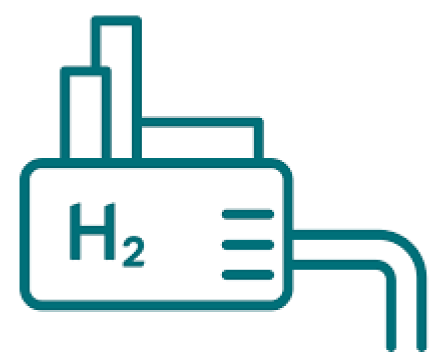
Hydrogen Energy



LYNX Industry Notes
December 2020

Background

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- Hydrogen energy is witnessing unprecedented interest, not only from long-time enthusiasts like Japan and Korea, but from upstarts like Australia and Chile. Germany recently announced a plan to spend € 7 billion on hydrogen as part of an economic stimulus package. The International Energy Agency (IEA)–born in the oil crises–is publicly suggesting that we need more hydrogen in the energy system, and the World Economic Forum helped seed the Hydrogen Council, whose members include oil and gas companies, carmakers, trading companies and banks. European Commission Vice President Frans Timmermans sees hydrogen as essential to Europe's Green Deal.
- Hydrogen is a super-versatile energy carrier with exceptional energy density (MJ/kg). Today, around 70 million metric tons of hydrogen are produced globally, used across an array of sectors – fertilizer, refining, petrochemicals, solar panels and glass manufacturing. In the future, hydrogen will have a huge role to play in decarbonizing the global economy, especially in hard-to-decarbonize sectors such as steel and cement, and in fuel cells for vehicles, particularly mass transport and any other applications.

The Evolving Hydrogen Economy

- The emergence of a broad social movement demanding stringent policies for climate change mitigation in Europe and elsewhere changed the political landscape in a number of countries as green parties scored record votes. Therefore, policymakers in many countries are sharpening their emission reduction targets for 2030 and 2050. At the same time, strong interest in an integrated hydrogen economy is emerging, where hydrogen would become a key fuel for transportation, industrial uses and even electricity generation. Countries as diverse as Australia, China, European Union (EU) member states and Japan are embarking on far-reaching strategies for a hydrogen economy, starting with the support of fuel-cell electric vehicles (FCEVs) but reaching beyond the transport sector.
- The rising membership of the Hydrogen Council, formed in 2017 to over 90 members today, reveals the widespread interest among big players across multiple sectors in hydrogen. This includes automakers (among them BMW, GM, Toyota and Honda), power and gas utilities (Engie and EDF), as well as engineering (Bosch, Alstom), finance (BNP Paris Bas, Credit Agricole) and oil and gas companies (Mubadala, Aramco, Shell, BP, Total and Equinor).

Hydrogen Strategies

National Hydrogen Strategies

- There has been a proliferation of published national hydrogen strategies, starting with Japan in 2017, and subsequently followed by South Korea (2019), New Zealand (2019), Australia (2019), Netherlands (2020), Norway (2020), Portugal (2020), Germany (2020) and, most recently on July 8, 2020, from the EU. The latter will be an important document for driving the hydrogen agenda in Europe.

Basic Hydrogen Strategy in Japan 2050

- **Vision:** Position H2 as a new energy option (following renewables)
- **Target:** H2 Volume: 300k t/y by 2030 ⇒ 5〜10m t/y by 2050 -- H2 Cost: $3/kg by 2030 ⇒ $2/kg by 2050
- **Uses:**

Power Generation: 17¥/kWH by 2030 ⇒12¥ /kWH by 2050

Fuel Cell Vehicles (FCV): 40k in 2020 ⇒ 800k by 2030 ⇒replacing conventional gasoline mobility

Hydrogen Refueling Stations (HRS): 160 in 2020 ⇒900 by 2030 ⇒replacing gasoline refueling stations

Fuel Cell Buses: 100 in 2020 ⇒ 1.2k by 2030 ⇒replacing conventional gasoline & introducing large FCVs

