# Future of a Hydrogen Economy

The need for sustainable energy supply is becoming more pressing in the light of declining fossil energy resources, environmental pollution, climate change and the increasing dependency on oil- and gas-exporting countries. In this context, hydrogen is being discussed as a promising energy source.

Right from the beginning of the discussion about a hydrogen economy it has to be born in mind that hydrogen is not a primary energy source. Instead, it is an energy carrier comparable to the electricity grid or district heating network, and as such it needs to be converted from other sources of energy. Hydrogen is already being produced in very large quantities - several tens of millions of tones a year worldwide - for use in the process industries.

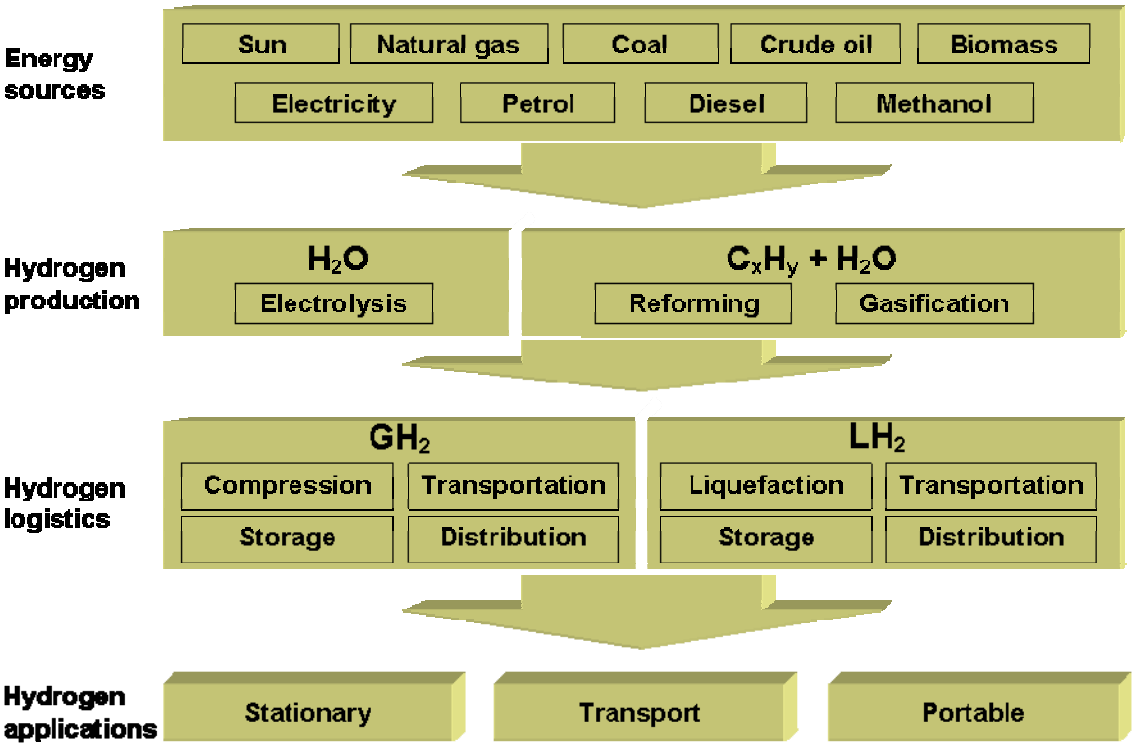


Figure 1: Sub-systems of hydrogen pathways

- **Hydrogen production**

Hydrogen is a gaseous, clean energy carrier. It does not occur in nature in any significant amounts but can be produced from a wide range of primary energy sources, such as coal, natural gas, nuclear and renewable energy sources. Feedstock preparation or electricity generation is the first step or the first sub-system within a hydrogen pathway. The main methods of producing hydrogen are:

- Electrolysis
- Production from natural gas (Reforming)
- Gasification of coal and biomass

Water electrolysis and natural gas reforming are proven technologies that can be used in the early transition phase to hydrogen as an energy carrier. Electrolysis is a costly process to produce high-purity hydrogen, while the cheaper and more efficient process of gas reforming is used for large-scale production where quality is not such an issue. Promising innovative hydrogen production processes are e.g. high-temperature electrolysis, photochemical and biological hydrogen conversion technologies. However, these technologies are still at the very beginning of their development.

- **Hydrogen logistics**

Hydrogen has only a low volumetric energy density. It has therefore to be conditioned, i.e. compressed or liquefied, before it is transported or stored. If hydrogen is produced in centralized production plants, it needs to be transported to the site of use. For pipeline delivery, the gas is compressed to 75 bars for 30 bar delivery.

For mobile applications (transport sector) hydrogen would need to be stored at a pressure of 700 bar ($GH_2$) to get the same volume of tank and the same autonomy as gasoline or diesel cars. Liquid hydrogen ($LH_2$) has a high-volume related density, which makes it also interesting, in particular for transport applications. The highest volumetric density is achieved by liquefaction at -253°C.

Compression and liquefaction processes of hydrogen have significant costs and energy requirements. About 1/3 of the energy contained in the hydrogen is needed for liquefaction.

