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The geostrategic challenges of hydrogen

Hydrogen is seen by many as an effective solution to decarbonise polluting sectors. Many countries have made this energy vector a central element of their energy transition strategy with a view to drastically reduce industrial emissions, storing electricity and propelling the mobility of tomorrow. Renewable hydrogen breaks the codes as it can be produced almost anywhere thus changing the energy geopolitics. European countries want to take part in this green revolution and have announced major investments, such as France with €7B by 2030. The race to master this industry will include Japan, China, South Korea, and the United States who also want to impose their leadership.

In this article, we lay the foundations of what could be the future geopolitics and geoeconomics of hydrogen. As the whole world is thinking about hydrogen, we will try to understand how the hydrogen economy could be and which countries may dominate the market. Finally, we will identify new geostrategic dependencies that could emerge for the European Union and how it intends to deal with them.

With hydrogen industry comes challenges

States' energy strategies and policies consider supply security, costs and, more recently, environmental impact, in particular climate impact. With a need to phase out from fossil fuels, hydrogen is seen as a solution to decarbonise energy systems and establish energy independence from some countries.

Developing a renewable hydrogen economy and making an economically attractive alternative give rise to two challenges: creating the demand and ensuring the supply. It is on one side based on the uses' development (industry, mobility…) to replace fossil fuel consumption, and on the other side, the hydrogen supplied must be low-carbon or renewable.

Globally, 90 Mt of hydrogen are produced annually and mainly from fossil sources and associated emissions. The share of decarbonated hydrogen, i.e., the production of which does not emit CO_2, is still embryonic (less than 1% in 2020). This proportion shall increase within the coming years as there are several hundred electrolysis projects under development. Despite this encouraging momentum, if all projects are completed, their output would only represent about 5% (5 Mt) of hydrogen annually consumed in 2030.

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Another way to decrease the carbon content of the hydrogen produced is to capture and store carbon emitted during production processes. This low-carbon hydrogen could represent 10% (9 Mt) of the global production. Renewable hydrogen made from electrolysis is seen as a major mean of producing tomorrow's hydrogen. Projects will have to deal with the resources' availability, both renewable (solar, wind…) for electricity supply, and water, consumed at 9 kg to produce 1 kg of hydrogen.

Once hydrogen is produced in a renewable or low-carbon way, uses can be decarbonised. Both current and future usages will, for sure, increase the hydrogen demand. For now, refining and chemistry industries are highest hydrogen consumption sectors. Tomorrow's carbon neutrality implies the development of new uses for hydrogen: electricity production for mobility and stationary usage, natural gas pipelines injection (and so, heating), synthetic fuel production etc. Hydrogen will be relevant in sectors where emissions are hard to abate but not that easy to implement. Let's not paint it all "pink and shiny" …

For uses, we should start with industry, which is a top priority in terms of potential use (e.g., amounts of hydrogen) and as a high emission sector to be decarbonised. The industry transition to renewable hydrogen use is likely to be lengthy as it involves the transformation and adaptation of infrastructure (e.g., furnaces, turbines) involving substantial investment. For now, demonstration projects are announced as, for example, a decarbonised hydrogen steel plant in Sweden.

Secondly, the transportation sector accounts for more than 20% of GEG emissions and relies on petroleum products at 90%. Despite the hype, still a very tiny proportion of vehicles are powered by hydrogen. Focus is on Heavy transportation, starting with road transport (trucks & buses) but shipping and aviation sector transition shall take more time. It will probably require the use of liquid hydrogen or hydrogen derivates, that rely on a higher energy density than gaseous hydrogen. However, adoption in light road transport is still questionable as hydrogen faces competition from batteries.

Thirdly, hydrogen represents an interesting alternative to batteries for storing surplus electricity from intermittent energy sources on short or long period. It can also be injected into natural gas pipelines to fuel domestic boilers.

Current and future hydrogen use

Zoom 1: what future for each type of mobility?

