White paper

The role and potential of hydrogen in Switzerland

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The Power of Energy

axpo

'Hydrogen still has a few hurdles to overcome, but Axpo is convinced of green hydrogen's potential as a clean, renewable, and versatile energy carrier. We are actively committed to the establishment of a hydrogen industry in Switzerland and elsewhere in Europe, and we are about to begin operations at our first hydrogen production plant.'

Christoph Brand
Chief Executive Officer

The role of green hydrogen in Switzerland's energy transition

Hydrogen has a central role to play in decarbonisation. In this white paper, we explore green hydrogen's potential as a clean, renewable, versatile energy carrier. Axpo is actively committed to the establishment of a hydrogen industry in Switzerland and we are on the brink of producing the first kilograms of hydrogen from our hydrogen production plant at the Reichenau hydropower plant in Domat/Ems.

We are also planning to establish further plants in Switzerland, and invest in hydrogen production plants and green hydrogen derivatives in other countries. In this report, we summarise the most important findings from our evaluation of the potential for deployment of pure green hydrogen in Switzerland, along with an analysis of the key production figures.

Management summary

Hydrogen: flexible energy carrier, fuel of the future

- Green hydrogen, which is produced from renewable energy carriers, has a decisive part to play in our efforts to reduce carbon emissions. The energy transition presents major opportunities for hydrogen, particularly in sectors that cannot easily switch to electricity, such as industries with high-temperature processes and energy-intensive mobility with high energy density requirements.

- Green hydrogen and its derivatives offer long-term, compact energy storage potential that presents opportunities for use in heavy-duty transport, shipping and air transport, possibly through the use of e-fuels. Hydrogen and its secondary products may also offer seasonal, location-independent energy storage for renewable energy carriers.

- In the future, the transformation of cheaply-produced electricity into hydrogen could contribute to a secure, reliable and continuous energy supply. However, current efficiency levels mean that electricity production from hydrogen is still not economical, so we expect its deployment for electricity production in Switzerland to remain limited, at least in the short term. Whether or not reconversion proves economical depends on several factors, with the key prerequisites being favourable economic and political framework conditions. It also requires certain technological developments, which are currently the subject of intensive research.

- The creation of a hydrogen transport infrastructure requires considerable investment in Switzerland and throughout Europe. Coordination with existing gas infrastructure is crucial, and the dismantling or conversion of existing gas transport infrastructure must be carefully analysed, technically coordinated and scheduled in parallel with the development of hydrogen infrastructure. As such, Axpo welcomes recent developments[1] in which Transitgas AG, a Swiss representative, has also become a member of the European Hydrogen Backbone initiative.

- Optimised deployment of electrolysers will be a decisive factor. Low capacity is associated with high fixed costs, while at high capacity, electricity costs are the dominant factor. The analysis we present in section 2 points to a theoretical optimum when capacity reaches 85%, with hydrogen production costs in the range of CHF 8 to 14/kg H_2 where electricity prices are between CHF 50 to 125/megawatt-hour (MWh).

- Hydrogen will assume a central role in the future energy and mobility landscape – but its contribution to the energy transition remains to be seen. Long-term models forecast an annual demand of about 125,000 tonnes of pure hydrogen in Switzerland in 2050, split between domestic production and imports. If this demand is to be met solely with green, locally produced hydrogen, it would require a substantial amount of electricity – about 7.5 terawatt hours. And this does not take into account the high degree of energy required to produce hydrogen derivatives such as synthetic methane, which would require significantly higher volumes of energy.

1. Definition and description

What is hydrogen?

Hydrogen (H) is the most common chemical element in the universe. It is found in water (H_2O) and in most organic compounds. Molecular hydrogen (H_2) is an invisible, colourless, odourless gas. It is 14 times lighter than air and has a high energy value. One kilogram of hydrogen contains about three times more energy than benzine and seven times more energy than wood pellets. However, gaseous hydrogen has a lower energy density by unit of volume (per cubic metre) than natural gas. This means that for storage and transport, it is usually compressed at high pressure or intensively cooled and liquefied.

