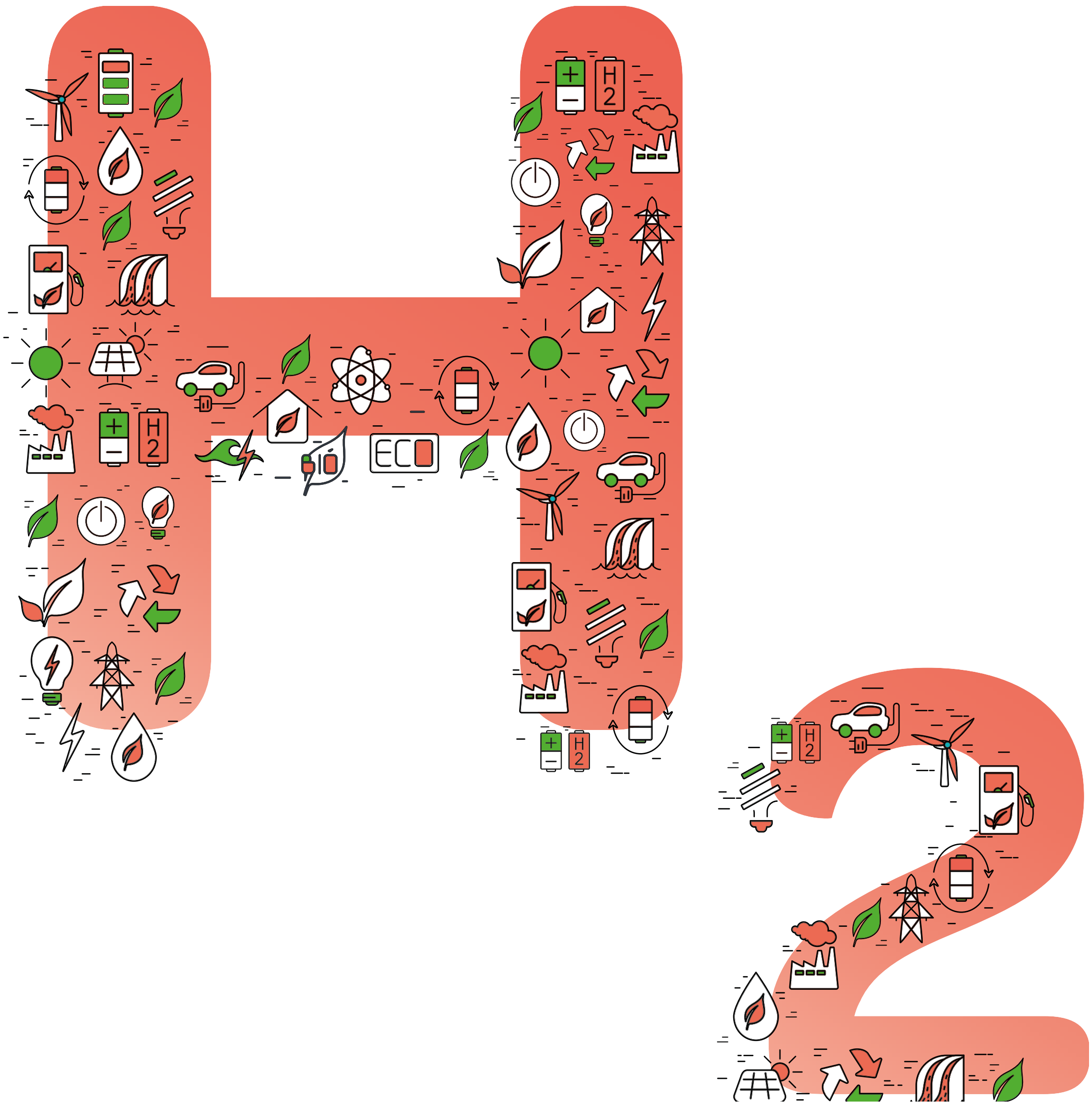
SPECIAL REPORT

Cleantech ALPS
Western Switzerland Cleantech Cluster

Hydrogen in Switzerland

What role can Switzerland play in this sector ?



In partnership with INNOVAUD

CleantechALPS
Western Switzerland Cleantech Cluster

INNOVAUD

With support of

ARI-SO
Association Réseau Innovation Suisse Occidentale

GGBa
Invest Western Switzerland

SATOM

P&TS
INTELLECTUAL PROPERTY

FMV

ROMANDE ENERGIE

ONE CREATION
Think Sustainable

CleantechAlps is an initiative of the Cantons of Bern, Fribourg, Vaud, Valais, Neuchâtel, Geneva and Jura. Supported by the SECO under the New Regional Policy (NRP).