Despite enabling policies in South Korea, Japan, China or California, fuel-cell electric light vehicles have not caught on, unlike battery vehicles. Indeed, less than 50,000 hydrogen fuel-cell vehicles were circulating at mid-2021 against 11 million of battery-powered vehicles. These countries have the largest number of vehicles thanks to their leading policies and their automotive industry players offering hydrogen mobility. South Korea, which is the world's largest market for fuel-cell electric vehicles, benefited from a generous subsidy program on the Hyundai Nexo locally produced. Other Asian markets like China and Japan still want to enhance this mobility with targets of around 1 million vehicles on the road by 2035 (including bus and trucks). On the opposite, Europe accounts for a small share of fuel-cell electric vehicles (6%).
Despite the enthusiasm of Asian countries, light mobility seems struggling to gain a foothold, suffering from a lack of competitiveness and lower efficiency with battery technology.

Heavy mobility fuel by hydrogen vehicles will probably aspire to a better future as direct electrification (battery-powered vehicles) which may not be optimal considering the reduced autonomy conditioned by the battery capacity. Nonetheless, nothing is written considering the progress of battery technologies and the difficulty of deploying hydrogen charging infrastructures.

On the shipping side, particularly on large ocean-going vessels, hydrogen could be a relevant solution if used as intermediary to produce synthetic fuels. According to its low volumetric density, hydrogen-based fuels are preferred as they can be directly injected into combustion engines and benefit from existing infrastructures without major changes. Ammonia could endorse this role thanks to its higher volumetric density and its facilitated and costless logistics (including production, storage, and distribution). However, there are still some techno-economic obstacles to overcome, but several shipbuilders have announced their intention to market ships with 100% ammonia engines from 2023, and to offer ammonia retrofit solutions for existing ships from 2025. Moreover, some ports have initiated the integration of hydrogen bunkering infrastructures allowing the future use of hydrogen and ammonia.
Although the maritime sector is a behemoth to be decarbonised, ammonia could account for up to 45% of global shipping fuel demand by 2050.

Aeronautics is also a matter of interest for hydrogen integration. Tracks are being studied to design aircraft burning hydrogen in their engines and producing electricity thanks to the fuel-cell. Airbus is already handling the subject, but commercialisation is not expected before 2035. As for maritime sector, hydrogen could also be used to produced synthetic kerosene.

Finally, hydrogen in railway sector is seeking interest to replace diesel on non-electrified lines. Germany commissioned the first Alstom hydrogen train in 2018, followed by other countries such as France. This decarbonisation option should however remain marginal.

Hydrogen for mobility is thus a matter of interest according to its decarbonisation perspectives. Market will certainly remain embryonic in the short-term, but its adoption could accelerate after 2030 thanks to the increasing demand in both consuming sectors, such as shipping, and aeronautics.

Zoom 2: what status for hydrogen in electricity production and storage?

In terms of electricity generation, hydrogen can be used in a stationary fuel-cell or as ammonia or as a fuel in gas turbines. Some gas turbine manufacturers indicate that their systems can already accept 50% of hydrogen blended into natural gas. Even if this application still represents less than 0.2% of global electricity generation, this segment could represent in the long-term an important consumption source.

