Industrial wastewater as an alternative source for the production of hydrogen

Industrial wastewater is the obvious solution to the issue of a limited water supply and the need to increase green hydrogen production.

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Introduction

According to estimates, around 40 per cent of the world's population will live in water-scarce regions by 2050. At the same time, the demand for water will increase by up to 30 per cent due to climate change and population growth. Even formerly water-rich regions in Europe are now struggling with periods of drought and falling groundwater levels. A sufficient and secure supply of water is closely linked to food and energy supplies. Differing utilisation interests can therefore lead to distribution conflicts.

The energy and chemical industries' switch to green hydrogen could further exacerbate this situation, as its production results in high water consumption. The electrolysis process requires around 10 litres of water per kilogramme of hydrogen (l/kg H_2) for feedstock, and a total of 30-70 l/kg of H_2 for feedstock and cooling, depending on the electrolyser technology used and the local climate conditions [1]. The table below shows the potential water demand based on the estimated growth in green hydrogen production in the coming years. By 2050, clean hydrogen demand could increase to 585 Mt per year [2], which corresponds to annual water demand for feedstock of 5,850 million m^3. This potential water demand equals the drinking water consumption of approximately 134 million people. If the water requirement for cooling is included, the amount shown increases tenfold and corresponds to the water use of one billion people.

Table 1: Potential water demand for green hydrogen production in the coming years

	Global clean hydrogen demand (million t H_2/a)[1]	Water demand for feedstock[2] (million m^3/a)	Number of people consuming the same amount of water (person equivalent)[3]
2024	< 5	50	1,100,000
2030	~ 60	600	13,700,000
2050	585	5,850	134,000,000

[1] According to McKinsey Energy Solutions Global Energy Perspective (2023) [2]
[2] Calculated with 10 l/kg H_2
[3] Calculated based on drinking water consumption of 120 l/(person*d)

Alternative water sources and innovative water treatment technologies must now be found in order to prevent distribution disputes and increased scarcity of local water. The following options are available as alternative water sources to the drinking water network:

1. Seawater
2. Surface water (lake or river)
3. Wastewater reuse from municipal WWTPs
4. Wastewater reuse from industrial WWTPs

When selecting suitable processes, the aim is to keep costs, labour, energy consumption and environmental impacts low. Seawater treatment and surface treatment are state of the art but will not solve the challenges on their own. Seawater treatment leads to high energy consumption (2.6-8.5 kWh/m³ [3]) and the environmental impact of discharging brine back into the sea. Surface water treatment is low in energy demand, but problematic in terms of the year-round availability of water in sufficient quantities to minimise downstream effects. Using effluent from municipal wastewater treatment plants, energy consumption between 1.2 and 1.96 kWh/m³ is reported, depending on the process technology used [4]. However, given the centralised nature of municipal wastewater treatment plants, it may be difficult to distribute large quantities of water to remote locations.

To provide sufficient feedstock water for hydrogen production, the focus is shifting to more local sources, especially industrial wastewater. Some alternative water supply solutions based on using industrial wastewater are introduced below, including solutions for both slightly contaminated wastewater and heavily contaminated wastewater, which could be used as feedstock water for an electrolyser or to relieve pressure on the drinking water network.

Figure 1: Integration of industrial wastewater and other feedstock water sources into a holistic approach for hydrogen production

Introduction of alternative water supply solutions to relieve pressure on drinking water networks

Treatment of inorganically low-polluted streams, e.g. mine water or surface water

For treating inorganically and organically low-polluted mine wastewater, a process chain combining pre-filtration, ozone dosing, ceramic ultrafiltration, activated carbon filters and reverse osmosis is suggested (see Figure 2). At its heart is ceramic membrane filtration, which is supported by upstream ozone treatment. The ozone both destroys organic pollutants and significantly reduces fouling potential on the membrane. Labelled CembrOzone, the solution minimises membrane fouling while maximising membrane performance and service life. An activated carbon filter to remove residual ozone is followed by reverse osmosis to provide the required water quality.