EU Hydrogen Strategy Key Aspects

- The EU strategy sets an ambitious vision for 40GW of electrolyzer capacity within Europe by 2030 to produce “renewable hydrogen” (also known as “green” hydrogen), plus an additional 40GW electrolyzer capacity in the southern and eastern neighborhoods of Europe (e.g. Ukraine or Morocco) from which Europe could import renewable hydrogen.
- It sets a target for 6GW of electrolyzers by 2024.
- It estimates the list of potential global investments in electrolyzers planned to be operational by 2030 to be 8.2 GW, 57% (or ca. 4.5GW) of that capacity is in Europe.
- It recognizes that there is a need to build a clear pipeline of viable investment projects, and the European Clean Hydrogen Alliance has been established to promote the creation of that pipeline.
- It acknowledges that in the short and medium term, “blue” hydrogen” will play a role. To illustrate their view of the relative importance, it suggests that by 2050 cumulative investments in renewable hydrogen could be €180-479 billion.
- In the shorter term, up to 2030, it envisages that investments in electrolyzers could range between €24 billion and €42 billion.
- It envisages 80-120 GW of solar and wind energy and a cost of €220-340 billion.

IOCs' Strategies

IOCs' Strategy Review

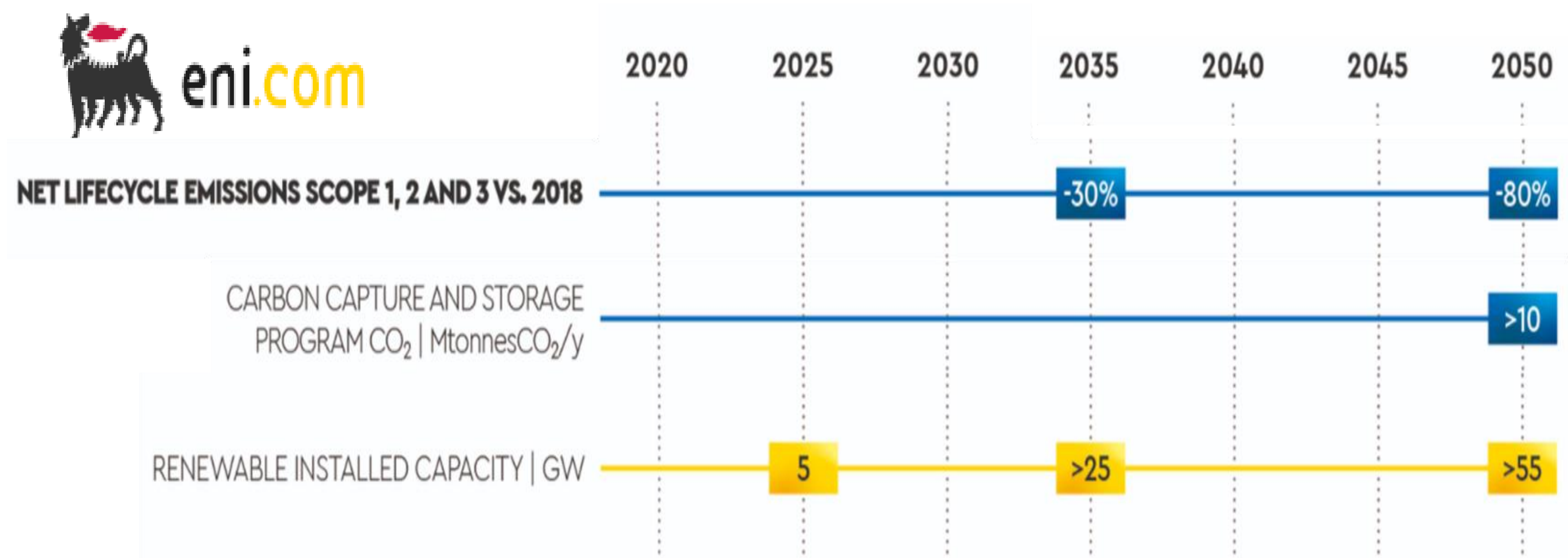
- The rising membership of the Hydrogen Council, formed in 2017, reveals the widespread interest among big players across multiple sectors including international oil companies (IOCs), such as Aramco, Shell, BP, Total, Mubadala, and Equinor.
- Pressure from activists and institutional investors is intensifying on oil majors to enhance their energy transition, increase their investments in renewable energy and develop new technologies. As a result, several IOCs announced revised strategies.