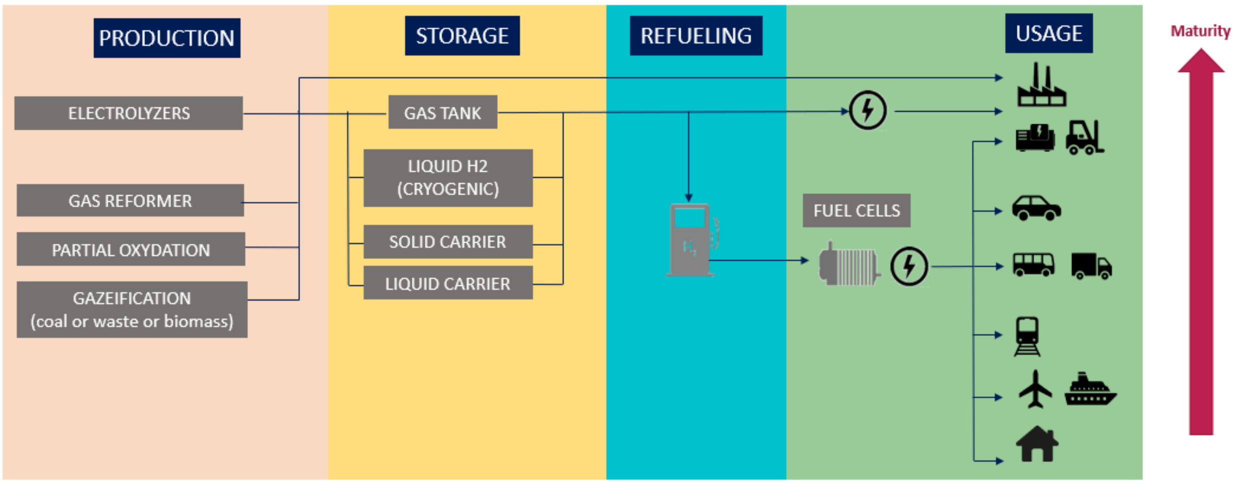
Fuel-cells are seen as a tool for grid flexibility, allowing electricity to be stored when there is a surplus and returned to the grid during periods of high-consumption. However, this option competes with other storage options including pumped-storage hydroelectricity, batteries, thermal-storage, etc. Batteries benefit from better round-trip efficiency than hydrogen are already deployed and are still fast developed. Batteries will probably be preferred for short-term matters: temporary storage and intra-day fluctuations management in electricity grid. In seasonal, long-term storage applications or large excess production (e.g., excess of PV production in summer to be stored for winter electricity peak demands), hydrogen could be the optimal solution to capitalise on its production during renewable electricity excess periods, to benefit from geological storage, and then, to convert it back when electricity supply is needed. If batteries are most interesting for short-term and cycling, hydrogen is more plausible for seasonal storage, especially as low-cost storage per megawatt-hour.

Stationary fuel-cells can also be used to back-up power supply in critical sectors such as hospitals and data centres, and to provide off-grid electricity. In 2020, there were 2 GW of stationary fuel-cells operating, mainly in Japan.

As a gas, hydrogen can also be directly injected into gas grids. It can be blended into existing natural gas networks (with a proportion from 5 to 20%) or pure in dedicated pipelines. Hydrogen in gas grids represents another electricity production decarbonisation track for gas-based power plants. Pilot projects are already in place in the Netherlands or in France. Partially injected into natural gas grids, it doesn't need major infrastructure changes.

Even if hydrogen is addressing the electricity production and storage sector, the future of these applications remains uncertain. Few countries integrated this option into their strategic plans except pioneers such Japan, South Korea or Germany. Developments of these uses are likely to suffer from their low visibility. Hydrogen should, at best, only contribute to 1 or 2% of electricity production by 2050.

Figure 1 : Hydrogen Value Chain



Source: Enerdata

Prerequisites for the emergence of a Hydrogen industry

To reach climate neutrality, hydrogen is valuable for sectors where direct electrification seems hard to implement. In some cases, hydrogen will be competing with other technologies but most of the projections state that hydrogen and its derivatives (e.g., synthetic fuels) will supply a fifth of global final energy in 2050. Industry (cement, steel) will be the most consuming sectors, certainly followed by shipping and aeronautics.

Integrating renewable hydrogen in the energy mix will call for key enablers as public policies to support hydrogen (or to discourage the use of fossil fuels), encouraging technological advances and innovations, and consumer preferences.

Public supports are mandatory to elevate the hydrogen demand and make hydrogen economically affordable. They will enhance the development of low-carbon hydrogen projects then the infrastructures and thus the usages. Some countries have already demonstrated their intention to develop the hydrogen industry by publishing their national hydrogen strategies and, thus, encouraging investors to get involved in turn. On the technological side, governments must commit in supporting R&D and innovation to reach maturity and competitivity of disruptive technologies. On the regulatory side, defining a clear and consistent regulatory framework to facilitate the uptake of hydrogen throughout the energy system will be crucial. It will require to set up and harmonise, at national and international levels, standards to ensure a global interoperability of technologies and infrastructures. Work will also consist in defining low-carbon hydrogen, setting up a certification system to ensure fair competition, defining safety and technical… Finally, to attract investors interest, it is necessary to mitigate the risks of investment in production capacity or infrastructures. Investments are estimated to be massive (e.g., $1,200 billion by 2030, and $10,000 billion by 2050) to reach carbon neutrality in 2050.