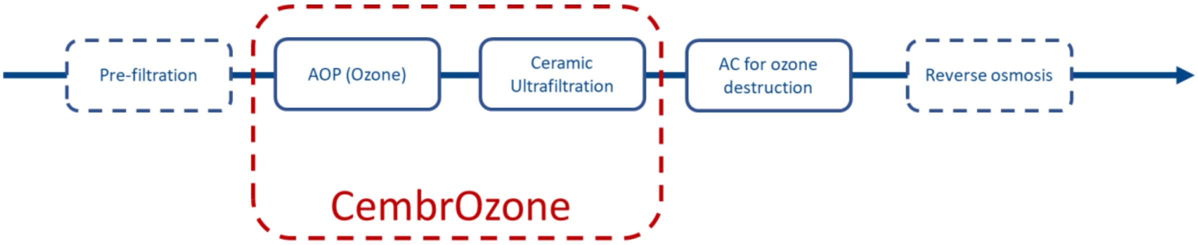

Figure 2: *Flow diagram of the* CembrOzone *solution*

For a mine in Sweden, the inorganically and organically low-polluted mining wastewater (TOC < 5 mg/l and 16 NTU) is treated in shipping containers, which allow a modular design for the plant (see Figure 3). The net flux of the plant is 200 l/(m^2h) and the operation pressure is very low at -0.1 to -0.25 bar due to the special silicon carbide (SiC) membrane. The system requires 3-5 g O_3/m^3, which results in a total energy consumption of 0.15-0.25 kWh/m^3 including peripherals. Added to this is the energy required to treat the water to the quality required by the electrolyser.

Figure3: EnviroChemie container plant for treating mining wastewater (left) und example of the modular design of an EnviroChemie plant (right)

The plant is designed for a permeate volume flow of 4800 m^3/d, which, greatly simplified, could be converted to 480 t of H_2/d.

This combination of technologies is also suitable for the energy-efficient treatment of surface water.

Treatment of organically low-polluted streams, e.g. rinsing waters or vapour condensates (cow water) [5]

The production site of a large dairy in Germany manufactures various dairy products including skimmed milk concentrate, condensed milk and milk powder, the production of which generates vapour condensate. Together with the dairy, EnviroChemie GmbH has developed a treatment strategy to allow this vapour condensate to be reused in the production area.

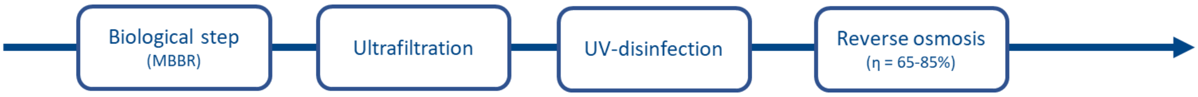

Figure 3: Flow diagram of the treatment strategy for treating organically low-polluted streams to drinking water quality.

The vapour condensate is low in organic (TOC < 50 mg/l) and inorganic pollution (electrical conductivity < 15 µS/cm). The treatment starts with an aerobic biological process in which dissolved organic compounds are biodegraded by microorganisms that grow in biofilm compounds. Downstream of the aerobic bioreactor is the second stage, a fixed-bed reactor, in which the solids are reduced, and the organic load and nitrogen compounds are further degraded at the same time. The purified water from the fixed-bed reactor is of high quality, but subsequent treatment steps can polish the water. Combining a multi-stage membrane process with the option of hot water sanitisation is essential in order to produce treated water that meets drinking water quality standards. Biological pre-treatment has the advantage of breaking down small organic compounds that might otherwise pass through a reverse osmosis membrane and makes the water storable with a lower risk of microbial regrowth/contamination.

Figure 4: 3D model of the installed plant producing 188,000 m³ per year of water in drinking water quality using cow water as a water source.

At the dairy, 188,000 m³ of process water per year is provided with this solution. The required energy input for treatment is around 1.2 kWh/m³ of process water. An electrolyser producing 20,000 tonnes of hydrogen per year could be installed in this case, while also relieving the drinking water supply.

Industrial wastewater recycling treating wastewater with a high organic load (end of pipe)

Wastewater with a high organic load often requires complex treatment and multiple process steps for wastewater recycling. As an example, an existing wastewater treatment plant at a potato processing company in Germany with only a biological aerobic treatment step was expanded and modernised by adding flotation, anaerobic digestion, ultrafiltration and reverse osmosis (see Figure 3). By expanding the plant and returning the permeate from reverse osmosis to production, water consumption was reduced by 30-40%.

Figure 5: Flow diagram of wastewater recycling treating wastewater with a high organic load.

The treatment plant processes 1,800 m³/d with a COD of 4,170 mg/l, a TOC of 1,540 mg/l and 310 mg/l of chloride. In the reuse water, the quality criteria of TOC < 4 mg/l, chloride < 50 mg/l and coliform bacteria of 0 CFU/100 ml were met.