Green, grey and blue hydrogen

Hydrogen can be extracted through various methods. The most common methods at present are steam reformation of natural gas or biomass. The chemical reaction of natural gas (with methane as the primary component [CH_4]) and water vapour (H_2O) produces carbon monoxide (CO) and hydrogen. Another production option is the chemical reaction of electricity and water. If the electricity comes from the electricity mix or directly from nuclear energy is referred to as yellow or pink hydrogen. Green it is if the electricity is produced exclusively from renewable energies.

The production of green hydrogen is carbon-free and may contribute to decarbonisation, making it an important pillar of the energy transition.

Untapped potential of white hydrogen

A largely unexplored field is 'white hydrogen', which is found in its natural state in subterranean reservoirs. Examples include the discovery of hydrogen deposits during drilling in Mali in 1987 and then again more recently in the neighbouring French region of Alsace-Lorraine in 2023[2]. Experts warn that the precise volume of hydrogen deposits beneath the surface of the earth is still largely a matter of speculation. Nonetheless, a model by American geological body USGS shows that hydrogen extraction from the earth could meet more than half of the world's hydrogen demand by 2100[3].

Areas of application

Currently, hydrogen is used primarily as a raw material in various branches of industry, such as to produce fertilisers and in refineries. In future, hydrogen is expected to play a central role in decarbonisation, as it is a flexible energy carrier with a wide range of applications.

The first priority will be to replace grey hydrogen, which currently dominates in industry, with green hydrogen. In parallel, hydrogen would be deployed in industrial processes that are currently dependent on fossil fuels, resulting in a direct reduction of carbon emissions. Hydrogen can assist in the storage of electricity from renewable energy carriers and be transported over long distances in the form of secondary products (such as synthetic methane). The combustion or chemical reaction of hydrogen produces nothing but water, which means hydrogen can serve to decarbonise areas that cannot be readily switched to electricity, such as transport (trucks, shipping, air).

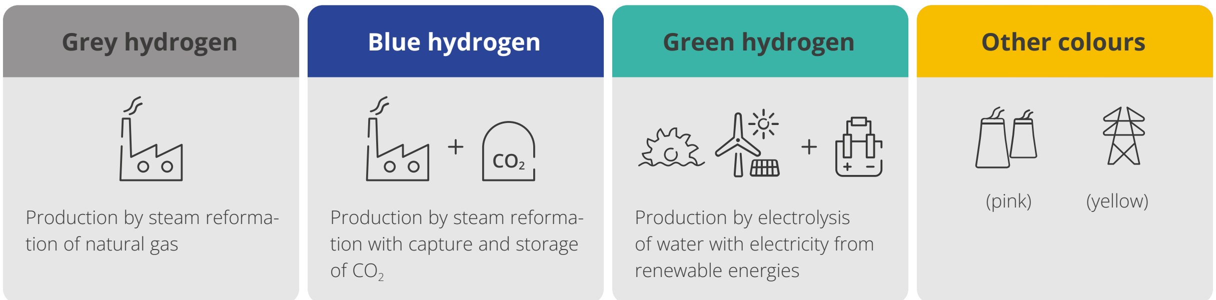

Figure 1: The colours of hydrogen depending on the production method.
For a better overview, only the most important colours and production methods are listed.

