The Role of Hydrogen in Energy Transition

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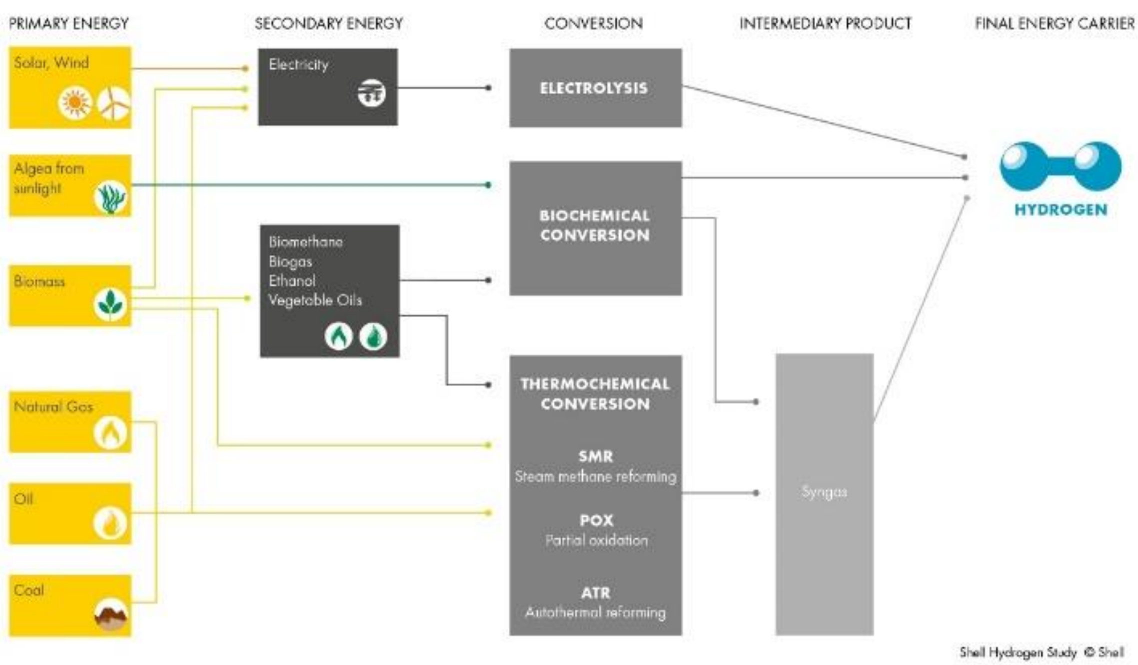
Hydrogen is the lightest element in the periodic table, and it is one of the most common chemical elements found on the Earth and in the universe (hydrogen is the chief constituent in stars). Hydrogen has a very simple atomic structure, consisting of one proton and one electron. Hydrogen is an energy carrier and not an energy source, it can store and deliver a tremendous amount of energy, but it does not commonly exist by itself in nature. It needs to be derived from the compounds of hydrogen such as natural gas and water etc. Due to these unique properties of hydrogen, it is often argued that it can play a crucial role in the energy transition. Some expert even claimed that it has the potential to supply 24% of the energy demand of the EU by 2050.

The purpose of this article is to discuss hydrogen's potential in the upcoming distributed energy transition, to find out how it can be generated and transported, what are its types, to discuss the key projects in the EU and to discuss its economic and technical viability.

Hydrogen can be used in a wide range of applications such as fuel cells (used to power cars, houses and portable appliances), chemical industry to manufacture fertilisers and other products, oil refining, heating industry and transportation sectors by synthesising clean fuels. The extraction process of hydrogen is relatively simple as it can be produced or extracted using any energy source such as fossil fuels, nuclear energy and renewables (basically almost all energy sources can be used). It is this ability of hydrogen, which makes it unique and one of the best alternatives to tackle climate change.



Hydrogen production methods (source: Hydrogen Europe)

Methods of Producing Hydrogen

Although new methods are being developed every day, the most promising methods to generate hydrogen are Steam Methane Reforming, Electrolysis, Hydrogen as a By-product or Industrial Residual Hydrogen and Pyrolysis.

