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Federal Ministry
for the Environment, Nature Conservation,
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ENVIRONMENTAL made PROTECTION in Germany

Water-Hydrogen Nexus

Water use in decentralised energy systems with hydrogen and fuel cell technologies

Which role does green hydrogen play in decentralised energy supply?

Green hydrogen represents a sustainable alternative to fossil energy sources such as coal, oil or natural gas. In addition to its potential as a transportable and tradeable energy source, such as for applications in mobility, it can also be used in combination with batteries for long-term energy storage in decentralised energy systems. Consequently, it can be utilised as an environmentally friendly alternative to diesel generators at locations without sustainable and reliable energy supply.[1]

How is green hydrogen produced?

Hydrogen is produced by splitting water molecules (H_2O) into their components hydrogen (H_2) and oxygen (O_2) using electricity in a process called water electrolysis.

The production of one kilogram of hydrogen requires, from a purely stoichiometric perspective, nine kilograms of water. The higher the demand for hydrogen and thus the electrolysis capacities in practice, the more electricity and water must be provided. The hydrogen produced can only be considered “green”, if the electricity used comes from renewable energy sources, such as wind or solar energy. A sustainable production and use of green hydrogen takes into account both the electricity and the water demand. This requires careful provision and management of water as a resource. Depending on the electrolysis technology used, the local source of raw water, the water treatment set-up and the cooling concept applied, additional water requirements may arise that then need to be provided for the production of hydrogen (LBST, DHI WASY & Water Science Policy 2024).

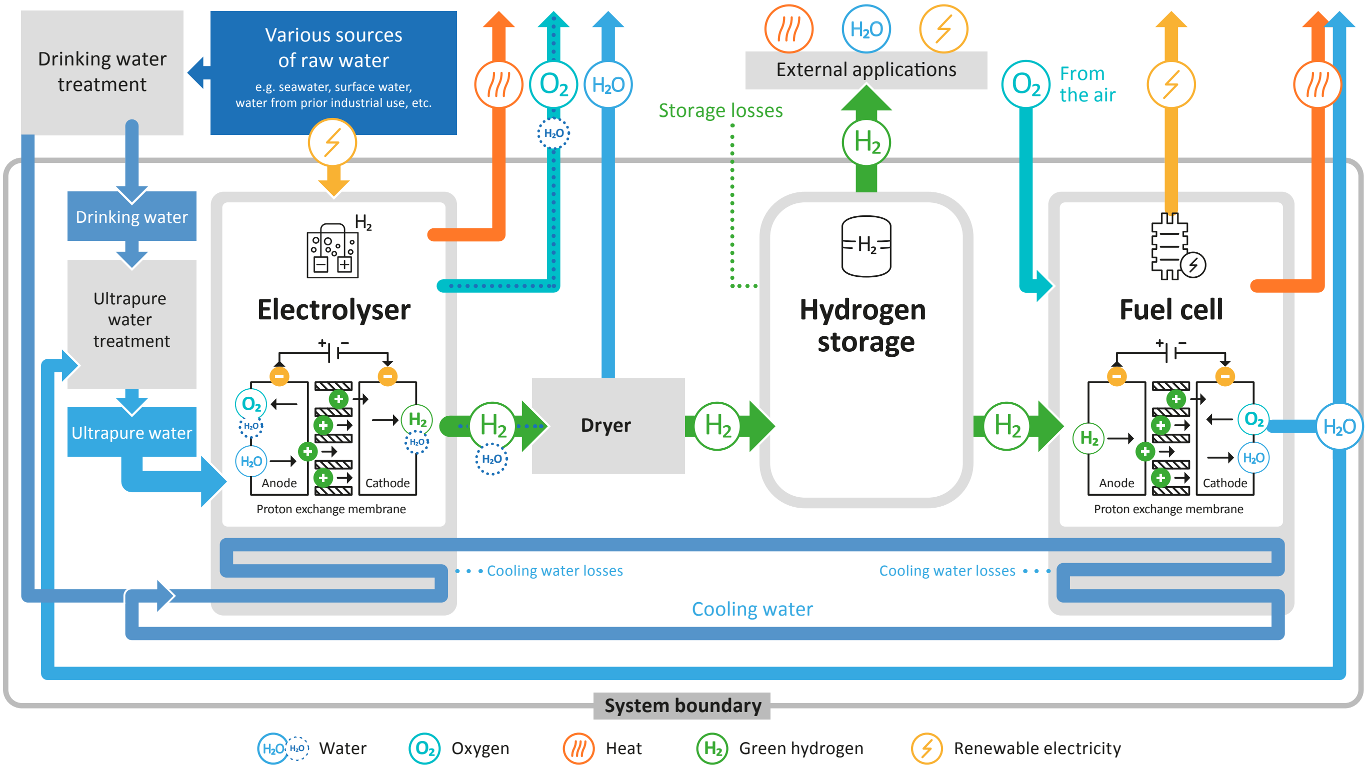
Why does the use of water play a special role?