Zoom 1: hydrogen transportation and storage infrastructures, 2 key foundations

Hydrogen storage infrastructures are necessary to ensure supply consistency and thus, usages. In the long-term, technologies of this value chain step will open a large-scale hydrogen economy. According to distance and temporality, three main types of storage are intended: pressurised tanks for low quantities and short-term storage, re-use of methane storage, and geological formations (e.g., saline cavities), well suited for large quantities and long-term storage. On very large distances, gaseous pipeline transport or liquid shipping are two options. Over long-sea distances, hydrogen can be transformed in intermediary products, easier to store, and which benefit from existing infrastructures such as methanol or ammonia. Lastly, special mention can be made on port facilities to become key nodes in hydrogen refuelling infrastructure networks and hubs of the hydrogen market on a global scale moderating infrastructure adaptation.

Figure 2: Comparison of a selected storage-transport technologies

	Pipelines	Cryogenic	Liquid carriers
Long distances	+	+	++
Long-term storage	++	-	++
CAPEX	++	++	-
OPEX	-	++	++ (Highly depending on electricity cost)

Source: Compilation of data and research from Enerdata

Zoom 2: low-carbon hydrogen economics

Competitivity of low-carbon hydrogen against of fossil hydrogen and alternative solutions is the cornerstone of its development. Today, one kilogram of hydrogen made from natural gas costs from $0.5 to $1.7. If the emitted carbon is captured during production processes, this cost doubles. Renewable hydrogen, which is expected to be deployed at large scale, still suffers from high production costs (e.g., $4 to $9 per kilogram). Both renewable electricity and electrolysis systems costs decrease and could, over time, make renewable hydrogen competitive with carbon alternatives. Indeed, electricity cost is a major component of the hydrogen production cost by electrolysis, it accounts for 50 to 90% of the total cost. This major price component could create a hydrogen export market in countries with large solar resources in Middle East, North Africa, or South America (Peru & Chile)

Focus on three pillars of the hydrogen value chain

Zoom 1: manufacturing of Electrolysers

Two technologies of electrolysers are leading hydrogen production: alkaline and proton exchange membrane (PEM). Alkaline systems currently account for more than 60% of global installed capacities. This advance benefits from the solution maturity and its relatively low costs. Despite their high-efficiency (75 to 90%) and a long-service lifetime (above 10 years), these systems are not flexible, which affects their compatibility with the intermittency of renewable energy.

Proton exchange membrane (PEM) systems are best suited with the intermittency of renewable electricity. They account for 40% of electrolysis facilities. The integration of membranes alters their lifespan (10 years vs above 30 years for alkaline), but they have several advantages: more compact, simpler in design and use, less prone to corrosion problems thanks to their solid (proton-conducting polymer membrane) electrolyte, and significant lower performance. This technology calls for electrodes based on platinum group metals, which affects their manufacturing costs.

Other promising electrolysis technologies are under development such as Solid Oxide Electrolysis (SOEC) and Anion Exchange Membranes (AEM) systems. SOEC rely on high temperature operations and ceramics material to produce both hydrogen and heat. Higher temperature allows to reach a better efficiency compared to PEM and alkaline technologies but calls for more input energy.

