand for mixed hydrogen went down by over 25%, mainly due to a slowdown in hydrogen-consuming activities like oil refining and the chemical industry.[6]

2020 marked a turnaround for the industry: low-carbon hydrogen took pride of place in announcements of post-lockdown investments in both the private and public sectors. Several sources have attempted to list and monitor the different announcements promoting hydrogen.

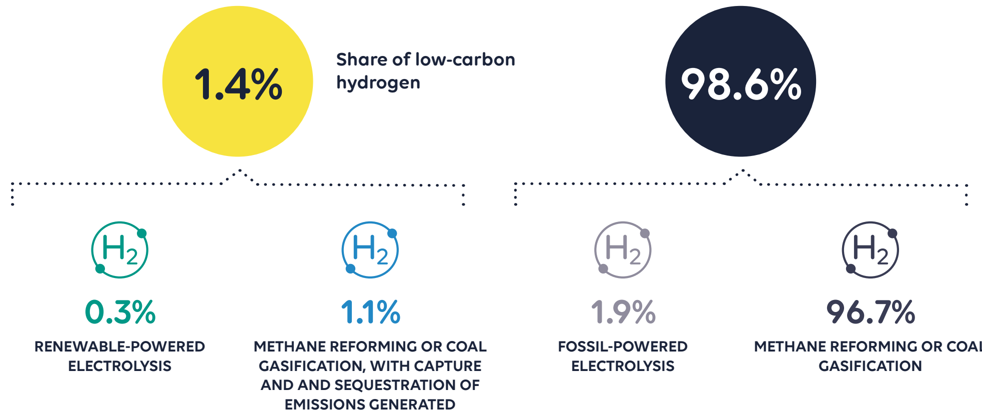
According to Energy Policy Tracker, since the start of the pandemic, ten countries[a] and the European Union have committed to investing around 20 billion dollars in hydrogen.[7]

REN21 counts 12 jurisdictions (11 states and the EU) that have put forward targets and policies on low-carbon hydrogen.[8] For example, in Europe, Portugal has announced that it is investing €7 billion in "green" hydrogen, while France has pledged €9 billion, targeting the installation of 6.5 GW of electrolyzer capacity by 2030. The United Kingdom hopes to attract £4 billion to develop the use of hydrogen in building

a Canada, France, Australia, the United Kingdom, Poland, Russia, New Zealand, Spain, Germany, and Norway

FIGURE 1

SHARE OF DIFFERENT HYDROGEN PRODUCTION METHODS - *Source: Climate Chance, based on [Global CCS Institute](), 2021*



heating (combining it with natural gas to reduce the amount of gas used), decarbonize heavy industries, and develop hydrogen-powered transport.[9] In Australia, the government has committed to investing AU$284 million to support the development of green hydrogen projects. In the United States, the government has planned to inject $64 million into developing 18 green hydrogen projects.

The International Energy Agency (IEA) lists 17 states that have adopted a hydrogen strategy, totalling investments of $37 billion, compared to only three in 2019 (France, Japan and South Korea).[10] Chile, which has multiplied its renewable energy production capacity by five over the last six years, published a strategy for developing green hydrogen in 2020, with a scheduled budget of $50 million.[11] Canada has also published a hydrogen strategy[12] that aims to have 30% of low-carbon hydrogen by 2050.

Green hydrogen also receives strong political backing in Africa, with multiple announcements of projects and partnerships over the last year. In June 2020, Morocco concluded an agreement with Germany for a green hydrogen project led by the Moroccan Agency for Solar Energy. While recent political tensions between the two countries have slowed the project down, Morocco and IRENA declared in June 2021 that they had signed an agreement aimed at driving the development and consumption of green hydrogen in the kingdom.[13] The German government has also granted Namibia a funding of €40 million to support research and development in the green hydrogen industry.[14] In Mauritania, the government and the renewable energy company CWP Global have signed a protocol to develop an electrolyser with a capacity of 30 GW using wind and solar power and covering 8,500 square kilometres in order to produce green hydrogen and its derivatives, such as ammonia.[15] Lastly, as part of its "Energy Strategy 2035", the Egyptian government has announced that it intends to invest $4 billion in producing green hydrogen, in partnership with Siemens.[16]

In addition to developing production facilities, states are pumping a large share of their investments into the transport sector. For example, the German hydrogen strategy aims to inject 3.6 billion euros into transport out of the 12 billion earmarked for developing hydrogen.[17] Japan is also making mobility central to its hydrogen strategy, with a target to produce 800,000 fuel cell cars by 2030 (**see Tokyo Case study**). To this end, the government is subsidizing the purchase of new vehicles by up to $18,000, while prefectures are granting up to $9,000, which is 42% of the price of a standard hydrogen vehicle.[18] Similarly, France will devote 27% of the 3.4 billion euros allocated for the period 2020-2023 as part of its National Hydrogen Strategy on decarbonization of the heavy mobility sector.