This necessary link between hydrogen and water, also referred to as “nexus”, is particularly critical at locations that are characterised by water stress, water scarcity, inadequate water infrastructure or insufficient energy supply. In the context of sustainable development, as described in the United Nations' Sustainable Development Goals (SDGs) 6 and 7, it is essential to apply a systemic perspective on the energy and water footprint and a context-oriented view of the respective application.

Water stress

Water stress is defined as the ratio of total water requirement (e.g. for domestic, industrial, irrigation and livestock use) to the available renewable supplies (surface and groundwater) in a certain area. It also takes the effects of the natural hierarchy of water use into account. The higher this ratio, the higher the competition for use and consequently the higher the level of water stress (World Resources Institute 2023). Currently, a quarter of the world’s population lives under extremely high water stress (UNESCO 2024).

Infographic: Energy and Water System



Which system boundary is defined in the system depicted?

The definition of a system boundary (represented in the figure above by the grey outer box) allows to determine the water footprint of a system, identify important influencing factors and make them comparable. In the case of the decentralised energy systems with hydrogen and fuel cell technologies outlined here, the system boundary includes all central energy supply processes: hydrogen supply (electrolysis), hydrogen storage and reconversion via the fuel cell. Ultrapure water treatment is also included in the system boundary, since the projects currently being implemented are connected to the local drinking water supply.

Depending on the local situation, however, the additional or different steps within the system boundaries should also be considered, which are necessary to transform various raw water sources into ultrapure water for electrolysis. This factsheet exclusively considers systems with the system boundary described above. It deals with their technical fundamentals and initial findings on their water use and consumption. Alternative (e.g. biogenic) hydrogen production pathways or general questions regarding the assessment of water availability for hydrogen production for export or local use in vehicles are not considered in this factsheet.

How are energy, hydrogen and water related in decentralised energy systems?

Renewable electricity (yellow) and water (blue) flow into the electrolyser as input materials for the electrolysis process. Depending on the initial quality of the available raw water source, various treatment steps are taken to obtain deionised ultrapure water[2] for the electrolysis process. As described on page 1, the electrolyser produces green hydrogen (green) as the main product of a chemical reaction. Before it is stored, the hydrogen first undergoes a separation and drying process. During this process, it is separated from water molecules and the resulting excess water is removed.

The oxygen (turquoise) that is created as a by-product is also usually released into the atmosphere, mixed with other gases and water, but it could also be used for other applications (e.g. for water remediation). These two points are therefore where water losses occur, which could theoretically be reduced by targeted measures. Heat (orange), another by-product, is also released into the atmosphere. In the case of local demand, it could also be used externally. After the hydrogen has been produced, it is stored. Depending on the available space and the necessary storage capacity, various technology options are available.

When electricity is needed and renewable energy sources are not producing electricity, hydrogen can be released from the storage again (with low storage losses) and used in a fuel cell for energy conversion. This process is called reconversion. Within the fuel cell, the hydrogen (H_2) reacts with oxygen (O_2) from the surrounding air to form water (H_2O) again, releasing electricity. As in the electrolyser, heat is also produced in the fuel cell during the reconversion process, which can also be dissipated and utilised. The resulting water can in turn be used with minimal losses as the resource material for water electrolysis.

In addition to the use of water for hydrogen production and usage, water is also necessary for cooling the electrolysis and fuel cell components. Although the cooling requirements increase with the lifespan of the electrolyser, the total water losses are low (LBST, DHI WASY & Water Science Policy 2024). In addition, they depend on the climatic conditions (temperature, humidity) on site. By using the waste heat from the system, the cooling water demand and thus the water consumption can be reduced while increasing system efficiency (DVGW 2024).

Most of the cooling water remains in a closed circuit for the duration of the components' use. When the system is shut down, (temporarily) taken out of service or due to maintenance, the cooling water can be returned to the local ecosystem (GET H2 2023) and must be replaced when operations resume.