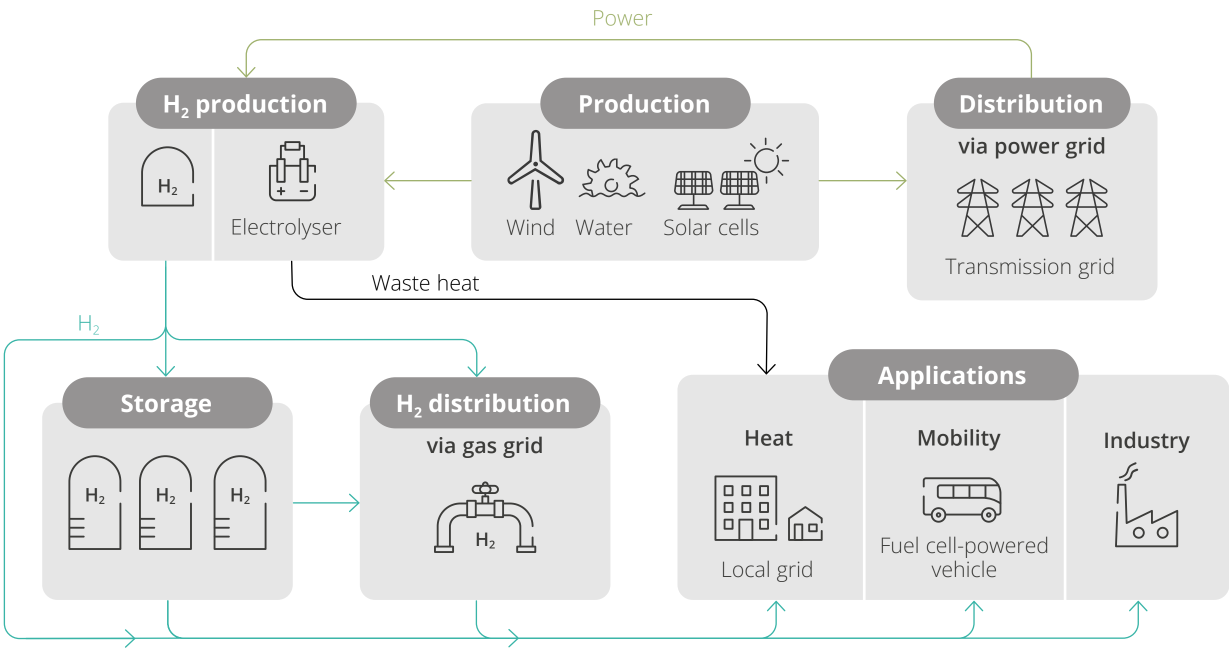

Figure 2: Elements of the hydrogen economy

The 'Clean Hydrogen Ladder' offers a comprehensive assessment of the suitability of hydrogen for various applications[4]. This shows, for example, that hydrogen fuel cells have a competitive advantage over batteries and combustion engines in long-distance transport. The limited storage capacities of batteries and the carbon content of the grid electricity mix have a negative impact, while combustion engines emit carbon and other harmful substances.

However, there are some applications for which hydrogen does not represent a viable solution. Using hydrogen to heat private homes, for instance, requires about five times more electricity than an efficient heat pump[5].

Hydrogen makes sense in applications where electrification as a replacement for fossil fuels is either uneconomical or technically unfeasible.

2. Introduction to H_2 production

(components, energy consumption)

Green hydrogen is produced through a process known as water electrolysis, which uses renewable energy. The central element of an electrolysis plant is the electrolyser, which splits water into hydrogen and oxygen. Among the electrolysis technologies available for industrial applications, alkaline and proton exchange membrane (PEM) water electrolysers are the most commonly used. The surrounding equipment provides all the necessary auxiliary services, from water purification to current rectification, gas compression and local storage. The total energy consumed by the plant to produce one kilogram of hydrogen depends on the technology of the overall system. This consumption is usually between 60 and 65[6] kilowatt hours (kWh) per kilogram of hydrogen.

What is LCOH?

The most important metric for assessing the economic viability of green hydrogen production is the total production cost, known as the levelised cost of hydrogen (LCOH). The LCOH represents the price at which the green hydrogen producer can cover costs. In other words, the LCOH is the price at which the plant owner should sell the hydrogen throughout the service life of the plant to avoid losses.
The LCOH is therefore an essential indicator when assessing the profitability of green hydrogen production.

The two key factors of the LCOH are the costs, including investments, operating costs and electricity costs, and the annual hydrogen production volume. Both factors involve significant uncertainties that make it difficult to accurately determine the exact production costs. It is therefore more reasonable to consider a range of LCOH and LCOH sensitivities. However, some assumptions must still be made.

The LCOH is typically divided into different cost categories, including capital expenditure (CAPEX), operating costs (OPEX), electricity costs and other costs such as funding costs. This division enables a detailed analysis of the cost structure and allows a better understanding of the economic viability of hydrogen production.