Despite the hype around renewable hydrogen made by electrolysis, current installed capacities are still embryonic (300 MW in 2020). Few hundred of projects are under development pipelines, mostly in Europe, Australia, and Latin America. Efforts remains to be done to stick to countries or regions' ambitions such as 40 GW installed capacity for European Union or 25 GW for Chili by 2030. Increasingly large projects are to be developed with an average project size estimated around 250 MW by 2030. Facilities deployment is linked to manufacturing capacities. Global systems manufacturing capacity was around 3 GW/year in 2020, with alkaline designs accounting for 85% and PEM less than 15%. Capacities mostly located in Europe and China. Gigafactory scales are planned. Major companies (Thyssenkrupp, Nel Hydrogen, ITM, McPhy, Cummins and John Cockerill) have announced plans to expand their production capacity, which, if achieved, could increase manufacturing capacity to around 20 GW/year by 2030.

With the increase in manufacturing capacities will come higher demand for minerals, particularly nickel (alkaline) and platinum group metals (PEM). This supply chain has to be secured to ensure a European manufacturing industry, both in securing supply of materials and in developing a recycling industry (e.g., recycling of PEM electrolyser cells).

Zoom 2: Fuel-cells manufacturing

Fuel-cells technology relies on the opposite mechanism of electrolysis. Systems use hydrogen to generate electricity thanks to oxidation principle, that can be enhanced thanks to platinum. Their use is quite clean as it outputs only electricity, water, and heat, but the overall efficiency of the electricity-hydrogen from electrolysis-electricity chain is around 25%[1].

Two technologies are leading the fuel-cells industry: PEM fuel-cells (PEMFC) and Solid Oxide fuel-cells (SOFC). SOFC are well-suited for high-power applications (kW to MW).

As of today, light-mobility represents the largest market of fuel-cells usage. Currently, global manufacturing capacity is around 200,000 systems a year including 30,000 systems for the Japanese car manufacturer Toyota and 20,000 systems for the Korean company Hyundai. 1.3 million of systems are expected to be manufactured per year by 2030, which would represent 90 GW/y.

As for electrolysers, fuel-cells face several challenges: the decrease of their production costs, the competition with other decarbonised uses (battery vehicles), and more. Other use of hydrogen is also developed: internal combustion engines where hydrogen is directly burned as a fuel. This technology is reliable and less expensive to produce than fuel-cells, but less virtuous as it is noisy and polluting (NOx).

Zoom 3: Hydrogen-based fuels

Considering its low volumetric energy density, gaseous hydrogen for transportation may not be optimal. A solution is to produce synthetic fuels from hydrogen with better volumetric densities, e.g., ammonia or methanol. This transformation to another substances enables to decrease the technological and financial constraints associated to hydrogen transport, storage and refuelling (e.g., ammonia liquefies at -33°C versus -253°C for hydrogen). Ammonia produced from hydrogen has chemical advantages (less prone to leakage, liquefaction temperature, and more), is already well developed (combustion engines, chemical industries, etc.), and benefits from existing dedicated infrastructures (loading,

1 ADEME « Power-to-H2-to-Power »

unloading, storage). Market is nascent, only a hundred of pilot/demonstration projects are known to convert hydrogen to methanol, ammonia, or other synthetic fuels. Clean ammonia and synthetic hydrocarbon production industries will rely mainly on hydrogen costs (gas and CCUS), or the cost of electrolysers and low-carbon electricity. The democratisation of hydrogen and its derived fuels, especially in emitter segments for which reduction is difficult, will be linked to the implementation of fiscal policies, e.g., through a CO_2 price or stricter fuel standards.

Leading countries in the Hydrogen industry

In recent years, about 20 industrialised countries published (or are about to) national hydrogen strategies. Major regions are in the loop such as European Union (Germany, France, Spain, Italy), Pacific area (Australia) and North America (Canada). Asian regions were pioneers with South Korea and Japan, who were the first to set hydrogen policies. Ambitions are to establish a hydrogen market, spreading worldwide with proprietary technologies and massify hydrogen uses in the mid-term (2030).

Hydrogen is largely seen as a solution to decarbonise both transport sector and industry. In mobility sector, heavy-duty mobility and ammonia production for shipping segment are applications of interest at worldwide level. Disparities may appear in Asian countries (South Korea and Japan) who emphasise the development of hydrogen for light-mobility. Japan also targets electricity production from hydrogen, either injected in gas grids or as ammonia. Nevertheless, a cleavage may appear regarding hydrogen production processes. Competition will focus on low-carbon hydrogen, known as blue hydrogen, which is being promoted by Canada and Australia among others, and on renewable hydrogen, known as green hydrogen, whose production projects are being mainly studied in European countries.