Water use and consumption: What are the key factors that determine the water footprint?

Similar to a life cycle analysis, the water footprint can be determined using the infographic shown above. In this case, the total amount of all incoming and outgoing water quantities across the system boundary is calculated in relation to a specific functional unit (e.g. 1 kWh electricity): the incoming drinking water, the discharge due to hydrogen drying, the oxygen flow, the losses captured in the exhaust air of the fuel cell, as well as the cooling water losses.

Water footprint

DIN EN ISO 14046:2014 defines the water footprint as “indicator(s) for the quantitative determination of the potential environmental impacts related to water”. This standard follows a life cycle assessment-based approach and encompasses both the water footprint inventory and the life cycle impact assessment of the water footprint. The latter is intended to serve as an “assessment of the magnitude and significance of potential environmental impacts associated with water caused by a product, process or organisation” (ISO 2014). Various methods, most of which are ISO 14046-compliant, help to derive multidimensional indications for the conscious and sustainable management of water as a resource. While this factsheet shows key elements of the calculation, it does not claim to calculate the water footprint of a decentralised energy system.

This process is used to identify ways of keeping water consumption at a minimum by reducing all outflows (as far as technically feasible). The water from the oxygen and hydrogen flows and from the exhaust air of the fuel cell should be separated, collected and returned to the ultrapure water treatment system to the best extent possible.

The infographic also shows how the water footprint changes if the hydrogen is not reconverted in a fuel cell. Instead, the hydrogen can leave the system and be used in various external applications, for example in mobility, where it is not practical to return the released water to the original system. Furthermore, there are applications in which decentralised fuel cell systems without local electrolysis are supplied with hydrogen from a central electrolyser. Although it is possible to collect the water released in each case, it is, strictly speaking, removed from the original electrolysis system. A similar picture emerges if the fuel cell is used at the same location of the electrolyser for reconversion, but the released water is supplied to other applications.

A temporal effect in the consideration of the water footprint arises if the stored hydrogen is accumulated over several months and is used later on for reconversion in a different season of the year.

What insights can pilot systems provide with regard to water use?

A systemic approach to water use in decentralised hydrogen and fuel cell systems requires a specific and data-driven analysis. So far, however, experience with these types of systems is limited and data is often not publicly available.

The Export Initiative Environmental Protection (EXI) therefore supports pilot projects in this area and collects initial experiences from their operation. One example of an EXI project involves a decentralised energy system with a 10 kW AEM (anion exchange membrane) electrolyser, a 10 kg hydrogen storage tank and an 8 kW PEM (proton exchange membrane) fuel cell, and has been in operation for a year. This allows initial conclusions to be drawn about the corresponding water requirements.

During operation of the exemplary system, it became apparent that an additional 5 litres of cooling water per quarter is required. The electrolysis itself consumes 1.68 litres of water per hour when the 10 kW unit is running at full capacity. In this case, this corresponds to a daily requirement of 10 litres of fresh water, which are supplied to the system for water treatment and subsequent electrolysis.

The following practical experiences relevant to water consumption have also been gathered so far:

- Operating times and breaks of the power consumer may lead to a temporary downtime of the system and therefore require electrolyte replacement.
- Scheduled replacement of the electrolyte according to the maintenance plan.
- Pressure reductions in the cooling system can lead to an increased water demand of the cooling system (Fraunhofer IWU 2024).

Conclusion and outlook:

The water-hydrogen nexus links the energy system with the water system and must therefore be considered holistically to ensure the sustainable use of both resources. A central tool for this is the determination of the water footprint of the entire energy supply system. Systems in which hydrogen is used as a long-term energy storage medium and in which electrolysis and reconversion to electricity using fuel cell technologies are linked locally can enable a resource-friendly use of water.

Water use within such systems can be improved by collecting and analysing detailed data on their consumption. The results obtained can provide a thorough perspective of the actual extent of water use, that takes into account all components. On the one hand, optimisation potential within the systems can be identified. On the other hand, the overall effect of the system on the local situation, in particular with regard to water stress, can be evaluated.

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[1] Please also refer to the NOW factsheet series ‘Fuel cells for decentralised power supply’ (mobile telecommunications, emergency and uninterruptible power supply, mini-grids)

[2] Depending on the electrolysis technology used, the requirements for the purity of the water resource may vary.

[3] The Water Footprint Toolbox is an interactive collection of concepts, standards, databases and impact assessment methods related to water footprints.