Capital expenditure

The capital expenditure (CAPEX) includes all required components of the electrolysis plant, including the electrolyser, water purification systems, current rectifier, electronic components, compressor, on-site storage and construction work. Extensive, evergrowing literature is available on these capital expenditure, which shows an optimistic tendency to underestimate costs or only account for parts of the overall investment.

Operating costs

The operating costs (OPEX) are the elements associated with the most uncertainty within the cost estimate, as this aspect must cover the operating expenses and maintenance costs. Operating costs are generally viewed as proportional to the capital expenditure and are typically in the low single-digit percentage range of the initial investment per year. The operating costs must be subsequently updated based on the experience gained in operation of the plant.

Electricity costs

Long-term electricity costs are a main driver of hydrogen production costs and are expected to lie between CHF 80 to 100/MWh for the period 2025 to 2045, as expected by most market forecasts.

A practical example: LCOH analysis for our example plant

An electrolysis plant with a service life of 20 years serves as a reference case to analyse the LCOH. The key assumptions are summarised in table 1 on page 7 above.

LCOH – Absolute costs and proportion of different cost factors, depending on electricity price

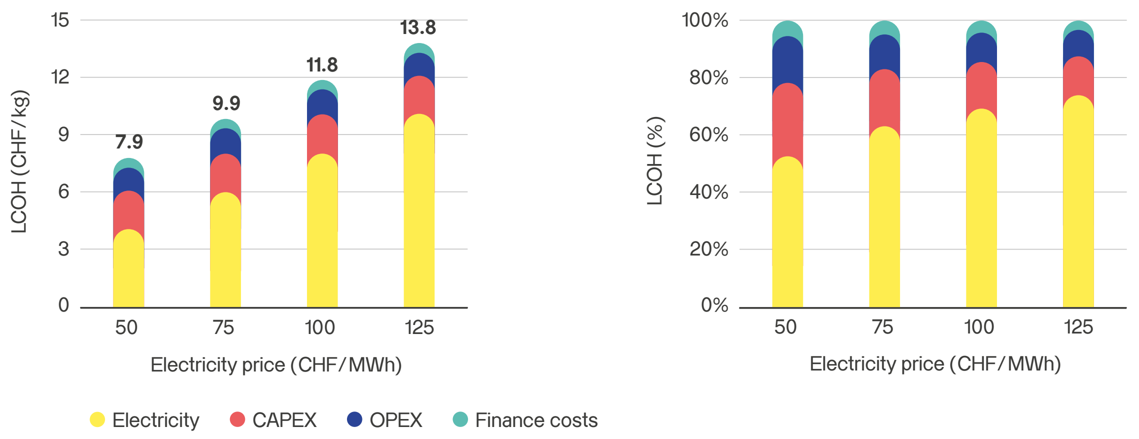

Figure 3: Levelised cost of hydrogen (LCOH) depending on electricity price (left); percentage share of different LCOH cost factors at different electricity prices (right)

Assumptions	Values
Electrolyser performance	2.5 MW (approx. 45 kg H_2 per hour)
Capital expenditure (CAPEX)	CHF 7.5 million
Operating costs (OPEX)	CHF 300,000 per year
Electricity costs	CHF 50 to 125/MWh
Average utilisation	85% (7,446 operating hours per year)

Table 1: Assumptions for LCOH calculation

Our project experience indicates that an investment of approximately CHF 7.5 million for a 2.5 MW electrolysis plant is realistic. The annual operating costs of CHF 300 000 correspond to 4% of the investment and should be viewed as a forecast still to be validated in plant operation. Electricity costs ranging from CHF 50 to 125/MWh cover a wide range of electricity price scenarios throughout the service life of the electrolysis plant.

Figure 3 (page 6 below) shows the LCOH and the split into the different components (CAPEX, OPEX, electricity costs and funding costs) for various average electricity price levels. As indicated above, the electricity price is the main driver of hydrogen production costs. Electri-city procurement accounts for between 50% and 75% of the LCOH share. This highlights the significance of electricity costs for the economic viability of hydrogen production.