According to IEA figures, government investments are only a drop in the ocean compared to the $300 billion announced by the private sector.[10] In particular, oil and gas companies and heavy industries are making hydrogen part of their low-carbon strategies and are counting on its large-scale deployment for their decarbonization.

THE OBSERVATORY'S LENS

When the old meets the new: Hydrogen offers a glimpse into a green future for the largest emitters

The Oil and Gas industry sets its sights on hydrogen

Oil and gas companies are particularly active in installing hydrogen production capacities, drawing from their investment capacities and their willingness to diversify (**see Energy sector**), and also from their transport infrastructures, since hydrogen can be transported by gas pipeline. For example, the European Hydrogen Backbone initiative, launched by twelve European transmission system operators, aims to create an immense network for transporting hydrogen throughout Europe based on converting two-thirds of the existing gas grid.[19] In the United Kingdom, the project Zero Carbon Humber, implemented by Equinor, British Steel and other partners, intends to convert the gas network at the Humber Estuary to transport hydrogen, and at the same time capture CO_2 from the hydrogen production installation and store it in the North Sea.

Blue hydrogen is of particular interest to these companies, as seen in the case of the Quest Project, set up by Shell in 2015.[20] This is primarily because blue hydrogen will undoubtedly remain cheaper to produce than green hydrogen, in regions rich in gas or coal and with high CO_2 storage potential, like the Middle East, North Africa, Russia and the United States (**fig. 2**),[21] where oil and gas companies play a central role in the energy sector.

In addition, blue hydrogen production facilities produce much bigger quantities than electrolyzers. Sturgeon and Nutrien, the two blue hydrogen production projects launched in 2020 (bringing the total to seven), have respective production capacities of 240 tonnes and 800 tonnes of hydrogen per day.[22] Both are connected to the Alberta Carbon Trunk Line, a 240 km pipeline that crosses the Canadian province, and can transport and store 14.6 $MtCO_2$ per year, $305 million of which is being financed by World Carbon Solutions, a company affiliated to the midstream oil and gas provider company Wolf Midstream.[23] In comparison, green hydrogen production projects are more numerous (the IEA counts about fifty currently in operation[24]), but their total production capacity is lower. The biggest green hydrogen production station began operating in 2020 in Fukushima, Japan, with a capacity of 10 MW, and it produces an average 2.4 tonnes of hydrogen a day.[25]

Previously little-known, blue hydrogen has therefore suddenly become the focus of considerable interest. In Russia, the world's biggest gas producer Gazprom announced in late 2020 that it was creating a new subsidiary, the Gazprom Hydrogen Company, which will notably construct a blue hydrogen plant at the German end of the Nord Stream gas pipeline.[26] Saudi Aramco, the biggest oil producer in the world, has committed to massive investments in blue hydrogen projects in China.[27]

Petroleum companies are also benefiting from the development of hydrogen in Japan, which, as part of its low-carbon growth strategy for 2050, intends to produce 20 million tonnes of hydrogen per year by 2050. In September 2020, the Saudi company made its first delivery of ammonia produced from blue hydrogen in Japan to feed power plants (**see Keys to Understanding**).[28] A few months later, Saudi Aramco signed a memorandum of understanding with the biggest refinery in Japan, ENEOS, to develop a supply chain for blue hydrogen and ammonia.[29] The Abu Dhabi National Oil Company (ADNOC), the leading oil company in the United Arab Emirates, has concluded a joint study agreement with Japanese oil and energy companies and an independent administrative institution, the Japan Oil Gas and Metals National Corporation (JOGMEC), to explore the commercial potential of producing blue ammonia in the Middle East.[30]

At least fifteen blue hydrogen projects are scheduled to come into operation by 2027 in the United Kingdom, Germany, Norway, the Netherlands, and Sweden.[31] If all of the blue hydrogen projects are implemented on time, production should reach 1 Mt by 2030, which is close to the level forecast by the IEA in its *Net Zero By 2050* scenario.[10]

