Where Are We With the Hydrogen Economy?

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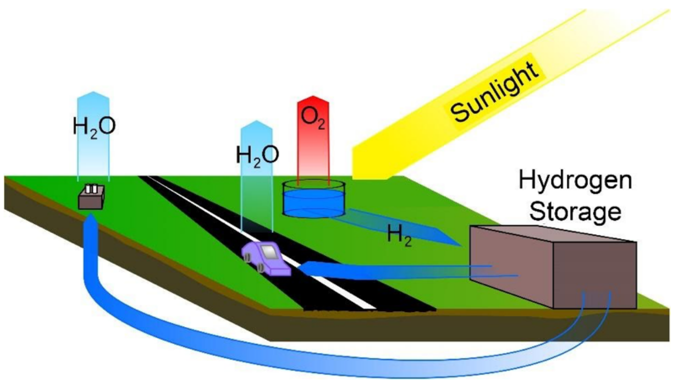
Hydrogen economy.



For many years, people have talked about a future 'hydrogen economy' in which hydrogen is the main energy carrier. In this vision, energy from renewables or nuclear could be stored indefinitely and transported wherever it is needed. It would be completely clean, only producing water when burned or used to generate electricity in a fuel cell. An energy-dense fuel would be available for every application, from heating homes to powering aircraft. For a long time, storage was seen as the main obstacle to a hydrogen economy, but composite pressure vessels have greatly reduced the significance of this issue. In many ways we seem to have overcome the technical challenges of hydrogen—there are now cars on the market, such as the Toyota Mirai and the Hyundai Nexo, as well as buses operating. Yet many experts still say we're a very long way from widespread use of hydrogen. This article looks at the reasons behind this apparent contradiction and the likely role that hydrogen will play in the energy transition.

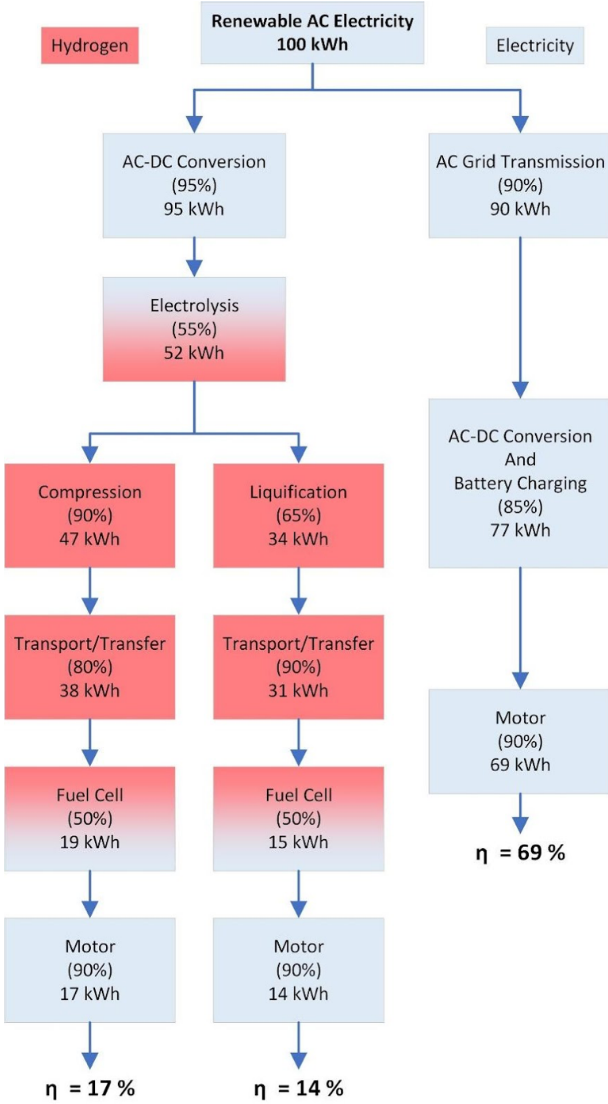
The first thing to understand about hydrogen is that there are effectively two types:

- '**Blue Hydrogen**' is produced by reforming methane from natural gas, therefore it is not a renewable energy technology and depends on a finite resource. It can be a useful way to decarbonize the use of natural gas since it is easier to capture the carbon dioxide during centralized methane reformation than at the many final points of use. This form of hydrogen is relatively cheap but without expensive further processing it is not pure enough for use in fuel cell vehicles. Blue hydrogen, combined with carbon capture and storage, may have a useful role as a transitional technology for decarbonizing domestic and industrial heat.