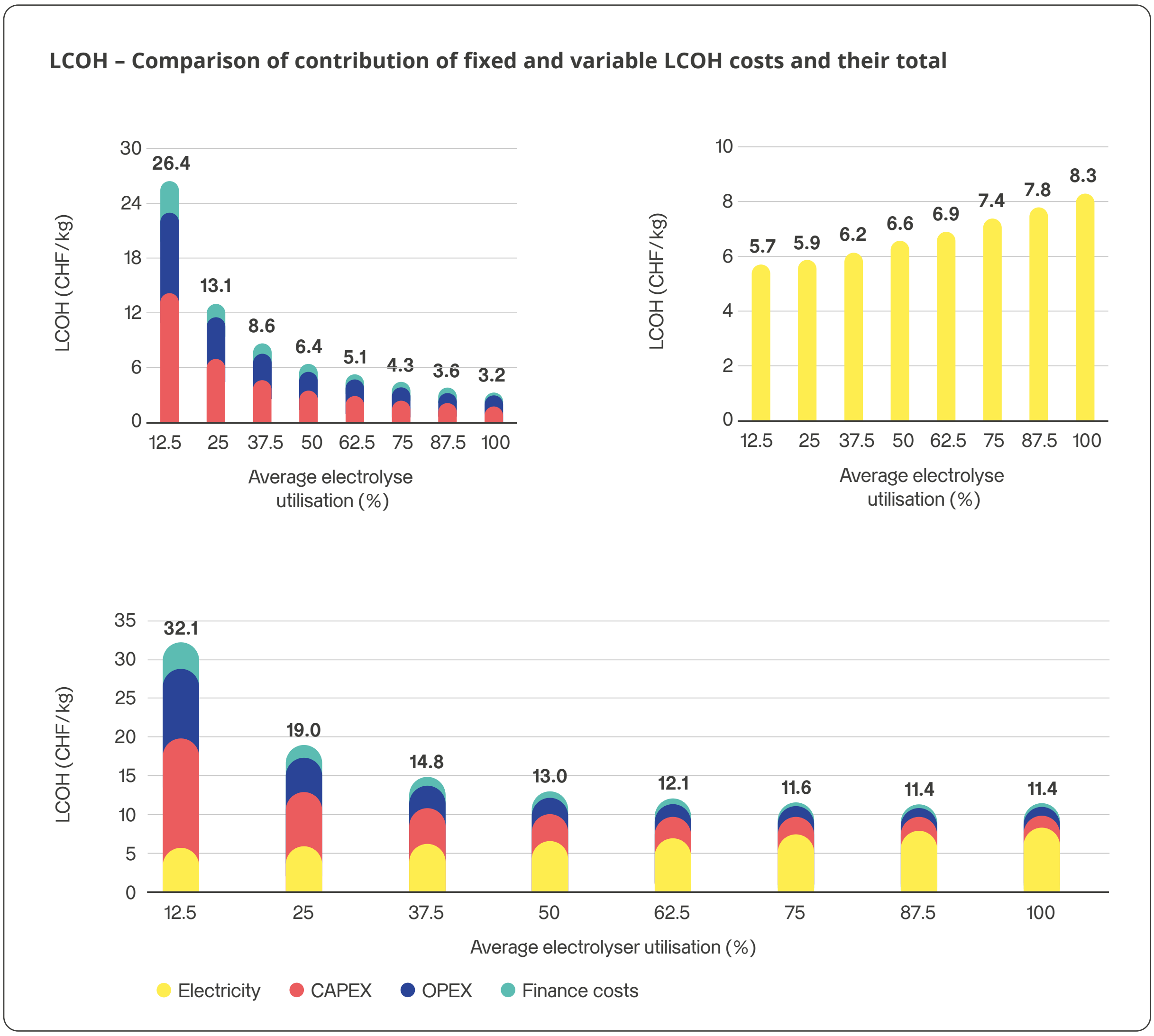

Figure 4: Contribution of fixed costs (top left) and variable costs (top right) to the LCOH, and the total of both cost categories (below), depending on electrolyser utilisation

Optimising of the use of electrolysis plants plays a crucial role due to short-term electricity price fluctuations and has a significant impact on the overall costs of hydrogen production.