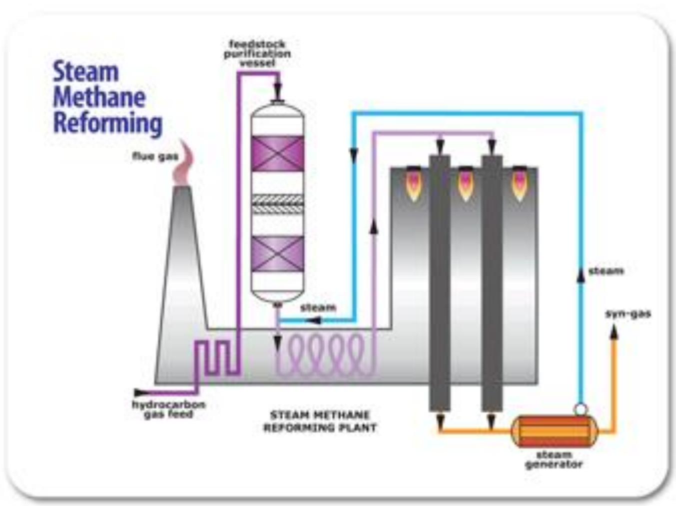
Steam Methane Reforming (SMR)

This is the most commonly used method of producing hydrogen. In this method, the reforming of natural gas is done. Here, natural gas, mostly methane is converted into hydrogen by reacting it with the steam (hence called steam reforming or steam methane reforming when methane is involved). It can be achieved by three methods:

Steam reforming where pure water vapour is used as the oxidant, this reaction is endothermic (requires external heat) in nature.

Partial oxidation where oxygen or air is used, this reaction is exothermic (releases heat) in nature.

Autothermal reforming where a combination of steam reforming and partial oxidation is done by operating a mixture of air and water vapour. The ratio of water and air is maintained in such a way that this process does not need external heat, and it does not release internal heat, i.e. the process becomes isothermal (constant temperature) in nature.

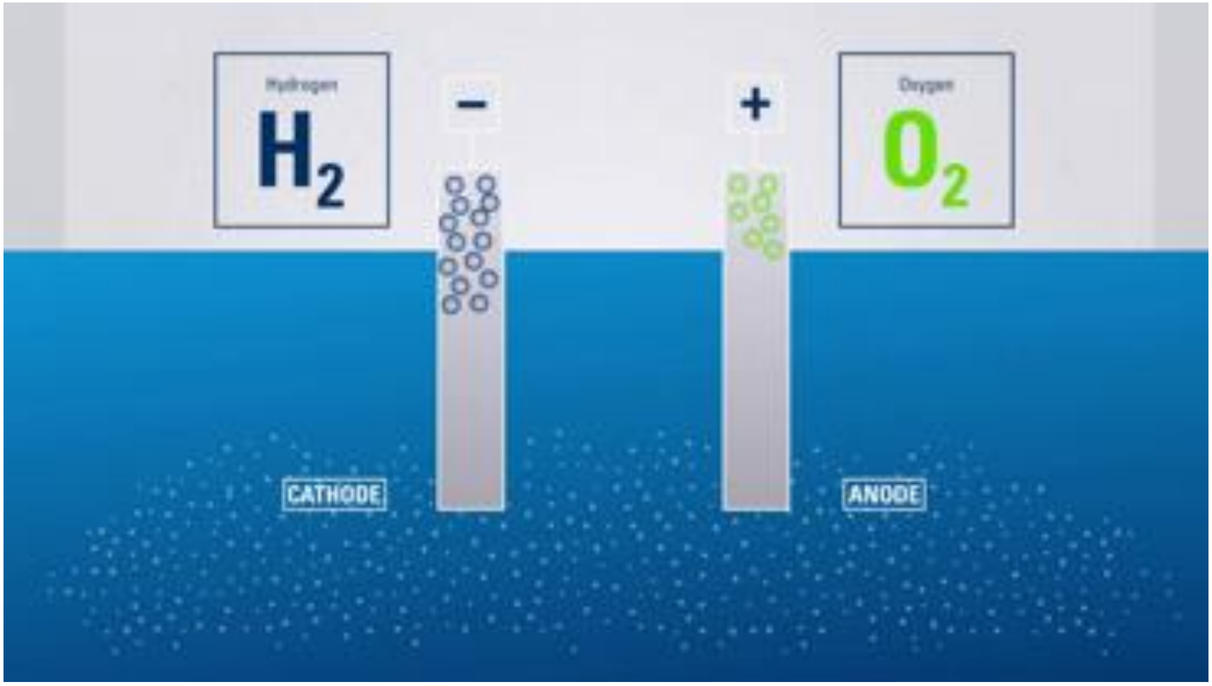


Process of Steam Methane Reforming (SMR) (source: Hydrogen Europe)

Additional details can be found here.

Electrolysis

In this method, water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) gas by using electric current or heat (in the case of high-temperature electrolysis).



Process of Electrolysis (source: Hydrogen Europe)

Additional details can be found here.

Hydrogen as a By-product or Industrial Residual Hydrogen

In this method, the electrochemical process, such as the production of caustic soda and chlorine are used, which releases hydrogen as a by-product. Here, an electric current is passed through brine (a solution of salt and water), which causes an exchange of electrons which are delivered by current resulting into gaseous chlorine, dissolved caustic soda and hydrogen gas. Additional details can be found here.