British Petroleum (UK)

Royal Dutch Shell (Netherlands)

Drivers

ENI (Italy)



Hydrogen Energy Drivers

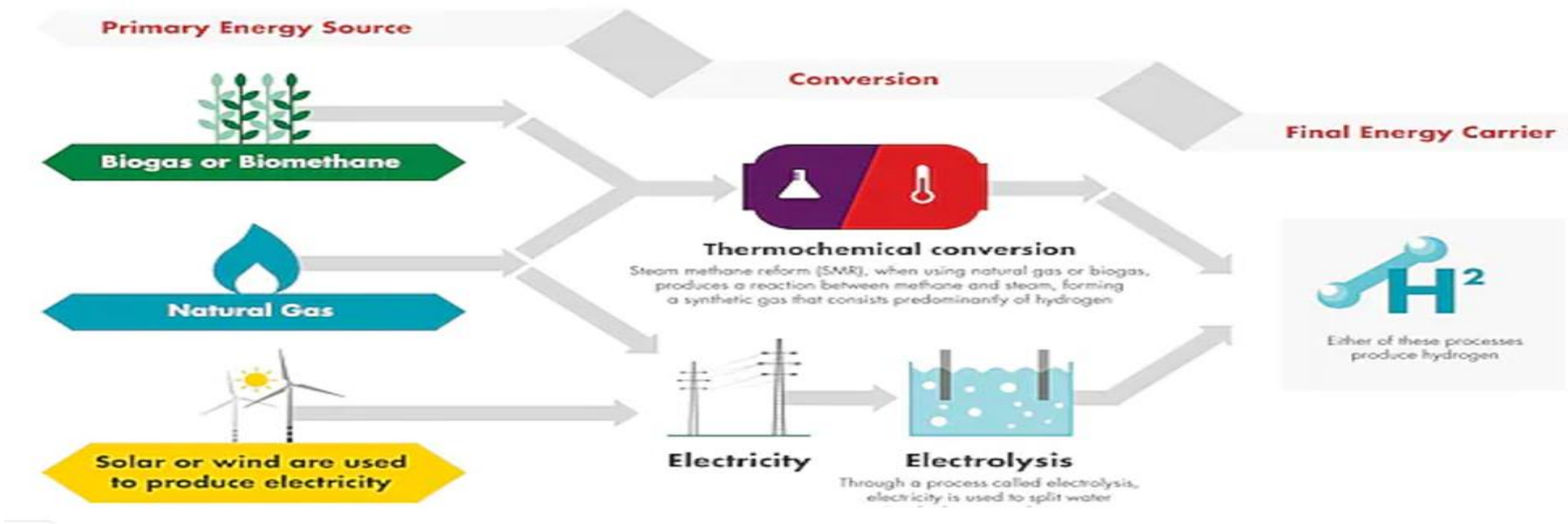
- Three powerful drivers are pushing hydrogen forward. Firstly, the concept of 'net zero' carbon emissions is gaining pace. National governments and energy companies alike are proclaiming it to be their goal. Models show that without hydrogen, net zero is almost impossible to achieve. Hydrogen is needed to help decarbonize heat, and shipping, and long-haul trucking, and fertilizer, and heavy industries such as steel.
- Secondly, our energy and transport systems are on the brink of upheaval, bringing dramatic economic pain. The growth of renewables is accelerating, cost is dropping, vehicles are becoming electric and maybe autonomous. Traditional industries are facing existential threats, and hundreds of thousands of discarded jobs. Hydrogen can help such industries in reinventing themselves, create employment and drive economic growth, while still meeting the climate imperative.
- Thirdly, Covid-19 has brutally exposed the inherent fragility and endemic risk in our economies. Supply chains are stationary, oil prices have gone negative, and fiscal rules have been rewritten. The risk from climate change is seen as many times worse. Major company shareholders, such as pension funds, are scrutinizing corporate Environmental, Social and Governance (ESG) reports for their willingness to limit social upheaval and exposure to carbon emissions.
- Investors and analysts increasingly regard hydrogen as an option for long-term sustainable investment, rewarding- rather than penalizing- company boards for pursuing it.

Overview

What is Hydrogen?

- Hydrogen the most abundant element in the universe. It’s also used abundantly as an input into oil refining, ammonia and methanol production, as well as steel manufacturing. Hydrogen is the lightest chemical element; its symbol is H. Under ambient temperature and atmospheric pressure, atomic hydrogen (H) does not occur. Instead, hydrogen exists in the form of hydrogen molecule (H2), where two hydrogen atoms are firmly combined.

Hydrogen Production



- Although hydrogen is abundant, it is rarely found in its pure form, produced mainly through chemical reactions. Around 99% of hydrogen today is produced through fossil-fuel reforming, a process that produces a reaction between natural gas and steam. Hydrogen can also be produced from renewable sources, using biogas, a gaseous form of methane obtained from biomass, or through electrolysis using electricity generated by renewable sources.
- Through electrolysis, water molecules are split into hydrogen and oxygen atoms. Produced with no hydrocarbons, green hydrogen can go a long way to reducing a nation's or company’s emissions.
- Electrolyzers can operate dynamically, requiring only seconds to be able to operate at maximum capacity. As such, they can be easily paired with renewable assets that are frequently interrupted either a long or short duration.