In addition, the LCOH depends strongly on the effective operating hours (the 'utilisation'), as shown in Figure 4 (page 7). The graph shows two overlapping effects: a higher number of operating hours enables the fixed costs to be spread over a larger production volume. However, lower utilisation creates the opportunity to benefit from lower electricity prices for hydrogen production. The combination of these simultaneously occurring and opposing effects means an equilibrium is reached at an electrolyser utilisation of about 85%.

As such, using electrolysers exclusively to store solar power with an expected utilisation of under 25% will not be an economically viable operation. To operate electrolysers efficiently, plants in Switzerland and neighbouring countries usually seek a combination of different renewable electricity sources.

3. Potential

As a flexible energy carrier and fuel, hydrogen could play a central role in the energy transition. Energy storage options are becoming increasingly important, particularly in terms of the global shift of the energy system towards increased electricity production from volatile renewable production sources.

Hydrogen and its derivatives can be produced from renewable electricity, such as solar and wind energy, with flexibility in terms of time and place. Energy carriers can therefore be produced at the most efficient location, regardless of timings and distance, with the energy then transported to the place of use.

Although hydrogen is not the only solution available for dealing with the winter energy gap, it plays an important role in the interaction of different technologies to ensure a secure and stable energy supply in the future. While profitable implementation is still a long way off, the long-term potential of energy imports in the form of hydrogen or its derivatives with possible electric reconversion through hydrogen power plants must not be overlooked.

The storage and transport of hydrogen over long distances is already possible in limited quantities. This opens up far-reaching possibilities for a carbon emission-free supply of energy.

An integrated hydrogen economy would link various sectors such as mobility, heat, industry and electricity generation into an overall system. Hydrogen can be used in a wealth of applications, such as locomotion in fuel cell vehicles, energy storage and industrial processes.

New applications, such as the production of ammonia, methanol and other chemical compounds from hydrogen, are constantly being developed. Although solutions for private transport are not economically viable, the outlook is more promising for the lorries, ships and planes of the transportation industry. In addition to hydrogen, this industry could also use synthetic hydrogen-based fuels. Furthermore, the industrial use of green hydrogen offers considerable potential to help reducte current greenhouse gas emissions.

Of course, various challenges, such as energy losses when converting electricity into hydrogen and its derivatives or the limited options for compact storage, still need to be overcome as the hydrogen economy progresses.

As a storage technology, hydrogen has a significantly higher energy density per kilogram compared with batteries, but it requires compression under high pressure due to the larger volume required for this energy density. However, steady progress is being made on all fronts: technological developments are contributing toward the further reduction in energy losses and research into more effective storage options is ongoing.

How much hydrogen does Switzerland need?

Given the high transport costs and the required dispersion, Switzerland will focus on hydrogen applications in the mobility sector. To achieve the decarbonisation strategy targets, the widely discussed winter energy gap will probably have to be covered through imports of hydrogen derivatives. For example, the use of hydrogen is necessary in all scenarios envisaged by the Energy Perspectives 2050+ study, which assume a complete decarbonisation of Switzerland.

Against this backdrop, we compare two models that calculate the future pure hydrogen demand* in Switzerland. Figure 5 shows this demand in different scenarios of the Axpo Power Switcher and as a result of the ZERO Basis scenario from the Energy Perspectives 2050+ study. The modelling in the Axpo Power Switcher considers critical changes in the framework conditions, including low production from renewable plants across Europe, low gas availability, and low nuclear energy in France. The hydrogen demand is calculated to estimate the impact of greater electricity demand, induced by electrolysis to produce green hydrogen, on the electricity market.

A closer analysis of Figure 5 shows that the results of both models indicate greater deviations in the expected hydrogen demand over the next few years as the hydrogen economy evolves. However, these differences decrease significantly towards the end of the considered period up to 2050.

The Energy Perspectives 2050+ study also makes a distinction between imports, which will be possible as of 2040 (through connection to the European Hydrogen Backbone), and domestic hydrogen production. The trade-off between the greater security of supply with local production and the economic aspects of the expected lower-cost imports plays a particularly important role when considering this distinction.