- **Hydrogen applications**

Hydrogen needs to be converted into power and heat. A differentiation is made between the application in portable small devices, the mobile use in transport and traffic and the stationary application of hydrogen in domestic energy supply or in decentralized power plants. Hydrogen can be transformed into electricity by different generation technologies, e.g. in fuel cells. Fuel cells are electrochemical devices that combine hydrogen and oxygen in the presence of a conducting electrolyte to generate electricity and heat, emitting water vapour as their primary by-product. As a consequence, fuel cells represent the technology of choice for using hydrogen as an energy carrier. The capital costs of fuel cells are extremely high at the moment. In addition the durability and the reliability of fuel cell systems have not been established yet.

## Comparative evaluation of energy technologies

A hydrogen economy involves different stages between the production of hydrogen and the end use. The produced hydrogen needs to be packaged by compression or liquefaction to make it marketable. Then this chemical secondary energy carrier has to be transported, stored and distributed. Finally hydrogen has to be converted into electricity, e.g. in a fuel cell. All this transformation processes lead to a decrease of the total efficiency.

Figure 2 shows a simplified analysis of a hydrogen pathway. In the process shown, the amount of the electricity generated is reduced to only approximately 25%. Within various international projects different hydrogen pathways for the stationary, mobile and portable energy sector have been analysed. Evaluation criteria are energy efficiency (primary energy demand), carbon emissions and costs. It can be summarised that if hydrogen is used as fuel in the stationary sector, the total costs are continuously higher compared to the direct use of natural gas. This is due to the fact that hydrogen is about 3 to 8 times more expensive than natural gas. Within the hydrogen pathways the generation costs of stationary applications (fuel cells, Stirling engines, internal combustion engines) differ between 10 and 30 €-ct/kWh.

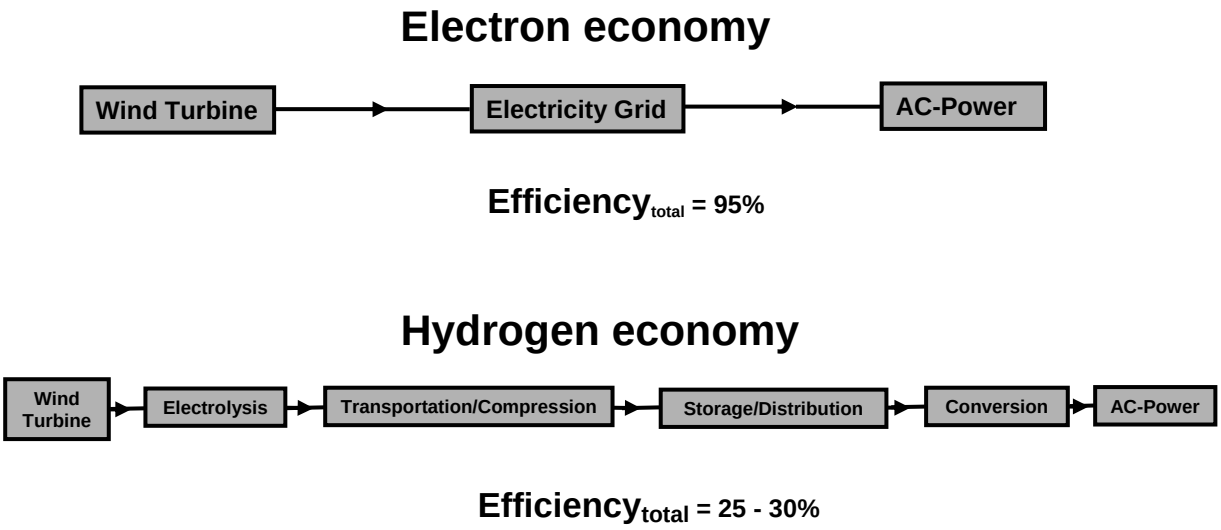


Figure 2: Analysis of a hydrogen pathway versus the direct use of electricity

For stationary applications it can be summarized that the produced electricity should be used directly as long as it is possible to transport electricity via the transmission grids.

## Conclusions and recommendations

Hydrogen and electricity together represent one of the promising ways to realise sustainable energy supply, and fuel cells represent the most efficient option for converting hydrogen into electricity. Although the potential benefits of hydrogen and fuel cells are significant, many challenges - technical, economical and others - have to be overcome before they will be able to offer consumers a competitive alternative.

The first and most important understanding about the proposed hydrogen energy system is that hydrogen is not an energy source. Hydrogen is an energy storage medium and energy carrier. Hydrogen can be produced from a wide range of primary energy sources, such as coal, natural gas, nuclear and renewable energy sources.

Due to the high efficiency losses hydrogen cannot compete with the direct use of electricity. Nevertheless hydrogen can be used in the transport sector in the long term and in special niche applications:

- One of the most important advantage of hydrogen is its potential to replace gasoline and diesel as transport fuels and thus to eliminate air pollution from vehicles with IC engines.
- Hydrogen-based energy systems will increase the opportunity to use renewable energy sources in the transport sector.
- Hydrogen-fuelled fuel cells can provide companies a new alternative for reliable backup power generation and energy storage.
- Fuel cells for battery replacement and backup power systems are important niche markets in which price and efficiency are relatively unimportant.
- Hydrogen can be used as an energy carrier/energy storage medium to supply remote areas with energy, which do not require a large hydrogen infrastructure.