Pyrolysis

In this method, heat is used to break down natural gas which produces hydrogen and solid carbon, which can be used for other applications.

Colour-coding of Hydrogen

Depending upon the type of method used to generate hydrogen and amount of carbon emissions, hydrogen is colour-coded in four different categories: grey, blue, green and turquoise hydrogen.

Grey Hydrogen

Hydrogen produced from reforming natural gas is called grey hydrogen. It releases a lot of CO_2, and it is mainly used in the chemical industry such as ammonia and fertiliser and oil refining. It uses SMR to produce hydrogen. This method is most widely used by current industrial practices to produce hydrogen on a large scale, and it involves extracting hydrogen from fossil fuels such as coal and natural gas, which releases CO_2 and CO emissions.

Blue Hydrogen

It is also called as low CO_2 hydrogen as it captures 90% of CO_2 emissions by storing it into empty underground fields or subsea storage by Carbon Capture and Storage (CCS) mechanism. H-Vision project in Rotterdam, Netherlands area are working on this type of system. This is seen as a transitional approach as demand cannot be fully met by green hydrogen. However, some environmentalists oppose this option.

Green Hydrogen

Hydrogen produced by using electrolysis by deriving the power generated from solar or wind or other renewable energy sources is called green hydrogen. This method is gaining a lot of attention these days (several projects are already in their planning stage). However, generating hydrogen by this method requires to overcome barriers related to production, transport, storage, use as a fuel and raw material and most important of all economic viability. This article will discuss in detail about all these barriers in the latter stage.

Green hydrogen is the only alternative for using wind and solar on a large scale as it offers flexibility to the energy system by acting as a large buffer and storage of the variable supply of solar and wind. It will make the supply stable and in a targeted manner which can be used to match supply and demand. Also, it will allow using wind and solar energy harnessed in summer, in winter, when the generation is low.

It can be used in sectors which are difficult to carbonise such as high-temperature industrial processes, heavy transports such as planes, ships and trains and where electricity from solar and wind is not feasible, green hydrogen is a good alternative. As electrolysis is mostly used to produce green hydrogen, it will lead to an increase in integration and extraction of solar and wind energy into our system. However, it is important to consider that a lot of electricity is needed for this purpose and that is why it cannot be generated on a large scale by means of additional energy generated from the fluctuation from solar and wind resources. Dedicated wind or solar farms might be required. TNO is working on electrolysers design which has more power output, are efficient, have lower cost and longer life span. Electrolysis is proven but is not matured yet to use it on a large scale.

Turquoise Hydrogen

This type of hydrogen is called low-carbon hydrogen and it generated by pyrolysis, where natural gas is passed through molten metal to generate hydrogen and solid carbon, as stated above. So far, only a small quantity is generated, and experts claim that it has the potential to be a gamechanger.

Key Projects in the EU

Nowadays generating green hydrogen from offshore wind turbines, is gaining popularity. The Netherlands, Germany, Denmark and Belgium are leading in this race. One such project is to supply electricity to the hydrogen facility in Eemshaven, Netherlands and possibly creating an offshore production facility. The current target is to reach 3 to 4 GW till 2030 and 10 GW (enough to power 12.5 million homes) up to 2040; these wind turbines will be solely used for hydrogen generation. The first turbine is planned to generate hydrogen in 2027. Green hydrogen production of 800,000 tonnes, avoidance of around 7 megaton CO2 annually, is anticipated from this project.

Another approach involves using wind energy generated by a wind farm to power an offshore electrolyser located on a remote platform. Dutch energy infrastructure company Gasunie joined the PosHYdon pilot, a project that aims to integrate three energy systems in the Dutch North Sea: offshore wind, offshore gas, and offshore hydrogen. This project is an initiative of Nextstep, the Dutch association for decommissioning and reuse. Other partners include, Neptune Energy, TAQA, EBN B.V., NAM, NOGAT B.V., and Noordgastransport B.V. Installation of a hydrogen-producing plant on the Neptune-operated Q13a platform is proposed where electricity generated by offshore wind turbines will be used to power the hydrogen plant, converting seawater into desalinated water then into hydrogen via electrolysis. The aim of the project is to gain experience in integrating working energy systems at sea and the production of hydrogen in the offshore environment, to see what effects does the offshore environment have on electrolyser. The pipelines owned by NOGAT and Noordgastransport are already declared suitable for hydrogen. The wind energy generated by the wind farm can be used to generate hydrogen, then can be transported onshore along with natural gas via the existing large pipelines.