In summary, there is a high level of uncertainty in the forecasts in the short term and the question remains as to when hydrogen production and use will really gain momentum. However, a significant need for hydrogen and converging expectations remain in the long term.

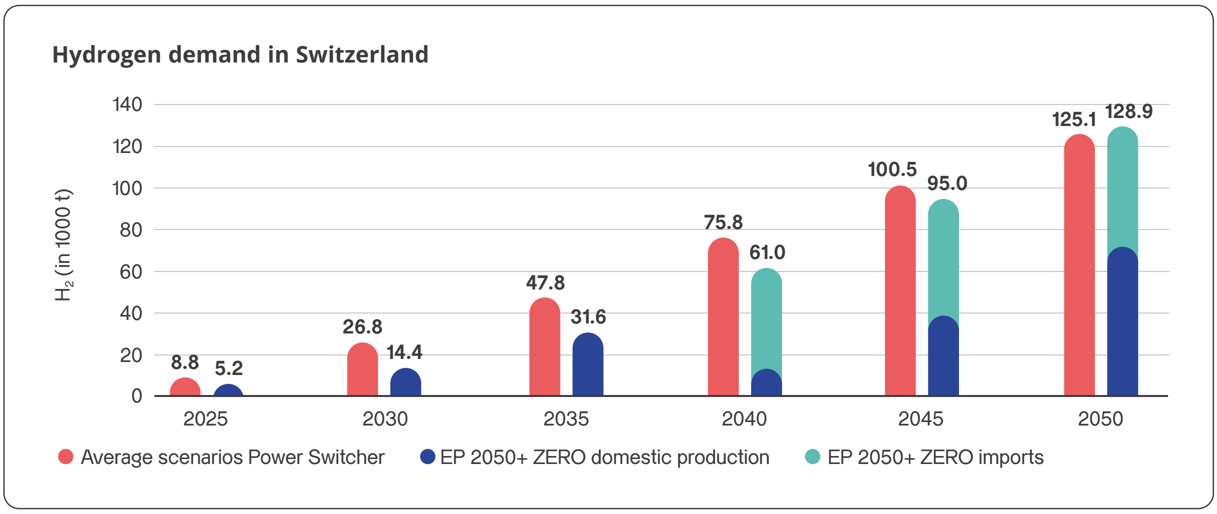

Figure 5: Modelled hydrogen demand in Switzerland. Comparison of Axpo Power Switcher** scenarios and Energy Perspectives 2050+[7] study.

* Demand for pure, green hydrogen. Hydrogen requirements for follow-up products, such as power-to-liquid applications, are not shown.

** Axpo Power Switcher, electricity demand for H_2 (subscript) production (conversion from TWh to tons). Method: Two extreme scenarios and one duplicate scenario were removed. The average hydrogen demand of the remaining nine scenarios is depicted.

4. Hydrogen in Switzerland

- In 2019, the Swiss Federal Council agreed that Switzerland should aim for net-zero greenhouse gas emissions by 2050,[8] in order to meet its obligations under the Paris Agreement. According to the government, green hydrogen should also be used to achieve this, particularly in areas that are difficult to electrify.

- Various studies have been conducted to examine the expected demand (see section 3). It should be emphasised that all scenarios under the Energy Perspectives 2050+ study require electricity-based energy carriers to achieve net zero.

- The Swiss Federal Office of Energy (SFOE) is expected to develop a set of Hydrogen Interpretation Rules[9] by November 2023, which will set out the areas in which the use of hydrogen applies, where and how it can be produced and stored, and the regulatory framework required for the targeted development of a hydrogen market in Switzerland. This will be followed by a hydrogen strategy for Switzerland in 2024.

- Switzerland's hydrogen sector has not yet received any dedicated funding. Following the decree[10] passed by the Swiss parliament at the end of September 2023, operators of hydrogen pilot plants will be reimbursed network usage fees of up to a total of 200 MW on request. They will also be eligible for refunds if the hydrogen is converted into electricity again. However, there is still no dedicated funding. Previous projects, such as the Hydrospider mobility ecosystem and production plants for green hydrogen, have emerged through industry-led initiatives.