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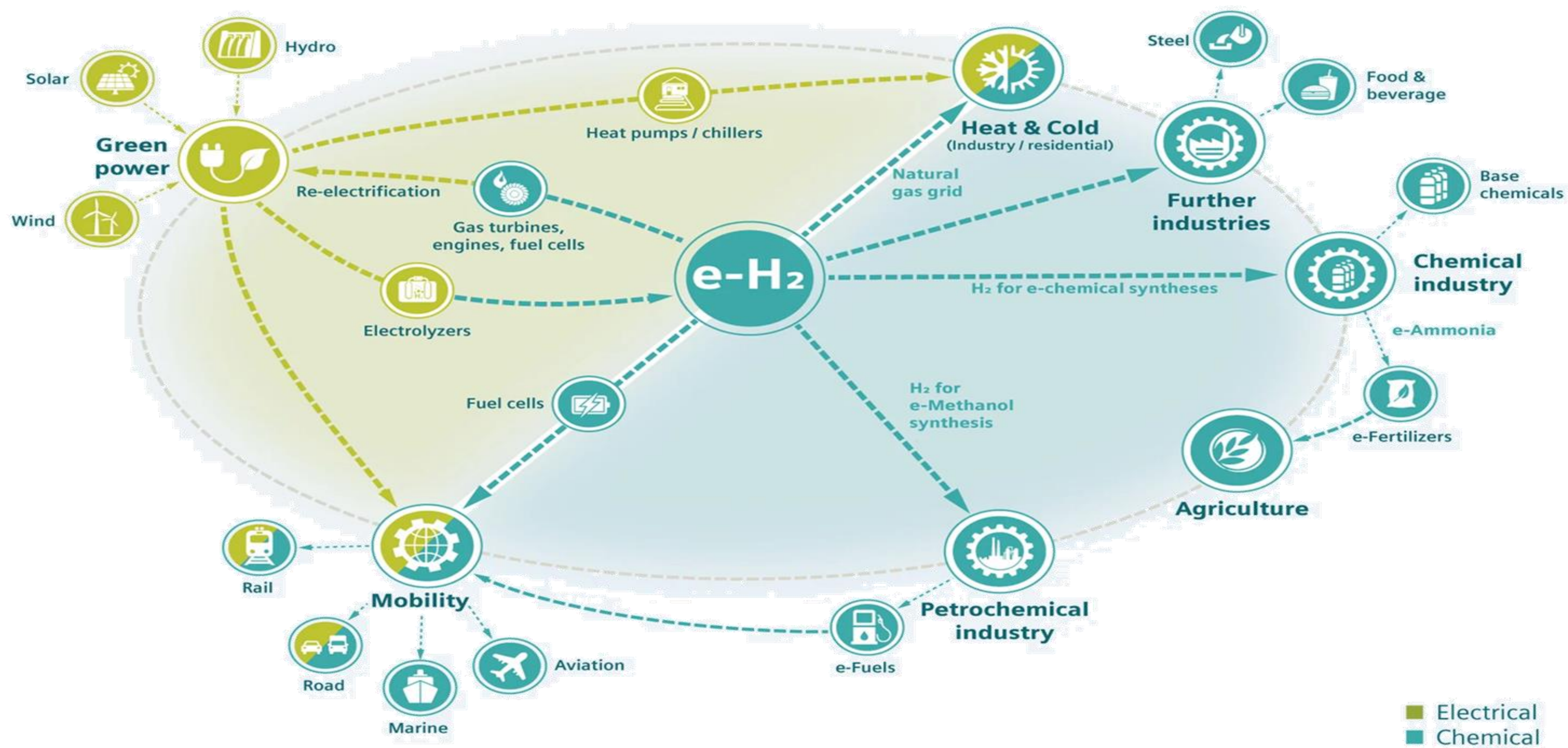
Overview

Hydrogen Color Palette

For a colorless gas, hydrogen gets referred to in very colorful terms. According to the nomenclature used by market research firm Wood Mackenzie:

- **Brown**, if hydrogen made through the gasification of coal or lignite.
- **Gray**, if it is made through steam methane reformation, which typically uses natural gas as the feedstock. Neither of these processes is exactly carbon-friendly.
- **Blue**, where the gas is produced by steam methane reforming but the emissions are curtailed using carbon capture and storage. This process could roughly halve the amount of carbon produced, but it's still far from emissions-free.
- **Green**, if it's by using renewable energy to power the electrolysis of water; could almost eliminate emissions.
- Green hydrogen is produced by wind and solar via electrolysis, splitting water molecules into hydrogen and oxygen atoms. Produced with no hydrocarbons, it can go a long way to reducing a nation's or company's emissions.