Japan is a pioneer in developing hydrogen industry. As an island, Japan is quite limited in terms of energy production and mostly rely on energy imports. Therefore, hydrogen is seen as a solution to strengthen its energy security by limiting oil and gas imports. In 2018, Japan was the first to adopt a national hydrogen policy framework enhancing the hydrogen use for light-mobility, capitalising on the pioneer Toyota, and electricity production, today mostly based on LNG. Supports will include a planned public investment of €6.5 billion over 10 years. Hydrogen sourcing will rely on two vectors: local renewable hydrogen production and the imports use. As local resources are limited due to the low renewable energy potential and the decrease of nuclear energy, the development and control of the hydrogen supply chain is a major challenge for Japan. Discussions are occurring and projects are developing with potential exporter such as Australia or Saudi Arabia.

Quite similarly to Japan, South Korea pioneered the hydrogen economy. In 2019, the government published its Hydrogen Economy Roadmap then the Hydrogen Economy Promotion and Hydrogen Safety Management Law. Legal framework and business support schemes have been established. Their hydrogen strategy is not motivated by environmental and climate reasons but rather by ambitions for economic growth and industrial competitiveness. South Korea wants to maintain its position as the world's largest hydrogen mobility market (presence of the hydrogen car manufacturer Hyundai) and to develop the use of large-scale stationary fuel-cells for electricity networks. Strategy relies at first sight on carbon-based hydrogen. On the same pattern as Japan, the country will also have to resort to imports from large producers.

The EU intends to develop a hydrogen economy with the aim of massive decarbonisation. As part of the European Green Deal, achieving carbon neutrality by 2050 was set as a primary goal and hydrogen is perceived as a mean to reach the goal. A hydrogen strategy was published in 2020, and a consortium, bringing together industrials, national and local public authorities etc. along the lines of the European Battery Alliance was formed. Strategy is fostering the growth of renewable hydrogen demand from industry and transportation, focusing on heavy transport (and in the longer term, maritime and air transport), and balancing role in the integration of variable renewable energies. With a local market focus, it aims at creating an integrated European hydrogen market, allowing facilitated transnational flows between potentially exporting production (e.g., Spain) and importing (e.g., Germany) regions. Clean hydrogen will be the sinews of war, EU intends to develop 6 GW of electrolysis capacities by 2024 and 40 GW by 2030. Strategy clearly prioritises renewable hydrogen but is however allowing blue hydrogen as an intermediary solution to initiate mass production then demand. Finally, EU is aware that it may have to rely on external imports given the large-expected demand (60 Mt in 2050).

France differs somewhat from the European strategy in its desire to establish a sovereign sector, limiting as much as possible the use of external imports. Ambitions are to set up a fully integrated hydrogen value chain in order to increase technological independence and strengthen energy security context. France plans to invest €7 billion by 2030 to support all segments of the value chain to rapidly decrease the decarbonised hydrogen production costs so that it becomes competitive with carbon hydrogen. By 2030, ambitious goal is to count 6.5 GW of electrolysis capacities, largely showing the focus on clean hydrogen. Other cross-border countries such as Spain and Italy also set up a national hydrogen strategy. Spain and Italy are respectively reaching 4 and 5 GW of electrolysis capacities by 2030. Spain relies on its high renewable energy potential to massify hydrogen production and export it to European countries. On the other hand, Italy intends to capitalise on its central position in the Mediterranean to become a hub for hydrogen exchange between North Africa and Europe by repurposing its existing gas grids.

Australia is capitalising on its very high renewable energy potential to become a major player in global hydrogen production and trade by 2030 based on economic motivations rather than environmental. Australia has considerable potential, to produce clean hydrogen and hydrogen from lignite with CCS. Currently, a dozen projects with capacities of over 1 GW are under development or under review. With a large exporting profile and gas exporting facilities, Australia will certainly be able to produce low-carbon hydrogen at low-cost and has entered into a series of international partnerships to promote hydrogen trade through discussions with Japan, South Korea, China, among others. The country aims to be among the top three exporters of hydrogen to Asian markets.