There is also an idea to generate hydrogen directly using wind turbines. Hygro is already working on a wind turbine which has an integrated electrolyser, see how the hydrogen turbine works. The first hydrogen turbine will start to produce hydrogen for the Duwaal project in the Netherlands. The aim of Hygro is to convert as many wind turbines to hydrogen turbines or to build them as hydrogen turbines from the start. Ørsted and ITM have developed a similar concept for electrolyser installed inside the tower of the wind turbine or very near to it. These concepts are better in design as they can produce hydrogen in bulk and avoid using a terminal or platform or onshore, remotely away from the turbine. This increases the efficiency of electrolysis, as electrical conversion losses (DC link is used to convert water into hydrogen and oxygen) and electricity transport losses are minimised.

Another interesting development is happening in Denmark, where, Copenhagen Airports, A. P. Moller – Maersk, DSV Panalpina, DFDS, SAS and Ørsted have formed a new partnership with a vision of building the world's largest electrolyser and e-fuel facilities in the Greater Copenhagen Area. COWI, BCG and Municipality of Copenhagen are supporting this project. The aim of this project is to reduce the cost of renewable hydrogen and sustainable fuels to competitive levels. Denmark can become a hub for a new green industry as it has taken the lead to reduce carbon emissions to 70% less by 2030 compared to 1990. The vision is to develop this hydrogen and e-production plant by 2023 and to fully scale it up by 2030. It could deliver more than 250,000 tonnes of sustainable fuels to buses, trucks, maritime vessels and aeroplanes every year and this will be based on electrolyser capacity of 1.3 gigawatts. The project has the potential to displace 5% of fossil fuels at Copenhagen Airport by 2027 and 30% by 2030.

Another project involves plans to build artificial islands in the North Sea combining several offshore wind farms, convert part of the power to hydrogen and to transfer this hydrogen to land by using the existing offshore gas infrastructure.

Storage and Transportation of Hydrogen

Hydrogen is relatively easy and safe to produce and store. As stated earlier, due to the compatibility of natural gas pipelines to transfer hydrogen with a little or no modification makes the transportation economical on both onshore and offshore. Also, if the network of pipelines is sufficiently large, they can store hydrogen inside them. This makes rapid deployment of green hydrogen projects possible. Where this is not possible, a concept such as Equinor's subsea drone can be used to transport hydrogen.

Equinor's subsea drone concept (source: Equinor)

Economics of Green Hydrogen Generation

Talking about the economics of green hydrogen generation, the Levelized Cost of Energy (LCoE) per GJ of hydrogen is similar to the cost of bringing electricity from an offshore wind turbine to onshore. The higher generation costs are offset by the fact that transport of gas is much less expensive compared to electricity (underwater hydrogen pipes cost less compared to underwater electric cables). However, even with this low LCoE, to compete with fossil-fuels, hydrogen has a long way to go. The green hydrogen and sustainable fuels will need to be matured, built to industrial scale (electrolysers with individual capacity in GW) and go through cost-cut out journey similar to wind and solar energy. For example, the cost of offshore wind has dropped by 70% in Northwest Europe since 2012. Another such example is, in order for fuel cell vehicles to be competitive, the total untaxed, delivered and dispensed, the cost of hydrogen needs to be less than $4/gge. A gge, or gasoline gallon equivalent, is the amount of fuel that has the same amount of energy as a gallon of gasoline. One kilogram of hydrogen is equivalent to one gallon of gasoline.

Green hydrogen produced by dedicated European off-grid offshore wind farms would reach about $2.50 per kg by 2030, a new study by the Hydrogen Council and consultant McKinsey estimates. That compares to an average of about $1.50 per kg for grey hydrogen currently being produced from steam reforming of natural gas. This proves green hydrogen has a long journey ahead of it and needs rapid development in technology and deployment. Reducing the cost of green hydrogen should be the primary target while developing such projects.

Conclusion

Green hydrogen has a tremendous potential to replace fossil-fuels and grey hydrogen in the EU. But to do so, it needs to go through a steep cost cut-out journey which is possible by rapid interlinking of Europe's electricity and gas grids. The gas infrastructure should be adapted rapidly for the transport of hydrogen to achieve climate targets. Also, all the above-mentioned methods despite having great potential, need more funding and research and development efforts along with necessary economic evaluation before deploying. Future development is particularly required in the areas of electrolyser module specification suitable for offshore operation, prototype development, build, deployment and testing, onshore, offshore deployment planning and demonstration and assessment of operational expenditure costs. To achieve all these goals, a close collaboration between industries and government is of utmost importance, and it should happen as early as possible, then only green hydrogen can play a key role in the energy transition.