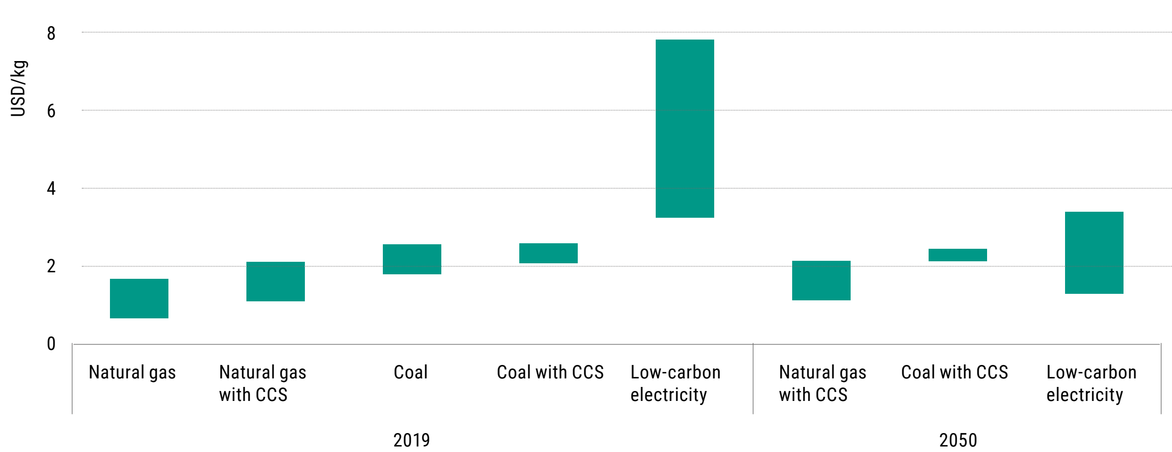
However, in terms of reducing GHG emissions, blue hydrogen production is not an obvious contender. A recent study published by researchers at Stanford and Cornell Universities estimates that the emissions from the entire life cycle of blue hydrogen are only 9% to 12% lower than from gray hydrogen.[32]

It seems that despite its high cost, green hydrogen is not out of the running. In 2020, according to the IEA, new capacities installed for the production of hydrogen by electrolysis amounted to almost 65 MW, a record, and over 400 million dollars were invested in electrolyzers for hydrogen production, which is almost four times more than in 2018.[10] BloombergNEF observed a rise in investments in installations to produce hydrogen by electrolysis amounting to $168 million in 2019 and $189 million in 2020.[39] New capacities for production by electrolysis could surge to over 275 MW in 2021.[33] The average

FIGURE 2

AVERAGE COST OF HYDROGEN PRODUCTION BY ENERGY SOURCE AND TECHNOLOGY IN 2019 AND 2050 (FORECAST)

Source: IEA, 2020



size is also increasing: almost 80 projects are aiming at a capacity of over 100 MW, and 11 are even targeting a capacity of more than 1 GW.[10]

Here once again, oil and gas companies are active players of the market. In early 2021, Shell began operating an electrolyzer with a 10 MW capacity, which is the same size as the one in Fukushima.[34] The British major BP has partnered up with Iberdrola, the Spanish renewables giant, to build a 20 MW green hydrogen power plant near Valencia, which is due to start operating in 2023.[35] In France, Total and Engie have signed a cooperation agreement to develop a 40 MW green hydrogen project with a daily capacity of five tonnes in the south of the country.[36]

KEYS TO UNDERSTANDING

AMMONIA, AN "ALTERNATIVE" FORM OF HYDROGEN FOR THE ENERGY TRANSITION

The production of ammonia (NH_3) is one of the main uses of hydrogen, and well known for its use as a fertilizer in farming. Ammonia takes the form of a gas at room temperature and can be stored as a liquid when compressed (at -33°C, compared to -253°C for hydrogen). It is also cheaper to store in the long term ($0.5/kg-$H_2$ compared to $15/kg-$H_2$ for hydrogen), and up to trice as cheap to transport by pipeline and up to a third cheaper by boat. As a result, more and more actors are thinking of using ammonia as an alternative fuel, similar to hydrogen, for transport or in power plants for example. In fact, its combustion only generates water and nitrogen, and emits no carbon molecules or soot particles. Japan in particular is relying on this molecule to decarbonize its maritime industry, transport hydrogen, and store energy. In November 2020, the Japanese Ministry for Energy, Trade and Industry (METI) announced the creation of a Council to work on employing ammonia as an energy product. By 2030, Japan's ambition is to import three million tonnes of "clean" ammonia and to accelerate its international cooperation (in particular with the Middle East, Australia and New Zealand) to achieve it.