On the other side of the world, despite the current lack of a national strategy, the US was one of the first countries to consider hydrogen in the 2000s as a political way to move away from dependence on oil imports. The configuration of federal policies plus the alternation of powers (Democrats vs. Republicans) coupled with a decrease in the country's oil dependence due to the strong increase in national production over the last fifteen years has resulted in a lack of progress in this area. Recently, a new dynamic has been given impetus by the arrival of President Joe Biden. At the end of 2021, the Hydrogen Energy Earthshot aims to both reduce the costs of manufacturing electrolysers and produce clean hydrogen at $1 per kilogram by 2030 with the ambition to achieve a five-fold increase in demand for clean hydrogen in the country. Local dynamics of the refining and chemical industries are propelling the US into the world rank of major hydrogen producer and consumer, leaving a clear opportunity to consume clean hydrogen. However, industrials seem to focus on the deployment of blue hydrogen production capacity, particularly encouraged by the tax credits offered by the government.

China is the world's largest user of hydrogen, mainly in the refining and chemical sectors. Despite its current domestic production is based on fossil fuels, of which 60% is coal and 25% is natural gas, China announced in 2020 its commitment to achieving carbon neutrality by 2060. Hydrogen is seen as a cornerstone to decarbonise industry sector.

As part of the 14th Five-Year Plan (2021-2024), China is targeting to produce by 2030 half of its hydrogen from renewable energy sources. Like its neighbours, hydrogen use in transportation is the main sector supported by the government.

On its side, Russia must adapt to the changing global energy landscape brought by the energy transition, and thus avoid a strategic downgrading. The hydrogen economy is likely to greatly alter its established place in the oil and gas sector. Russia wants to capitalise on its existing gas grids to export low-carbon hydrogen and takes a technology-neutral stance, considering the production of hydrogen from hydrocarbons with carbon storage, from nuclear power or from renewable energies. However, renewable hydrogen production will likely be limited considering its low renewable energy potential (e.g., low sunshine and reduced wind potential).

The Russian hydrogen roadmap, quite blur, gives a special role to the state-owned gas company Gazprom and the nuclear company Rosatom in achieving the objectives set out.

Elsewhere in the world, some countries have begun investments to become global exporters. Among them, Chile is betting on its enormous potential for renewable energy, far greater than its consumption. The Middle East could also become a low-carbon hydrogen mass production region thanks to both its huge oil and gas reserves and its huge renewable energy potential.

Figure 3: Countries that have defined a hydrogen strategy (or are in the process of doing so)

Source: WEC (2021) and Bloomberg (2021b)

Future power relationships within Hydrogen economy

Hydrogen economy is likely to shake-up power hierarchies in international relations, but nothing is done yet. Uncertainties about the development of the low-carbon hydrogen value chains are risky. While huge investments in production-storage capacities and transport infrastructures are a necessary condition for reducing the overall costs of the sector, on the other hand, the lack of visibility on the real evolution of supply and demand as well as on the way the market will be structured makes these investments particularly hazardous.

Transition to an energy system dominated by renewable energy and hydrogen can be defined as a revolution because it redistributes the factors of power and dependence. This will particularly be the case for countries importing fossil fuels. This transition would offer an opportunity to break the hegemony of the oil and gas producing countries, and to free themselves from their dependence. As hydrogen will be technically producible anywhere, countries will choose their way of supply on economic grounds.

The first challenge is to master the technologies of the renewable hydrogen value chain. Some countries will have the opportunity to become international leaders. Some have already taken a lead and begun to assert their technological influence such as Germany, South Korea and Japan, which have a clear technological lead in the field of fuel-cells, holding nearly 40% of all patents in this area. China could also benefit from its industrial know-how and competitiveness and strong government commitment easing access to capital to conquer the market with the lowest prices. To avoid a similar relocation scenario of the battery and photovoltaic panel industries to Asia, the European Clean Hydrogen Alliance was launched in December 2020, which aims to strengthen cooperation between industry and public authorities at European level in order to facilitate the emergence of an integrated hydrogen industry in the EU.