- '**Green Hydrogen**' is produced by splitting water into hydrogen and oxygen. This is currently done using electricity to perform electrolysis; solar reactors are also being developed which can directly split water. High purity hydrogen is produced suitable for use in fuel cells and it is only limited by the availability of electricity. Only green hydrogen could enable a hydrogen economy.

The fundamental problem with green hydrogen is energy efficiency. If the starting point for our energy system is electricity, produced from solar, wind or nuclear, then it is generally most efficient if it stays as electricity for as long as possible. Electricity can be converted into mechanical work by a motor with at least 90% efficiency, and it can directly produce heat with almost 100% efficiency. If a heat pump is used then 200% to 400% of the electricity is realized as useful heat. Producing hydrogen, compressing it, pumping it and turning it back into electricity or mechanical work, all involve significant losses of energy.

Consider the difference in efficiency for cars with batteries or with hydrogen fuel cells. After allowing for the energy losses producing hydrogen from electricity, compressing or liquifying it, transporting it and then generating electricity again, a typical fuel cell vehicle is four or five times less efficient than a battery vehicle. Even with a very optimistic view for what might be achieved by 2050, with electrolysis at 75%, compressed storage and a fuel cell efficiency of 60%, the combined efficiency of 28% is still less than half of a current battery vehicle.



Comparison of the efficiency of hydrogen vehicles with battery vehicles—the hydrogen vehicles require four or five times as much electricity generation to power them!

Hydrogen is sometimes seen as the only option for heavy vehicles which must sustain high power outputs over long distances, such as heavy trucks and trains. However, electrification of roads and of railways is not only more efficient but also less capital intensive if all costs are considered. For example, the cost of electrifying the UK's major roads has been estimated at $39 billion, but the improved efficiency compared to hydrogen would reduce the required investment in new solar and wind installations by about $180 billion. And there would also be other economic benefits of road electrification. The individual vehicles are likely to be cheaper. Hydrogen refuelling infrastructure wouldn't be required. If a dynamic charging system compatible with private cars is used, it might cost more, but it would then bring further benefits in reducing requirements for battery capacity.

Roads may be electrified using overhead systems which are only suited to large commercial vehicles or conductive tracks which can be used by all vehicles.

There is a need to buffer supply and demand when intermittent renewables are used. A major technology here will be to use peaking power plants which burn biomass with carbon capture, usage and storage (CCUS). This will involve growing energy crops such as fast-growing trees which can be easily stored for use in a conventional steam turbine power plant when additional electricity is required. Combined with CCUS, this becomes a carbon negative technology, which will be vital to reversing the damage done to the environment. The most energy-efficient ways to store electricity are using pumped-storage hydroelectricity (https://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/19341/Harnessing-Seabed-Pressure-to-Store-Renewable-Energy.aspx) (PSH) or batteries, achieving round trip efficiencies of 70%-90%. Current grid storage using hydrogen has an efficiency of 30% and there is little prospect for it to increase dramatically. However, PSH is limited by suitable geography, while batteries are limited by metal supplies (https://new.engineering.com/story/critical-resources-for-renewable-energy-part-1) as well as being costly. Demand side response (DSR) will reduce the need for storage. This involves uses such as vehicle charging being carried out when electricity supply is greater than demand. DSR will be enabled by energy markets with time-sensitive or demand-sensitive pricing. Some projections, involving lower levels of biomass energy production, show that it may be economical to store about 14% of electricity as hydrogen. As the percentage of hydrogen in the energy system increases, the time-based electricity price becomes increasingly uniform, tending towards the levelized cost. Therefore, only relatively small quantities of hydrogen can be produced cheaply, if hydrogen became a more significant part of the energy mix, its energy cost would increase.

The limited quantity of hydrogen economically available in the energy system will be used in applications which cannot make use of the less costly electricity distribution. Most of it may be required for grid storage. Air transport and industrial processes requiring very high temperature heat are likely to consume the remainder. It makes very little sense to use it for applications which can be easily and efficiently electrified using the grid-supplied electricity of batteries.

We remain a very long way from a hydrogen economy. Blue hydrogen has an important transitional role in decarbonizing natural gas use, while green hydrogen will have a niche use in the future carbon negative energy mix. However, hydrogen produced by electrolysis should not be seen as a substitute for technologies which enable direct electrification. This could cause unnecessary increases in the demand for our renewable electricity, as we already struggle to ramp up production quickly enough. It would also significantly increase costs for consumers. In the longer term, green hydrogen produced directly from the clear desert sunlight in solar reactors may enable more widespread use of hydrogen through a global energy market. If we do one day lean more towards a hydrogen economy, leakage will need to be minimized since hydrogen is itself a powerful greenhouse gas.