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Economic Affairs SECO

Hydrogen in Switzerland :

What role can Switzerland play in this sector ?

The author

CLEANTECHALPS

CleantechAlps is Western Switzerland's cleantech cluster. Its mission is to foster collaborative innovation, bringing together players who are contributing to ways of using our natural resources sustainably and developing new forms of renewable energy. As the pre-eminent exponent of the innovation ecosystem, CleantechAlps is Switzerland's cleantech enabler. Created by the cantons of Western Switzerland, this inter-industry platform facilities interaction, stepping up and accelerating the capacity for innovation and the digital transition of Swiss enterprise. CleantechAlps increases the visibility of the region's cleantech businesses, positioning Western Switzerland as a centre of excellence at international level.
www.cleantech-alps.com

CREDITS
Study authors
Laura Schwery, Cédric Luisier and Eric Plan (CleantechAlps).
Business profiles
Inedit Publications, under the direction of Elodie Maître-Arnaud.
Layout
Valentine Fournier and Joanne Burr (CleantechAlps).
Pictures
Companies, Pierre Vogel (p.58), Sophia Haussener (p.65), iStock, Adobe Stock

250 copies.

Contents

Hydrogen: what role can Switzerland play in this sector ?

H2: a simple symbol that just might be the magic formula to combat global warming and protect the environment in general. The development of hydrogen technology is well underway in Switzerland, as this in-depth study clearly shows.

ERIC PLAN
Secretary General of CleantechAlps

It is no accident that Switzerland has become interested in hydrogen. Global warming is forcing governments to act to reduce their carbon footprint. The Paris Agreement, adopted in 2015, demands significant efforts in this respect, particularly in energy efficiency and creating a low-carbon economy. Achieving these two goals is going to be instrumental in our ability to meet the agreement's climate objectives by 2050.

In this context, hydrogen is one potential answer, the promise of a practical way of achieving a complete energy transition and weaning ourselves off fossil fuels for good. An energy carrier that is by essence multifaceted and versatile, hydrogen has a part to play in several major economic sectors (transport, energy and industry), with the potential for providing wide-ranging applications for each of them. In this context, it is reasonable to wonder to what extent Switzerland might benefit from the emerging 'hydrogen economy' and how we could use it to drive economic growth.

This study is therefore not an analysis of the technology nor yet another treatise on the impact that hydrogen will have on the Energy Strategy 2050. Our purpose here is to focus on the businesses and potential business opportunities that the hydrogen boom could generate. We need to ask ourselves whether we want to be in the driving seat in this sector or merely a spectator, as has happened so often in the past.

By describing actual projects and explaining the ins and outs of the sector, the purpose of this study is above all to inform, covering the basics to help explain the issues and constraints that apply to this emerging sector. It is also an opportunity to showcase the many Swiss players in the hydrogen sector who are already hard at work developing practical applications in areas such as components, systems, equipment and integration.

Read on to learn why and how Switzerland is capable of being among the frontrunners in the race to the hydrogen economy...

Happy reading!


H2
HYDROGEN
ENERGY
STORAGE
H2

Introduction

Why is there so much talk about hydrogen at the moment? This question was our starting point for this study. Hydrogen is indeed a hot topic, the catch-all solution offered up as the panacea to our planet's climate woes. There, we've said the C word... climate!

Constantly in the news, the climate and climate change seem to have unleashed the fury of not only crowds of protesters but also the elements. Despite what the (decreasing) numbers of naysayers may claim, evidence of the impact that human activity is having on the planet's natural balance is plain for all to see, with one natural disaster after another: fires, floods, landslides, disruption of the ocean currents and more. We do not propose to dwell on this subject – one just has to open the daily paper to read all about the latest climate events around the world. But what is new is that these unusual events are now happening on our doorsteps too and not just on the other side of the world. Let us not forget that in Switzerland, global warming is happening twice as fast as it is on average worldwide...

By ratifying the Paris Agreement, Switzerland has committed to reducing its greenhouse gas emissions by half compared to their 1990 level by 2030. Based on the most recent work carried out by the Intergovernmental Panel on Climate Change (IPCC), in August 2019 the Federal Council decided to review this objective, aiming to achieve carbon neutrality **from 2050**. In doing so, Switzerland intends to contribute to international efforts to limit global **warming to a maximum of 1.5 °C** compared to the pre-industrial era.

