An Introduction to Hydrogen – Key Element of the Energy Transition.

Germany aims to meet its net zero ambitions by 2045. The energy carrier hydrogen (H_2) is crucially important for reaching both this as well as the associated climate protection goals. This publication explains why the lightest chemical element, hydrogen, should play such a significant role in achieving our climate protection goals, and offers valuable information about this element.

The most abundant element in the universe is available in almost unlimited quantities

A colourless, odourless gas, hydrogen is the most abundant chemical element in the universe. This is hardly surprising, as it is present in water and in almost all organic compounds. However, the fact that at ambient conditions hydrogen is by its very nature bound to other elements requires the hydrogen molecules to be separated from these other elements to obtain pure, unbound hydrogen.

There are various methods by which hydrogen can be produced, and all yield the colourless gas hydrogen. Yet it has been given many colourful terms: green, grey, blue, or turquoise hydrogen. These are essentially colour codes used to differentiate between hydrogen production methods and the associated energy carriers.

Making hydrogen usable for everyone via the gas distribution networks

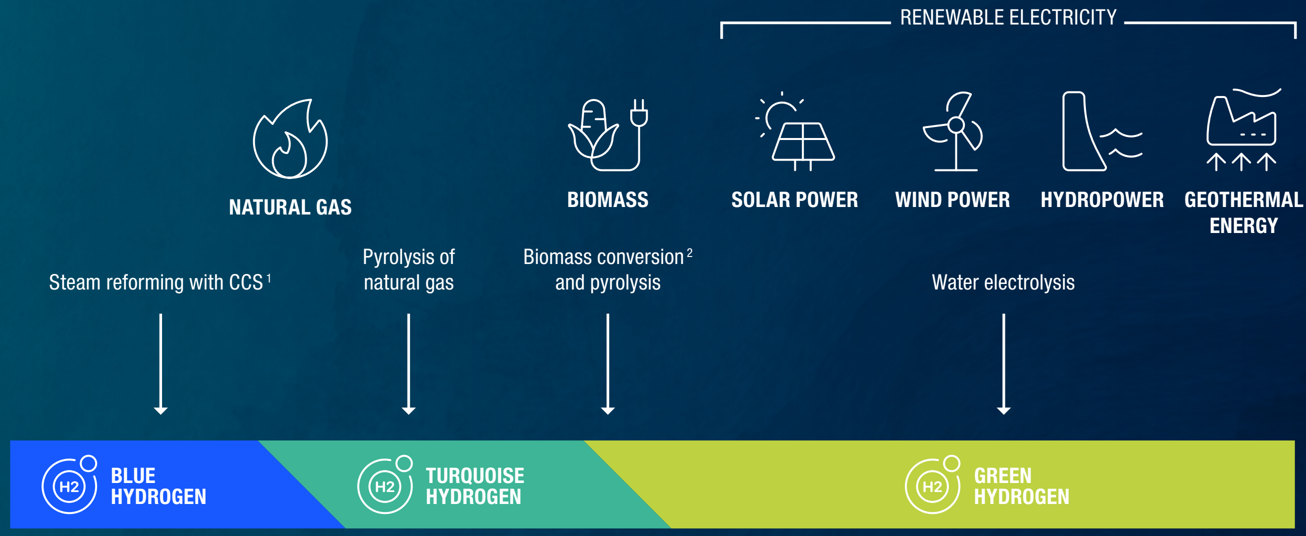
At present, most of the world's climate-friendly hydrogen is produced by steam reforming and electrolysis. The former involves using high-temperature steam to produce hydrogen – and CO_2 emissions – from an energy source such as, for instance, natural gas; the latter uses electricity to split water (H_2O) into hydrogen (H_2) and oxygen(O).

Grey hydrogen is produced from fossil fuels such as crude oil or natural gas. Using high-temperature steam, hydrogen and CO_2 are produced by steam reforming e.g. natural gas, or by an electrolysis process powered by electricity generated from fossil fuels. The CO_2 produced by these two methods is released into the atmosphere. In 2018, grey hydrogen met 95 percent of the annual global demand for hydrogen, which totalled 120m tonnes; this corresponds to about 4,000 terawatt hours or eight times the power generated annually in Germany.