Second challenge is to define standards for the production, trade, and use of hydrogen. This issue raises an international battle for influence. Several issues are at the heart of the debate, including the establishment of a certification system to accurately identify the carbon content of hydrogen and derived fuels. The choice that will be made by the major global powers will be decisive and will affect the entire production chain. Especially, the policy that the European Union will follow will have an essential impact on the countries status such as Russia, which has a very large production capacity potential for blue hydrogen, unlike green hydrogen.

Today, hydrogen is mostly consumed where it is produced, mainly in refineries. With future increase in hydrogen demand, this balance will quickly become obsolete and force countries to make a series of choices to ensure their own supply. The hydrogen cost from electrolysis is directly related to the energy cost used to produce it. Some regions will inevitably benefit while others will be constrained, and it may be more profitable for some countries to import renewable hydrogen than to produce it. For example, renewable hydrogen is driven by the price of a kilowatt-hour from solar or wind, power and blue hydrogen costs rely on the price of natural gas plus the cost of CO_2 storage solutions.

The hydrogen market will be established relying on several factors. First will be hydrogen production cost differential between countries. Second will be the availability of freshwater resources, essential for the hydrogen made from electrolysis. Third will be the existence or capacity to develop production and export infrastructure. In this respect, some countries already have an advantage if they have existing gas industry facilities. Fourth will be political, as governments of importing countries will have to arbitrate between their national economy competitiveness and the desire to ensure a certain level of energy independence. In this regard, France and Germany have two different positions as France wants to develop a sovereign economy and Germany will outsource its supply to safeguard the competitiveness of its industry.

The hydrogen market will account at least four categories of countries: major suppliers, suppliers constrained by limited water resources, rich resources countries but limited by lack of infrastructure, major importing countries, by choice or by compulsion. Chile, Australia, and Morocco are likely to become major hydrogen suppliers. They will capitalise on their huge renewable energy potential to produce a low-cost renewable hydrogen. Middle East and North Africa also have plenty of renewable resources, but they will be limited by their freshwater resources. They will not be able to supply hydrogen massively given this geologic limitation. It seems likely that the Middle East will play a smaller role in the renewable hydrogen market than it does in the oil market today. Russia will certainly witness its reducing energy dominance over the EU. The European Union, Japan and South Korea will inevitably resort to hydrogen imports to ensure their demand. European Union has the theoretical potential to ensure its own supply, but the point will be on maintaining the competitiveness of the hydrogen production.

Conclusion

The hydrogen vector development is undeniably at the centre of discussions. Substantial budgets of several tens of billions of dollars in public and private funding have been made available for this purpose. However, many uncertainties remain, as the timing and extent of the hydrogen market. A balance must be made between renewable hydrogen projects massification, and demand stimulation by supporting new applications. Competitiveness of hydrogen technologies and projects will be the cornerstone to expanding its use.

The definition of renewable production targets will not be enough to lower carbon emissions. They should be supported by concrete policies, essential for industry to trigger significant growth in hydrogen demand. In particular, government action will be needed to narrow the price gap between hydrogen and fossil fuel alternatives.

Although still highly localised and carbon-intensive, hydrogen production and consumption should, if the industry takes off, reshape the global energy trade map, creating a new class of exporters as well as a series of import-dependent countries. A new hydrogen geo-economy will emerge, changing trade links and the geography of risk by replacing old geo-political flashpoints related to oil and gas with new ones. These new dependencies will never be as restrictive as for oil and gas products, as it is technically possible to produce hydrogen from anywhere.

Hydrogen gives investors a choice of investment country, which will generally be economically and politically stable countries. This should significantly enhance the stability of global energy markets.

This Executive Brief stems from an analysis by Enerdata, the French Institute for International and Strategic Affairs (IRIS) and Cassini for the French Ministry of Defence (full report available in French here).