COP21 · CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

JULES VERNE'S PRESCIENT MYSTERIOUS ISLAND

But back to the matter in hand. Our interest in hydrogen is nothing new. A glance in the rear-view mirror tells us that. Hydrogen has been lauded as the miracle cure countless times before, and not just recently. Arguably, we can trace our current enthusiasm for H2 back to Jules Verne, when he realised its potential in The Mysterious Island, published in 1875.

"And what will they burn instead of coal?", asked Pencroft. [...] "Water decomposed into its primitive elements," replied Cyrus Harding, "and decomposed doubtless by electricity." [...] "Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. Someday the coalrooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces with enormous calorific power."

In any event, Jules Verne inspired Laurent Sciboz and Nicolas Tièche, the winners of the Gordon Bennett balloon race in 2019, in coming up with their Victoria project. With their planned balloon containing 2,500 m3 of hydrogen, the two adventurers from Western Switzerland are aiming to make a series of five-day balloon flights inspired by the balloon Victoria of Five Weeks in a Balloon fame.

UNANIMITY ON DECARBONISATION

On numerous occasions, hydrogen has been praised to the skies, but denounced – vilified even – on just as many others. This was what happened in 2002 when the American economic theorist Jeremy Rifkin published The Hydrogen Economy. So why does everything now suggest it is the right way to go and that hydrogen is gaining the upper hand?

Sparked by the adoption of the Paris Agreement at COP 21 in December 2015, public pressure to limit the effects of global warming to 1.5 degrees is steadily increasing. Incidentally, in scientific circles, the word is now that two degrees is more realistic. The necessity of completing the energy transition to a low-carbon economy and a more sustainable society is now a fact, accepted by everyone from citizens to politicians.

Thus, the Paris Agreement marked a decisive turning point in the recognition of the climate problem by governments around the world. For the first time, scepticism on the subject has been superseded by general consensus that creating a low-carbon society must be the way to go. In the history of climate awareness, this is a unique turn of events that should not be underestimated.

In theory, hydrogen appears to hold all the cards as the solution to the complete decarbonisation of society. The European Union and some 30 national governments (compared to 18 in 2020) have now officially announced their hydrogen strategy. These countries are talking about the wide-scale introduction of hydrogen as an energy carrier, in particular in the transport, industry and energy sectors. The chief objective is to create a low-carbon society while at the same time giving the industrial sector a boost by re-industrialising regions undergoing change.

Switzerland has taken a stand too, announcing both its Energy Strategy 2050, setting out the main areas for energy initiatives, and its 2050 climate target of zero net emissions. The latter now forms the cornerstone of Switzerland's climate strategy. In doing so, the country has thrown in its lot with the 66 other nations that have publicly stated their backing of the net-zero carbon emissions goal for 2050 announced at the UN Climate Action Summit in 2019.

A GROWING NUMBER OF PLAYERS

The world is a complex place and the hydrogen sector is no exception. Because hydrogen is a multipurpose energy carrier, it is appropriate to look at each of its facets individually. As far as possible, we have tried to separate the issues facing the sector to present a simple, comprehensible analysis of each segment and application in which hydrogen has a role to play. To properly explain the dynamics of the sector as a whole, we have found it essential to take into account the context (economic, geographical and strategic).

Switzerland's economic fabric comprises a growing number of public and private-sector players active in the hydrogen sector. For the reasons stated above, we have chosen to focus on the latter, providing more information about their solutions, the vast majority of which are already available on the market. Hydrogen is already a reality: the existing hydrogen technologies and solutions work. You will learn more about these in the pages that follow.

The idea behind this study is also to inform the general public about hydrogen, providing the reader with reference points that help explain, for example, the issues facing this energy carrier and the contribution it could make to the energy transition. Our modest aim is that it will reassure a large proportion of the population about the use of this gas, encouraging the exploitation of its potential in the relevant applications. But before we talk about the issues specific to each segment of the hydrogen sector, we need to cover the basics and provide some definitions.

www.swisscleantechreport.ch

ADDITIONAL CONTENT
IS AVAILABLE THROUGH
THE SWISS CLEANTECH
REPORT WEBSITE

PARTNERS

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

Federal Office for the Environment FOEN

IGE | IPI

SWITZERLAND GLOBAL ENTERPRISE
enabling new business

Cleantech ALPS
Western Switzerland Cleantech Cluster

SPONSORS

Empa
Materials Science and Technology

csem

energypolis

CONINCO
Explorers in finance

cimark

What do we mean by hydrogen?