Blue hydrogen, too, is produced by steam reforming natural gas: Natural gas is split into hydrogen and CO_2 in the presence of steam. The CO_2 that is generated during this process, however, is captured and stored (Carbon Capture and Storage, CCS) right away so that no CO_2 is released into the atmosphere, i.e. blue hydrogen burns without producing carbon dioxide emissions.

Green hydrogen is produced by water electrolysis, with the electrolysis process being powered by renewable energy so that no CO_2 is produced. Green hydrogen thus provides considerable potential for meeting net zero ambitions.

Turquoise hydrogen is made by pyrolysis, a process that produces hydrogen and solid carbon from natural gas or biomethane in the presence of extreme heat and under the exclusion of oxygen. The hydrogen thus produced is climate-neutral because the carbon is present in solid form instead of CO_2. If climate-neutral biomethane is used as a feedstock, CO_2 could even be removed from the atmosphere. Turquoise hydrogen production however has yet to be proven at scale.



[1] Carbon Capture and Storage, [2] Thermal processes and fermentation

Hydrogen: An all-rounder useable in every sector

Hydrogen is the all-rounder in the range of energy carriers. It can be flexibly used in all sectors and, what is more, may be used as a medium and long-term storage medium for renewables. In the heating sector, hydrogen can considerably contribute towards decarbonising residential heating even today: Injecting hydrogen into the natural gas grid may gradually decarbonise domestic heating systems, for instance. Climate-friendly hydrogen is also a leading option for decarbonising many industrial processes, as – unlike electricity – hydrogen can be used in processes that require the generation of extreme heat. In the transport sector, pure hydrogen can be used in fuel cells that power cars, trucks, buses, or trains. Even short-haul flights may soon become climate-friendly if operated by e.g. fuel cell-powered aircraft. And hydrogen will also play a major part in future power supply systems as it can be easily stored in existing gas storage facilities; if necessary, it can also be used to generate power in power plants or – decentralised – in fuel cells. It thus helps to ensure the safe supply of energy when only small quantities of power generated from wind or solar are available during dark and windless periods, eliminating the need to resort to fossil energy carriers.

Hydrogen burns to water without emitting CO_2

When hydrogen comes into contact with the oxygen of the atmosphere and the small amount of ignition energy required is supplied, both elements burn to form water. The combustion process releases up to 90% of the energy that was required to decompose the water in the first place,[1] with – apart from steam – only a very small quantity of nitrogen oxide forming due to a reaction with the nitrogen of the air. The process does not generate any hydrocarbons, sulphur oxides, carbon monoxide, and not even carbon dioxide (CO_2), which is emitted when fossil fuels are burned, and which significantly contributes to the greenhouse effect. Hydrogen can be justifiably called net zero if no CO_2 is produced during its production process (green hydrogen) or if the CO_2 is immediately and permanently stored (blue / turquoise hydrogen).

The existing gas infrastructure is suitable for the transportation of hydrogen

There are many hydrogen transportation modes, the mode of choice being primarily determined by the physical condition of the gas. At ambient conditions, hydrogen is present as a gas, so the most frequently used option is its direct injection into the existing gas grid or into new hydrogen pipelines, either in its pure form or blended with natural gas. The German gas infrastructure was used for transporting hydrogen as early as in the 19th century when German town gas was used, which contained 50% hydrogen. Hydrogen can also be shipped in its liquid state, either by sea or in tank trucks, which requires refrigerating the gas to minus 253 degrees Celsius and storing it in special transportation containers. Another option is to bind hydrogen to other molecules, e.g. methane, ammonia, or methanol molecules, for later transportation.

