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Power-to-Hydrogen

Seasonal energy carrier – Power-to-X technology

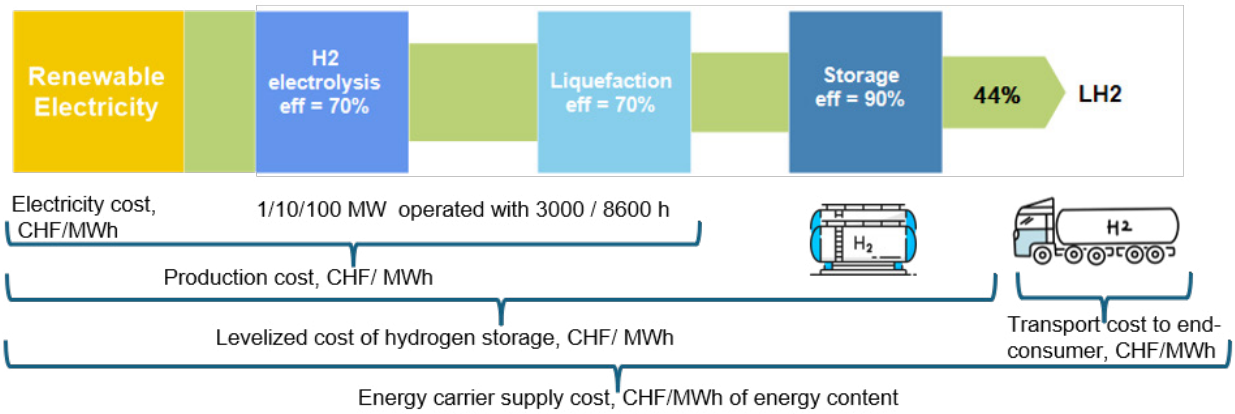
Hydrogen, produced through water electrolysis ($2\ H_2O \rightarrow 2\ H_2 + O_2$) powered by renewable electricity sources such as solar, wind, or hydropower, represents a clean energy technology. It is a crucial alternative for decarbonising sectors that are challenging to electrify directly, such as heavy industry, aviation, and long-haul transport, where hydrogen can be used either directly as a fuel or indirectly to produce fossil-free kerosene and other synthetic fuels.

Hydrogen electrolysis plant in the canton of Graubün-den, located next to the Reichenau hydropower plant in Domat/ Ems. Photo: Axpo

A key advantage of renewable hydrogen is the flexibility in electrolysis operation. However, the widespread adoption of renewable hydrogen faces significant hurdles, including high production costs and the need for extensive distribution infrastructure. The latter involves developing efficient transportation and storage systems to move hydrogen from production sites to endusers, which can be particularly challenging, given hydrogen´s low volumetric energy density. The InfraMap (https://www.h2in-framap.eu/#introduction) tracks the development of hydrogen infrastructure across Europe.

Renewable hydrogen production in Switzerland faces key challenges and opportunities. A major barrier is the high upfront investment, given current market scale limitations. The absence of specific goals in the national hydrogen strategy creates uncertainty about system implementation and regulatory clarity. Switzerland´s limited domestic renewable energy resources increase reliance on hydrogen imports, particularly in winter. Therefore, if hydrogen is used as an energy carrier to cover winter energy demand, long-term hydrogen storage is required. However, the low volumetric energy density of hydrogen, even as a liquid or at high compression, poses major technical and economic barriers to large-scale seasonal storage.

Considering hydrogen production with liquefaction for storage, a Power-to-Hydrogen-to-Storage efficiency of 44% can be achieved, as illustrated below [1].



The total cost of supplying hydrogen as an energy carrier encompasses production expenses (including the Power-to-H_2 process), long-term storage costs, and transportation costs to the end consumer. Together, these components represent the complete supply cost of utilizing hydrogen as a storable and transportable medium for renewable energy. Switzerland currently has no hydrogen backbone; integration with the planned European Hydrogen Backbone (EHB) is under discussion but not yet implemented.