Hydrogen Ecosystem



Applications

Storage and Transportation of Hydrogen

- Because hydrogen has a very low volumetric energy density, it has to be compressed for storage and transportation purposes. A higher storage density can be achieved by hydrogen liquefaction. The storage of hydrogen (for compression or liquefaction at -250°C) requires energy; work is in progress on more efficient storage methods. Unlike electricity, hydrogen can be successfully stored in large amounts for extended periods of time in long-term underground storage facilities, thus, acting as buffer store for electricity from surplus renewable energies.
- At present, hydrogen is generally transported by lorry in pressurized gas containers, and in some cases also in cryogenic liquid tanks. Moreover, local/regional hydrogen pipeline networks are available in some locations. In the long-term, the natural gas supply infrastructure (pipelines and underground storage facilities) could also be used for the storage and transportation of hydrogen.
- Liquid hydrogen is suitable for long-distance transport, compressed gaseous hydrogen is suitable for shorter distances in smaller amounts, while pipelines are advantageous for large volumes.

Applications and Future Usage of Hydrogen

- Hydrogen is used in large quantities for chemical product synthesis, especially to form ammonia and methanol. Refineries, where hydrogen is used for the processing of intermediate oil products, are another area of use. According to the Shell Hydrogen Study of 2017, about 55 % of the hydrogen produced around the world is used for ammonia synthesis, 25 % in refineries and about 10 % for methanol production. The other applications worldwide account for only about 10 % of global hydrogen production.
- Hydrogen holds long-term promise in many sectors beyond existing industrial applications. The transport, buildings and power sectors all have potential to use hydrogen if the costs of production and utilization develop favorably relative to other options with carefully crafted policy support.

Industrial Applications

- A potentially large-scale industrial use of hydrogen in the decarbonizing energy system is in iron and steel production. In 2019, a total of 1,870 million tons of CO2 were emitted, which would equate to around three gigatons (Gt) CO2 (or around 10 per cent of total global energy related emissions). Ninety percent of primary steel production today is by the blast furnace/basic oxygen furnace route, using coal as a feedstock. On the other hand, seven percent of primary steel production is by the direct reduction of iron-electric arc furnace route, using hydrogen and carbon monoxide as reducing agents.

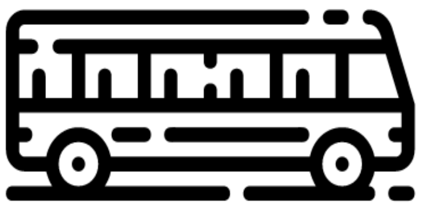
Power Generation

- Power generation offers many opportunities for hydrogen and hydrogen-based fuels. In the near term, ammonia could be co-fired in coal-fired power plants to reduce CO2 emissions. Hydrogen and ammonia can be flexible generation options when used in gas turbines or fuel cells. At the low capacity factors typical of flexible power plants, hydrogen costing under USD 2.5/kg has good potential to compete. Key low-carbon competitors for such services include natural gas with CCUS and biogas. In the longer term, hydrogen can play a role in largescale and long-term storage to balance seasonal variations.

Applications

Transport Applications

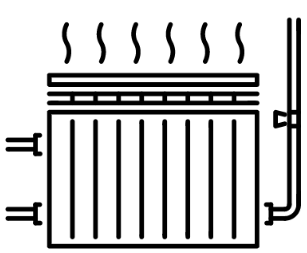
- Electric vehicles (EVs) are driven by electricity that is stored in an on-site battery. Charging can take place at home or a public EV-charging stations. While the technology has progressed significantly in the last decade, its key challenges remain: limited range, weight of the batteries and long recharging times (1 to 14 hours, depending on the capacity of the charger). Additional problems associated with EVs are the environmental impacts of battery production. Contrary to this, fuel-cell electric vehicles (FCEVs) are powered by hydrogen that is converted in a fuel cell into electric energy. FCEVs therefore do not need as large a battery as EVs. Hydrogen is stored in a tank similar to that for gasoline/diesel in conventional cars, and the re-fueling process is quick. The range of FCEVs is comparable to that of a conventional car. Today's challenges include that hydrogen cars are still very expensive due to the lack of mass production and that the underlying infrastructure, such hydrogen fuel stations, has yet to be built.