The efficiency of an energy system depends on storage capacity

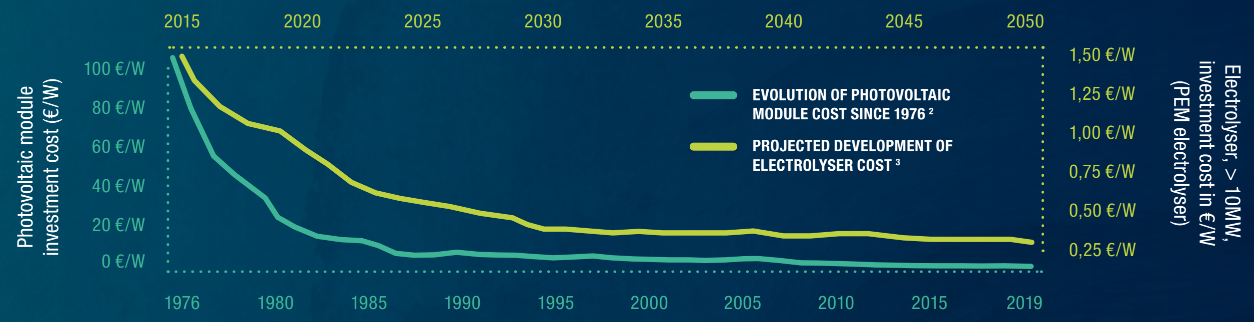
The production of green hydrogen requires a certain amount of energy input. Modern electrolysis processes require about 25 percent, which, however, may be reduced to about 10 percent so that up to 90 percent of the original energy input would be available as hydrogen after production by electrolysis. The efficiency of the process can be enhanced further if the waste heat generated by electrolysis is used by businesses or to heat buildings, for instance. Such waste heat can be easily transmitted by transferring it into a heating network, for example, to supply homes and businesses with green heat.

In order to understand why hydrogen must play an important part in shaping our future energy system – despite having to accept a certain energy loss – it is necessary to look beyond an individual plant and instead consider the energy system and its efficiency as a whole. Hydrogen can solve one of the biggest issues facing the energy transition, i.e., the question of how to efficiently store renewable energies. Up until now, it has been impossible to store large quantities of power for more than a few days. Hydrogen, by contrast, can be stored using the existing natural gas storage facilities, i.e., it can be used regardless of whether or not renewables are being generated. Its versatility and easy transportation through the existing natural gas infrastructure permit the flexible use of hydrogen virtually everywhere as well as the temporal decoupling of production of renewable energy from demand. This will pave the way for both a more resilient energy system and safer supply – especially when it comes to balancing seasonally fluctuating demand.

[1] The Future of Hydrogen. Report prepared by the IEA for the G20, Japan. Seizing today's opportunities, International Energy Agency (IEA), Paris, 2019.

Economies of scale will lead to drastic cost reductions in the short term

At present, climate-friendly hydrogen is not yet produced in large quantities and is therefore still relatively expensive, with production costs being greatly influenced by the production method. The cost of production of one kilogram of grey hydrogen is estimated to be 1.50 euros, whereas the current cost of production of blue hydrogen is about 4 euros and the cost of production of green hydrogen is approximately 8 euros. This however will probably change soon: The growing number of size- and efficiency-improved electrolysers that are being built around the world will soon increase availability, with the accompanying considerable decline in the cost of production. In the past, a similar decline in cost could be observed for other technologies where economies of scale played a major role, e.g. in the photovoltaic or semiconductor industries. The Hydrogen Council forecasts a 40 to 52 percent reduction in the cost of production of green hydrogen for the year 2030 as compared to 2020. In other words, within the next 10 years a considerably higher quantity of climate-friendly hydrogen will be available at ever decreasing costs.



[2] Lafond, F., Bailey, A.G., Bakker, J.D., Rebois, D., Zadourian, R., McSharry, P. & Farmer, J.D. (2018). How Well Do Experience Curves Predict Technological Progress? A Method For Making Distributional Forecasts. Technological Forecasting and Social Change, 128(3), 104-117; IRENA (2020). Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi.

[3] Element Energy Ltd (2018). Hydrogen supply chain evidence base. Prepared by Element Energy Ltd for the Department for Business, Energy & Industrial Strategy.

HYDROGEN IS…

… net zero: It does not release CO_2 during the combustion process

… versatile: It can be used for decarbonising all sectors

… very easy to transport: The existing gas infrastructure, among others, may be used for the purpose

… easy to store: Supply can be reliably ensured during dark and windless periods and in the winter

… in its ramp-up phase: The global rollout of electrolysers and the accompanying economies of scale will generate a large supply of hydrogen and reduce hydrogen production costs

About H2vorOrt

The "H2vorOrt" initiative is a collaboration of 37 distribution grid operators of the Deutscher Verein des Gas- und Wasserfaches (DVGW) working with the Verband kommunaler Unternehmen (German Association of Local Public Utilities, VKU), whose joint objective is to turn more than 500,000km of gas distribution infrastructure into a net zero system. The project partners have joined forces to investigate the issue of how to implement a regional, reliable supply of net zero gases across the Federal Republic of Germany in concrete terms. Hydrogen in particular can play a crucial role in achieving all climate goals without compromising economic efficiency.