Figure 6 shows the specific energy consumption during the modernisation phases. Expanding the existing plant by a flotation and anaerobic biological treatment (2015 to 2017) reduced the specific energy consumption to approx. 35% of the reference (2013, 2014). This was achieved by generating energy from the methane produced during the anaerobic digestion of organic substances. Modernising the plant for water reuse in 2018 increased the specific energy consumption to approx. 60% of the reference (2013, 2014). The subsequent optimisation phase showed the potential for and importance of operational improvements to reduce the energy consumption. By optimising features such as chemical cleaning to extend the filtration cycles of the ultrafiltration, the specific energy consumption was successfully reduced by 50% compared to the old plant in 2013/2014, to 3.5-3.7 kWh/m³. Due to the high effluent quality, the treated wastewater is a good basis for further processing to hydrogen.

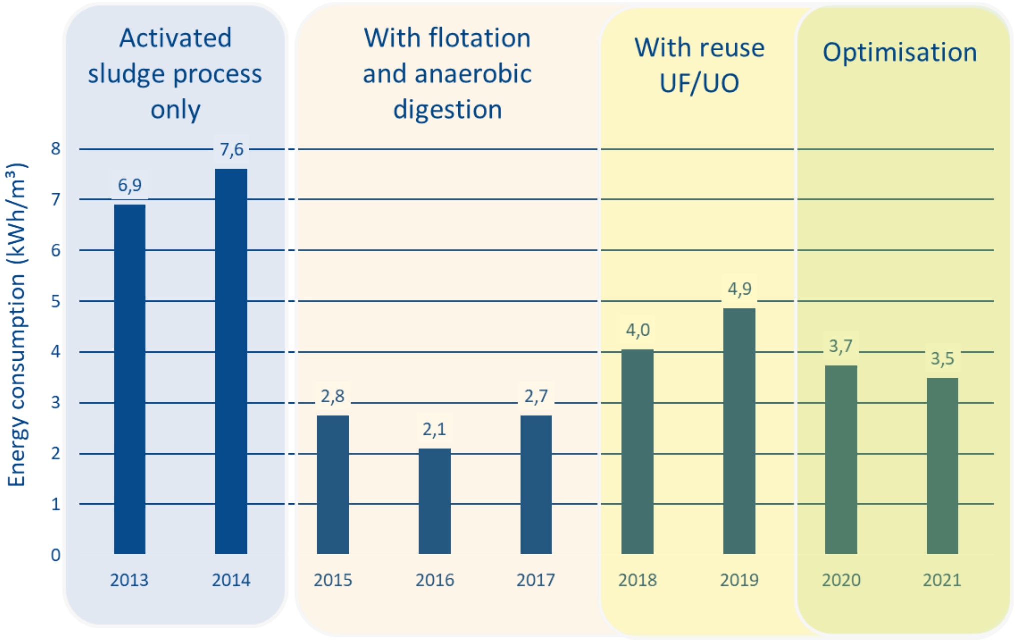

Figure 6 Energy consumption during the modernisation of a wastewater treatment plant for the potato processing industry

In this example, after deducting 40% for water reuse, 1,080 m^3/d of process water would be available for further use. Assuming a recovery rate of 75% at the reverse osmosis, around 80 t of H_2/d could be produced from the 800 m^3/d of water.

Summary

The case studies presented show that industrial wastewater can play a key role in the development of alternative water sources for providing the feedstock water required for green hydrogen production. They emphasise the importance of a holistic, systemic approach to local and integrated hydrogen production. In addition, the case studies demonstrate that the combining and optimising different technologies appropriately can provide not only sufficient water in the required quality, but also energetically advantageous and thus economical solutions. The solutions presented offer promising approaches for companies to respond to the challenges of hydrogen production.

Table 2: Feedstock water source and energy consumption

Water source	**Energy consumption (kWh/m^3)**
Surface water (lake or river)[3]	0.37
Groundwater[3]	0.48
Wastewater treatment[3,4]	0.62-1.96
Wastewater reuse[3]	1.0-2.5
Seawater[3]	2.58-8.5
Alternatives introduced	
Mining wastewater/surface water	0.1-0.25
Potato /food processing wastewater	3.5-3.7
Vapour condensate treatment, dairy industry	1.2

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Literature

[1] International Energy Agency (IEA), 2024. Global Hydrogen Review. www.iea.org.

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