Green hydrogen as a source of energy

The trillion-euro question

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If green hydrogen is to make a significant contribution to climate-friendly energy supply in the future, it will need to be produced (1) in large quantities, (2) cost-efficiently and (3) using low-carbon methods. Any solutions to these problems have remained in the realm of theory so far. Additional challenges arise in connection with the transport and storage of hydrogen. Initially, green hydrogen will be used to satisfy large-scale demand at specific locations, for example in energy-intensive industries. Like many other climate-friendly technologies, hydrogen will need government subsidies in the beginning. In the longer run, hydrogen might be used in the transport sector as well, for example as aircraft or ship fuel. In theory, hydrogen is highly versatile. However, it is quite expensive, too. That is one reason why hydrogen will probably make only a small contribution to the national and global energy transition in the next one or two decades.

Hopes are high that hydrogen may become the energy source of the future. Both the German government and the EU Commission presented new strategies for using hydrogen as a source of energy in summer 2020. The German government's National Hydrogen Strategy says that hydrogen "will play a key role in enhancing and completing the energy transition".

Policymakers regard green hydrogen as a potential "silver bullet"

In contrast to crude oil, coal, natural gas, nuclear fuels or biomass, hydrogen is not a primary source of energy and mostly occurs in bound form (usually water or hydrocarbons, such as coal, oil or natural gas). If hydrogen is to be used as a source of energy, it thus will need to be produced first – and that process requires energy. Today, this energy is usually provided by fossil fuels. The resulting hydrogen is called "grey hydrogen". The National Hydrogen Strategy calls for "green" hydrogen, which uses electricity from renewable sources for the electrolysis of water. The procedure yields liquid or gaseous downstream products which can be used as energy source (power-to-x, "P2X"). In this way, hydrogen may close one of the gaps in the energy transition strategy. Remember, for example, that (at least for the foreseeable future) it appears impossible or prohibitively expensive to have some types of vehicles, such as aircraft or ships, run on electricity. Green hydrogen may also offer a number of industrial sectors an opportunity to reduce (process-inherent) carbon emissions. This applies, for example, to the metals industry, the chemical industry or building materials production. And finally, it is theoretically possible to use green hydrogen for heating purposes.

P2X technologies are not only a way to direct electricity from renewable sources to areas where power cannot be used directly (sector coupling). They are also an energy storage solution. With energy policy supporting renewable power generation from weather-dependent sources, it will become ever more important to find reliable storage capacity. Apart from pumped-storage power plants, which need a specific topography, there are currently no cost-efficient electricity storage options on an industrial scale. As the share of weather-dependent renewables in the overall electricity mix increases, excess energy will be produced if the weather conditions are favourable. Even now, market electricity prices are sometimes turning negative and power has to be exported (with much of the exports going to pumped-storage power plants in Austria, by the way). The lack of storage options also means that it is impossible to take traditional power plants off the grid – after all, their capacities are needed for periods during which there is no wind and no sunshine. Excess installed power plant capacities have therefore steadily increased in Germany during the last few years – and driven up expenses. Green hydrogen production is meant to slow down or, ideally, stop this unfavourable development.

All in all, green hydrogen is hoped to be the ultimate solution both for sector coupling and for the power storage problem.

Federal government is not exuberant

That is the theory. There is no doubt that there are major practical hurdles. For that reason, the federal government's National Hydrogen Strategy does not claim that hydrogen will become a "game changer" in the energy transition during the coming years. The strategy also points out that Germany will probably import a large share of any future hydrogen supplies from countries which offer more favourable conditions for the production of green hydrogen. This means that hydrogen is unlikely to make a significant contribution to energy self-sufficiency. Let us take a more detailed look at the challenges:

- In the first place, a hydrogen infrastructure needs to be built. This includes electrolysers (which produce hydrogen), facilities and equipment to change the physical state of hydrogen and transport and distribution networks (devices to monitor the concentration in hydrogen mixes, problem of hydrogen embrittlement). If hydrogen is not transported by pipelines, but by ship (over long distances) or trucks (local distribution), additional investments will be necessary. In addition, factories (for example steel plants) may need to be re-fitted for hydrogen consumption. In the longer run, this will also apply to hydrogen-fuelled vehicles.
- Apart from these investments, operating costs will be high. At each step of the process, a share of the energy used to produce hydrogen will be lost. This is a common problem in the energy sector and not specific to hydrogen. Nevertheless, hydrogen's specific characteristics render its transport and storage particularly difficult and expensive (low density and high volatility as a gas, liquefaction requires very low temperatures). As a result, the overall efficiency is lower than that of other sources of energy. This weighs on profitability. Moreover, electrolyser capacities are likely to be considerably underused if they run only on weather-dependent renewables. This is even truer if they run only on "excess electricity". In that case, average costs will rise further, as electrolysers are usually built to operate permanently.
- Due to the high costs, it seems unlikely that green hydrogen is an economically viable option in the foreseeable future. For that reason, the government will need to subsidise hydrogen – like many other climate-friendly technologies. The National Hydrogen Strategy lists several support programmes. State-aid law needs to be adapted to permit such subsidies, for example for the use of green hydrogen in steel plants or in the chemical industry. There is also the question of whether electricity used for electrolysis may be exempt from the surcharge under the Renewable Energy Act. This is a competition-policy issue.
- There are also regulatory questions concerning the climate-policy categorisation of the different types of hydrogen production. The federal government considers only green hydrogen to be "sustainable in the long term". However, an international hydrogen market will also include "grey", "blue" or "turquoise" hydrogen, which may be consumed in Germany, too. "Blue" hydrogen is produced using fossil fuel and a carbon capture and storage system (CCS). "Turquoise" hydrogen is produced via the thermal splitting of natural gas (methane, CH4) at very high temperatures. This methane pyrolysis produces solid carbon instead of CO_2. This procedure will be climate-neutral only if the high-temperature reactor runs on low-carbon fuels. All in all, it will be necessary to categorise the different types of hydrogen, including mixed types, in terms of their climate impact and regulate their usage.
- The National Hydrogen Strategy does not harbour any illusions about the potential contribution of green hydrogen to total energy supply in absolute terms. The federal government expects that up to 14 terawatt hours (TWh)

of green hydrogen may be produced domestically by 2030. This is equivalent to just below 0.6% of Germany's total final energy consumption in 2019. Even if ten times that volume were imported by 2030, the overall contribution to the total energy supply would remain moderate.

Technological progress, but no quick solutions

It may appear counterproductive to emphasise during climate and energy-policy discussions what is not (yet) possible or which hurdles need to be overcome. However, wise political decisions need to be based on a well-founded assessment of the potential contributions of individual technologies towards resolving the climate and energy problem. In this process, policymakers need to consider not only technological feasibility issues, but also subsequent economic and social costs in order to keep public expectations realistic.

Even if green hydrogen will remain expensive for now and cannot make a major contribution to climate-neutral energy, there are reasons to be optimistic. We are likely to see technological progress at all stages of the process. Costs for running electrolysers will decline on the back of scale effects, and hydrogen may be transported in existing pipelines (via the natural gas network). And instead of liquid hydrogen, ammonia (NH3) may be transported by ship over long distances. This raises fewer technological problems. Engineers and scientists will certainly have some ideas on this. Still, there are no quick solutions around the corner. In any case, the government should provide research funds for hydrogen technology, if only to avoid that technologies gain ground only thanks to subsidies, but not because they offer efficiency advantages.

Hydrogen to be used mostly in stationary systems for now

Where is green hydrogen likely to be used first? As transport and storage are difficult, it seems probable that green hydrogen will be produced and used in large stationary systems in the beginning. This will lead to scale effects for electrolysers. The metal industry, the chemical industry and building materials producers might be some of the most important consumers at first. Hydrogen is unlikely to be used at a small scale for now, for example for fuel cell heating. Widespread use, for example as car fuel (fuel cells or direct combustion), is also becoming less probable by the day, as the range of battery-electric vehicles increases and the charging infrastructure is improved, not least with the help of state subsidies. Moreover, many car producers invest mainly in battery and not so much in hydrogen technology right now. In the long run, hydrogen may be somewhat more attractive as truck fuel, but there are interesting alternatives in this segment, too (synthetic bio fuels, overhead cables).

There is also the question of which countries will be large hydrogen producers in the future. Ideally, at least in terms of climate protection, hydrogen should be produced in countries which can rely on optimal climatic and topographic conditions for the cost-efficient use of renewable energies. High initial investment needs suggest that hydrogen will mostly be produced by prosperous countries. Many countries that have become wealthy on the back of gas and oil exports meet both of these criteria. In addition, they have natural gas reserves at their disposal so that hydrogen production will not depend exclusively on renewables. The US, China and some parts of Europe can also offer suitable locations for hydrogen production. And some countries, such as the US or Japan, will use nuclear energy as a base-load and low-carbon energy source to produce hydrogen. This hydrogen would be classified as "purple", to complete the colour spectrum. A cost advantage of using "purple hydrogen" is that electrolysers could run permanently. However, it will only be a viable option if nuclear energy is accepted by policymakers and the public. Even within the EU, opinions differ on this subject. And the National Hydrogen Strategy does not mention this option in any case.

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