- In terms of road transport, buses in the public transport network are the most thoroughly tested area of application for hydrogen and fuel cells. Modern fuel cell buses draw their energy from two fuel cell stacks, each with an output of approx. 100 kW. They also have a relatively small traction battery and are able to recover brake energy. In addition, they carry approximately 30 to 50 kg of compressed hydrogen on board, stored in pressure tanks at 350 bar. Fuel cell buses now have a range of 300 to 450 km and so offer almost the same flexibility as diesel buses in day-to-day operation. In early stages of deployment, building hydrogen stations that serve captive fleets on hub-and-spoke missions could help to secure high refueling station utilization and thus could be a way to get infrastructure construction off the ground.

- Shipping and aviation have limited low-carbon fuel options available and represent an opportunity for hydrogen-based fuels. Ammonia and hydrogen have the potential to address environmental targets in shipping, but their cost of production is high relative to oil-based fuels. Hydrogen-based liquid fuels provide a potentially attractive option for aviation at the expense of higher energy consumption and potentially higher costs. Policy support in the form of low carbon targets or other approaches is critical to their prospects.

In-Buildings Heat



- Displacement of natural gas for the purposes of heating is the principal opportunity that hydrogen represents. Heating accounts for almost half of all emissions in the UK, therefore tackling this source of carbon dioxide will be paramount in achieving the legally-binding reductions set by the UK government. Hydrogen deployment within the context of heat could take a variety of forms, from blending in the network, to full conversion of industrial users or even the wider network. The opportunity of hydrogen has been recognized by all gas distribution networks (GDNs) as demonstrated by the number of projects underway. The gas industry has a history of hydrogen; given that it was the single most abundant component in towns gas - the UK's gas supply prior to the discovery of natural gas beneath the North Sea.

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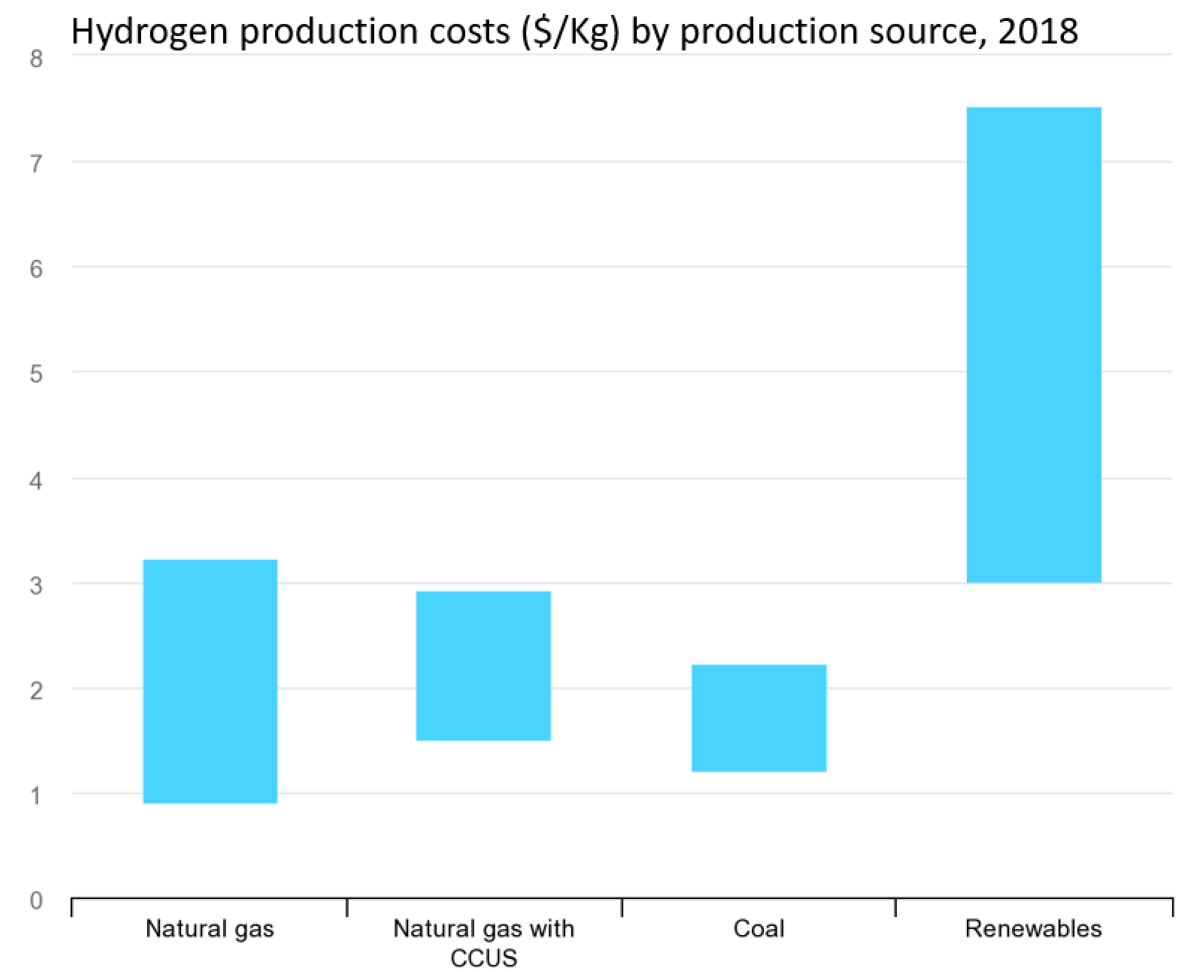
Hydrogen Economics