Source: Conférence des Présidents d'Université, 25/11/2020; Ammonia Energy Association, 25/02/2021

In Egypt, ENI has signed an agreement with the Egyptian authorities to produce and export green hydrogen.[37] In Mauritania, the government has granted an exclusive offshore concession of 14,400 km² to the British company Chariot with the aim of studying the feasibility of producing low-carbon energy to operate "Nour", a new green hydrogen project with a total planned capacity of 10 GW.[38]

Nevertheless, even considering recent announcements that seem to point to a new era for green hydrogen, the IEA observes that the industry is far off track. Even if all of the projects recorded in September 2021 are to be implemented, they would still only reach a production of around 2 MtH_2, which is barely one-third of the recommendation in the *Net Zero By 2050* scenario.[10] Added to that, actual investments are still well below the 337 billion dollars in public and private pledges counted by IEA. According to BloombergNEF, only $1.5 billion were invested in low-carbon hydrogen in 2020, most of it ($1.3 billion) on fuel cell vehicles (cars, buses, etc.) and for installing charging stations (**see Transport Sector**).[39]

Hydrogen rekindles hopes of decarbonizing heavy industries

While announcements and actual investments are still way off-target, it is clear that the low-carbon hydrogen industry is slowly taking shape. This new type of production carries high expectations from sectors in which decarbonization seems difficult. The most prominent sector, transport, is banking on hydrogen for cars, trucks, public transport, trains and even airplanes, although for now attention is centred on electrification (**see Transport Sector**).

However, hydrogen is also entering into the low-carbon plans of sectors that the public are less aware of, but in which dead-ends for reducing greenhouse gas emissions are a cause for concern, i.e. heavy industries. In fact, three industrial sectors alone represent 65% of GHG emissions from industry: cement, steel and chemicals. They only use about 1% of renewable energy in their activities, which is negligible compared to an average of 15% for the industrial sector as a whole.[8]

On the one hand, industries based on hydrogen can push to decarbonize its production. For example, half of the emissions related to manufacturing ammonia, one of the biggest uses of hydrogen, result from the production phase of the hydrogen used. In Spain, a pilot project to produce ammonia from green hydrogen is due to launch in late 2021, led by Iberdrola and Fertiberia.[10]

The steel industry has high decarbonization hopes from hydrogen, taking a different approach: hydrogen could be a way of decreasing the consumption of coal, which is a key fuel in steel production, and responsible for most of the sector's emissions. In Sweden, the first tons of decarbonized steel were produced in the first half of 2021 (**see Signals**) by the Hybrit project, which gathers the steelmaker SSAB, the mining company LKAB, and the public electricity production and distribution company Vattenfall. Hybrit employs a procedure to manufacture Direct Reduced Iron (DRI), which can then be transformed into iron or steel in an electric furnace, using only hydrogen. The use of this kind of procedure combined with "green" hydrogen would considerably reduce emissions from the manufacture of steel. Several other iron and steel companies, like ArcelorMittal, also intend to develop this production process.[40] The iron production company Fortescue aims at producing 15 million tonnes of hydrogen by 2030 in order to help its steelmaking clients decarbonize their steel production (scope 3).[41] Other pilot projects to decarbonize cement and glass production are also being developed.[10]

By offering new avenues for gas production, blue hydrogen also opens up possibilities for another breakthrough technology that had been left to a side in public and entrepreneurial spheres – CCUS technologies. Conversely, hydrogen could benefit from CCUS rollout: 1.8 GtCO_2 related to hydrogen production could be captured and stored by 2050 (**see CCUS Trend**).[42]

KEY TAKEAWAYS

Investments in hydrogen picked up strongly in 2020 with a view to use the gas in highly emitting sectors that are currently difficult to decarbonize: transport and heavy industry. Oil and gas companies looking for ways to diversify into low-carbon services have got the message, and rapidly positioned themselves on hydrogen markets, taking advantage of their pipeline networks and investment capacities. Green hydrogen, produced from renewable electricity still remains much less competitive than its blue equivalent, produced from the combustion of gas and capture of CO_2, which is less beneficial for the climate. Announcements of funding for blue and green hydrogen projects and partnerships between industries have also flourished in line with the pace of government commitments, pointing to a favourable situation for this breakthrough technology which many are counting on to decarbonize the economy.

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