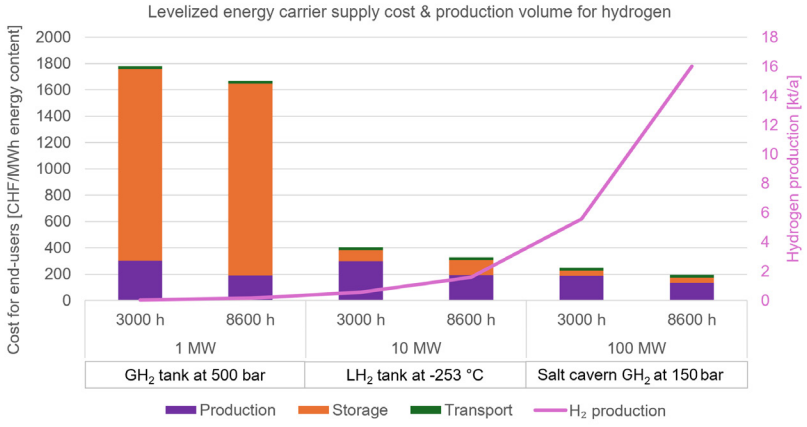
Availability

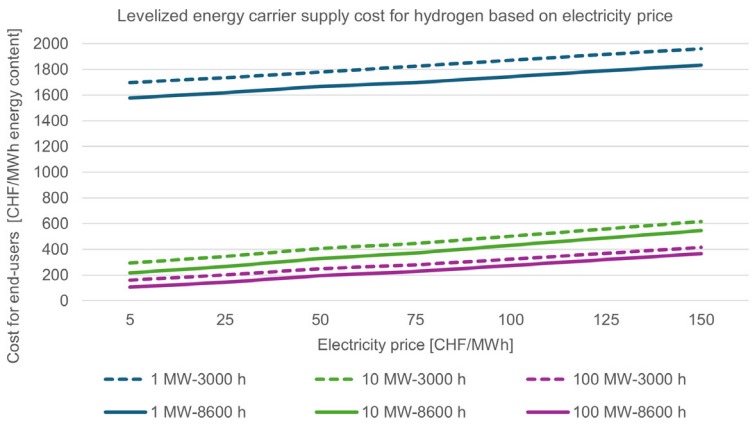
Total global hydrogen production in 2025	97 Mio. tonne [2]
Global production of renewable hydrogen in 2025	< 1 Mio. tonne [2]
CH production of renewable hydrogen in 2025	Max. 1500 tonne [3]

Chemical properties

Volumetric energy density (LHV): Net calorific value	LHV: ~3.0 kWh/m³ (1 bar, 0 °C), ~1100 kWh/m³ (500 bar, 15 °C), Liquid 2,360 kWh/m³ (-253 °C) [4]
Gravimetric energy density: Net calorific value	LHV: ~33 kWh/kg, HHV: ~39 kWh/kg
Melting point / Boiling point	-259 /-253 °C at standard atmospheric pressure
Auto ignition	535 °C
Flammability limits	Highly flammable from 4 to 75 vol.%
Explosive limits	4 to 75 vol.% [5]

Cost analysis





The upper graph on the left illustrates the relationship between levelized hydrogen supply cost to end-users (bars) and production volume (pink line) across installed electricity capacity scenarios for 1 MW, 10 MW, and 100 MW. Calculations are based on an electricity price of 50 CHF/MWh, a 5% interest rate, and a 25-year economic lifetime. Hydrogen production and storage costs depend strongly on system scale, storage technology, and utilization hours.

Small-scale systems using compressed hydrogen tanks at 500 bar (1 MW) have the highest supply costs per MWh of hydrogen due to very high storage CAPEX and limited utilization due to longterm storage. Liquid hydrogen storage at mid-scale (10 MW) achieves lower costs despite liquefaction energy penalties, while large-scale systems (100 MW) with salt cavern storage offer the lowest costs thanks to minimal storage CAPEX and strong scale effects. However, the use of salt caverns is limited to locations with suitable geological formations.

The lower left graph shows that levelized hydrogen supply cost increases linearly with electricity price, with larger systems and high utilization (8600 h/year) achieving substantially lower costs. Overall, high annual operating hours and large-scale deployments are essential for delivering cost-competitive hydrogen, while storage technology choices depend on site-specific conditions.

Projects

Switzerland is actively advancing its renewable hydrogen production capabilities through a diverse range of projects, from small-scale demonstrations to large industrial facilities. These initiatives target various sectors, including mobility, industry, and district heating. Most projects primarily utilize renewable hydropower as their energy source, with several already operational or soon to be commissioned. However, the production capacity, so far, is still in its infancy.

For most applications, hydrogen is currently transported using compressed gas tube trailers, each capable of carrying several hundred kilograms of hydrogen. While this method offers the greatest flexibility, it is also quite costly, particularly when dealing with low volumes.

Location	Capacity	Production	Status/Start	Main Use Cases
Domat/Ems GR	2.5 MW	350 t/year	Opened 2024	Mobility, industry
Bürglen UR	2 MW	260 t/year	End of 2025	Mobility, industry, shipping
Freienbach SZ	10 MW	1200 t/year	Planning	Trucks, gas grid, district heating
Gerlafingen SO	30 MW	4700 t/year	≥2027	Steel, industry, district heating
Schiffenen FR	2 MW	300 t/year	Opened 2023	Freight transport
Aigle VD		20 t/year	2025	Local industry (steel/metallurgy)
Glovelier JU		720 kg/day	July 2026	Industry, mobility (biomass-based)
Gösgen SO	2 MW	300 t/year	2024	Regional mobility
Bulle, FR	2 MW		2024	Industry, mobility
St. Gallen SG	2 MW		2023	Local buses, municipal vehicles, demo

Sources / additional information

[1] Baeuerle et al., «Seasonal energy storage for net-zero industrial heat,» Energies, vol. 18, p. 2204, 2025.
[2] IEA (2024). Global Hydrogen Review 2024. Paris: International Energy Agency
[3] Own estimation based on the operating projects.
[4] IDEALHY, «Liquid Hydrogen Outline,» https://www.idealhy.eu/index.php?page=lh2_outline.
[5] Daubitz, R., Bestimmung der Explosionsgrenzen von Wasserstoff/Sauerstoff-Gemischen bei erhöhten Anfangsdrücken, Research Report, BAM and TU Berlin, 2001.

SPF INSTITUTE FOR SOLAR TECHNOLOGY

Contact
Yvonne Bäuerle, Projektleiterin SPF
OST – Ostschweizer Fachhochschule,
Campus Rapperswil-Jona
Oberseestrasse 10, 8640 Rapperswil
T +41 58 257 42 04
yvonne.baeuerle@ost.ch | ost.ch/spf

Prepared as part of the ReWAX research project, funded by the Swiss Federal Office of Energy (SFOE), Buildings and Cities Program – Version 1.0, November 2025.