Economics

- Green hydrogen has to compete with SMR hydrogen, which costs between US$1- 2/kg without CCS – or 50 cents more when paired with CCS. These are costs that green hydrogen cannot get close to currently. Green hydrogen's economics are particularly sensitive to two factors – power prices and plant utilization rates. The economics only work on what are unrealistic assumptions today – high load factors (more than 50%) and low electricity prices (below US$30/MWh). But, right now, a green hydrogen plant paired with a renewable source could expect load factors nearer 20%; typically, power purchase agreement prices for renewables are nearer to US$50/MWh globally.
- How could green hydrogen become viable? First, cost reduction. Woodmac expects capex to fall by 30-40% by 2030, especially as the manufacturing process for electrolyzers moves to automation; unit feedstock costs reduces by 5% and electrolyzer efficiency improves by 8%.
- With declining costs for renewable electricity, in particular from solar PV and wind, interest is growing in electrolytic hydrogen and there have been several demonstration projects in recent years. Building electrolyzers at locations with excellent renewable resource conditions could become a low-cost supply option for hydrogen, even after taking into account the transmission and distribution costs of transporting hydrogen from (often remote) renewables' locations to the end-users.



Source: IEA

Multinational Investors

- Most of the world's energy companies and big industrial groups are involved in hydrogen. Recent announcements included that of Mitsubishi Power Americas Inc., which plans to build three hydrogen-ready gas-fired power plants in the US. Germany's RWE, also announced plans to supply hydrogen to steel maker Thyssenkrupp AG and to promote the use of the fuel at its planned liquefied natural gas terminal in Germany. The U.K.'s ITM Power and Ceres Power, Sweden's Powercell and Norway's Nel ASA are among the listed companies whose core business involve hydrogen technologies. Australia's Infinite Blue Energy outlined plans for an initial public offering that would make it the first zero-emissions hydrogen company to list on the Australian Stock Exchange. Utility giant Entergy Corp. is taking steps to throttle back its reliance on natural gas by investing in hydrogen production with Mitsubishi Power. European plane maker Airbus SE is working on designs for hydrogen-powered aircraft as it races to bring a zero-carbon passenger plane into service by 2035.

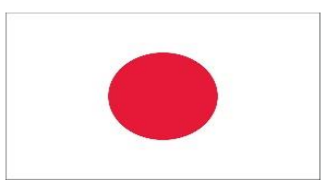
Gov't Directions

Investors

- **European Union:** The European Commission recently published the European Hydrogen Strategy and presented the Clean Hydrogen Alliance which expects a cumulative investment on green hydrogen from €180 to €470 billion by 2050. With the EU looking to promote green hydrogen to help reach net zero emissions, its hydrogen sector is expected to attract hundreds of billions of Dollars in investment in the coming decades. The recent EU Recovery Plan to overcome the economic crisis comprises the Next Generation EU fund and the revised EU budgets, and within it are two instruments with a total budget of €1.8 trillion for the period of 2021-2027. The recovery plan will also benefit EU Member States with ambitious plans for a sustainable hydrogen development.