- Major Swiss electricity companies*** are expanding their hydrogen production capacities as part of (pilot) projects, up to a maximum output of about 10 MW. In addition to Axpo, Alpiq, SAK and Groupe E are also expected to produce green hydrogen from hydropower in Switzerland by the end of 2023.

- The waste incineration plants KVA Buchs and Limeco now operate electrolysers, which produce renewable gas from waste and wastewater.

- It is estimated that Switzerland will have 13 MW of electrolysis capacity in operation by the end of 2023.

- Over the next five years, a further 50–100 MW of electrolysis capacity could be added if the conditions are favourable.

- Over the long term, it is unlikely that production capacity will be able to meet the demand for hydrogen and derivatives in Switzerland. As expected, efforts towards direct electrification are already exacerbating the electricity gap. The electricity produced should primarily be used directly. It is inevitable that hydrogen and derivatives will be imported from abroad in future, so efficient access to infrastructure and markets will become crucial.

- A particularly noteworthy development in the research landscape is the formation of the Coalition for Green Energy and Storage[11], consisting of the two Swiss Federal Institutes of Technology, more than 20 industrial partners – including Axpo – and guaranteed support from the Wyss Foundation. The coalition is expected to be formally established by the end of 2023. Demonstration plants built by the coalition are expected to become productive in the megawatt range from 2028.

*** For the sake of simplicity, only the hydrogen production plants' main shareholders are listed, although some plants are run as partnerships.

5. Challenges and summary

- The production of hydrogen remains expensive and energy-intensive at present. As such, most hydrogen sources are not yet able to compete with fossil fuels in terms of cost. A fall in production costs could make more applications economically attractive.

- Hydrogen infrastructure is not yet sufficiently developed to enable its wider application. There are still not enough pipelines for hydrogen transport and insufficient production capacity for electrolysers. Dismantling or repurposing the existing gas transport infrastructure requires in-depth analysis, detailed planning and technical and timely coordination with the development of hydrogen infrastructure.

- Hydrogen is a very light gas, so it requires special tanks for storage. The technology available for hydrogen storage is currently limited and cannot yet guarantee long-term storage in sufficient quantities.

- Hydrogen is produced predominantly from fossil fuels, which leads to high carbon emissions. However, efforts to produce hydrogen from renewable energy carriers, such as hydropower, wind or solar energy, are showing initial results and proving that green hydrogen, including its derivatives, can play a significant role in a sustainable energy supply.

- To summarise, Axpo believes that green hydrogen has immense potential as a clean, renewable and versatile energy carrier. As a solution for trucks, ships, aeroplanes and, in a global context, cars and trains, hydrogen and its derivatives can replace fossil fuels and make transport emission-free. Energy produced in the most efficient location and stored as hydrogen or derivatives can also be used in industry, and the energy supply at its destination at any time. Hydrogen therefore represents an investment in the future and has the potential to become an essential energy carrier for a climate-neutral society.

- It is incumbent on policy makers to set the right course without delay and thus enable and support hydrogen applications across a range of industries.

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Note on the cover image
Why we chose an AI-generated image for the cover: The cover of the white paper is the first thing the reader sees, so we wanted to make sure that it was instantly eye-catching. At present, meaningful and memorable graphic art relating to hydrogen is in short supply, and one tends to come across the same sort of imagery again and again. In keeping with the future-forward topic of this white paper, we opted for an image based on AI technology. By inputting specific keywords, we received AI-generation inspiration for hydrogen plants of the future. With the help of a professional graphic designer, we were able to incorporate our brand. Scale ratios and embedding in the landscape may deviate from realistic visualisations and concrete project plans. With the cover of the white paper – in keeping with the theme of hydrogen – we are combining a vision of the future with high quality standards.

For more information about hydrogen-related topics from Axpo:
https://www.axpo.com/ch/en/about-us/energy-knowledge.detail.html/energy-knowledge/hydrogen.html

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