- **United States:** The Department of Energy's Fuel Cell Technology Office leads a multi-year R&D program that aims to reduce the cost of hydrogen production, reduce the costs of hydrogen delivery, and is also starting a project to look at H2 at Scale. The Department of Transportation and the Environmental Protection Agency are investing in pilot programs for fuel cell buses and trucks. The State of California provides funding for all alternative fuels through the Alternative and Renewable Fuel and Vehicle Technology Program (often called "AB8.") The program is funded by a small surcharge on vehicle and boat registrations, along with smog check and license plate fees.

- **China:** The national Government is promoting the development of hydrogen and its application in several areas and with several instruments. For example, the Government provides tax reduction and subsidies for FCEVs, ranging from RMB 20k to 50k depending on the type of the vehicles and the capacity of hydrogen fuel cells. Local governments could offer additional subsidies for FCEVs that don't exceed the national ones.
- In addition, a number of funds have been set up for investments. Industry funds, for example, combine public and private investments including state-owned companies, research institutions and universities (such as Tongji University, China University of Geoscience), local governments (such as Dalian, Wuhan), commercial institutions and private companies.
- In June 2019, Dongfeng Electric Group signed an agreement with Three Gorges Capital and Chengdu Innovation Ventures to initiate a hydrogen industry fund of RMB 500 million (about USD 73 million).
- In May 2020, China Energy signed a cooperation agreement with Donghu Development Zone and Wuhan ITRI of Geo-resources and Environment Co. to establish a hydrogen industry fund in Donghu (Wuhan province), with a size of RMB1 billion (about USD146 million) for the first phase.



- **Japan:** Funding and financing support are available from key government organizations. For example, funding for hydrogen related research, feasibility studies and pilot projects is provided by the New Energy and Industrial Technology Development Organization (NEDO) and Japan Oil, Gas and Metals National Corporation (JOGMEC). The Government has taken considerable actions at the legislative and policy levels to facilitate this. JBIC's statutory law was amended in January 2020 to specifically include hydrogen as an eligible sector for JBIC's export credits and overseas investment loans for projects in developed countries.

- **Australia:** The Clean Energy Finance Corporation's Advancing Hydrogen Fund aims to invest up to A$ 300 million (US$ 231 million) to support the growth of a clean, innovative, safe and competitive Australian hydrogen industry.

- **Egypt:** The Government formed a ministerial committee to develop a national hydrogen strategy. And in response to the impact of the Covid-19 pandemic on the Egyptian economy and to target boosting green finance, the European Bank for Reconstruction and Development (EBRD), the EU and the Green Climate Fund (GCF) launched on November 10, 2020 two programs totaling €220 million to offer sub-loans to businesses for green investments in energy, water and resource-efficient solutions.

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Conclusion

Conclusion

- The trajectory for moving towards hydrogen is really picking up pace.
- International Energy Agency (IEA) reports point to hydrogen fuel as an important source of low carbon energy. There is increasing international consensus on the benefits of this fuel due to its enormous potential to reduce carbon emissions from various sectors. IEA also urges the countries to meet the challenges that impede the promotion of the use of hydrogen fuel as a potential source of energy, free of emissions. The Agency considers that its use as a fuel will contribute to reducing emissions in sectors such as transportation, chemicals, and steel. It expects that the cost of producing hydrogen from renewable energy will decrease by 30% by 2030.
- However, the IEA warns of the challenges in the path towards benefiting from hydrogen as an energy source, including its high cost, in addition to the fact that hydrogen gas itself is volatile and highly flammable.
- IEA recommends the development of policies to support the new investments needed to reduce costs and support this industry, noting that hydrogen has not previously received such international attention from various sectors.
- On the other hand, the Hydrogen Council, a global coalition of 90+ CEOs working to enable the energy transition through hydrogen, continues to call on governments around the world to invest in hydrogen as part of their Covid-19 recovery plans. In the Council's view, hydrogen technologies can empower a more robust, resilient and sustainable economy, but urgent action and global collaboration is required to deliver on their unique potential.
- The Government of Egypt is encouraged to swiftly respond to the recommendations of the IEA, Hydrogen Council and other international organizations' calls for the acceleration of energy transition through hydrogen. By doing so, Egypt would follow suit major energy players on both the regional and international level and advance Egypt's strategic objectives to enhance its energy economy and position the country as an energy hub.

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Thank you

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