H_2

>90%

IN TERMS OF THE NUMBER OF ATOMS

Hydrogen is the most abundant chemical element in the universe. It is also the lightest and simplest element.

- Energy density by mass: 33.3 kWh/kg (120 MJ/kgH_2)
- Energy density by volume: 3 kWh/m3 (10.78 MJ/kgH_2)
- Reminder: 1 kWh = 3.6 MJ

On Earth, it occurs most commonly in the form of water (H_2O)

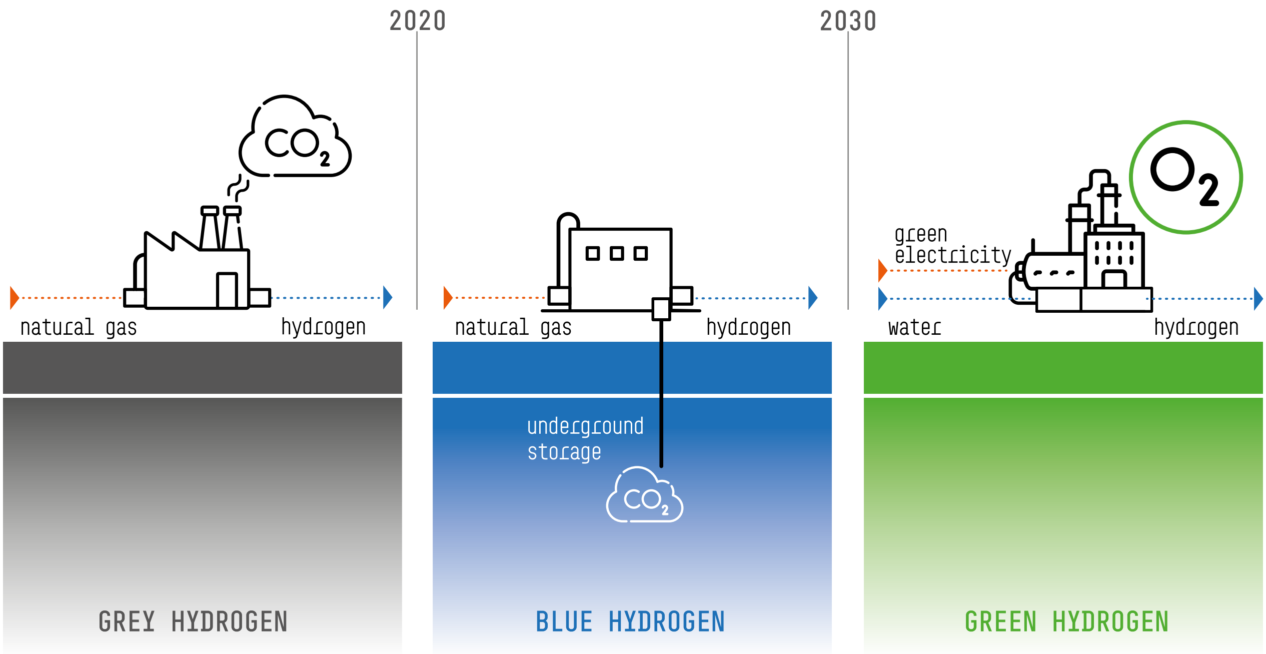
It is also – very rarely – found in its natural state (H_2) captured between geological strata, as in Mali for example.

Hydrogen accounts for around two-thirds of the atoms and 10% of the mass of the human body, largely in the form of water molecules.

Combined with carbon, it is present in a multitude of molecules such as methane and other organic chemical compounds.

At normal temperature and pressure it occurs as H_2, a colourless, odourless, tasteless, non-toxic, non-metallic and highly flammable diatomic gas. It becomes a liquid at -253˚C.

Hydrogen has the highest mass density of energy, with 1 kg of hydrogen containing as much energy as approximately 3 kg of oil. At the same time, it has a very low volume density.



Most hydrogen is classed as one of three types, depending on its origin:

- Grey hydrogen: produced from fossil fuels without carbon capture.
- Blue hydrogen: produced from fossil fuels with carbon capture.
- Green hydrogen: produced by electrolysis of water powered by sustainably produced electricity or electricity from a renewable resource.

The colours of the 'hydrogen rainbow'

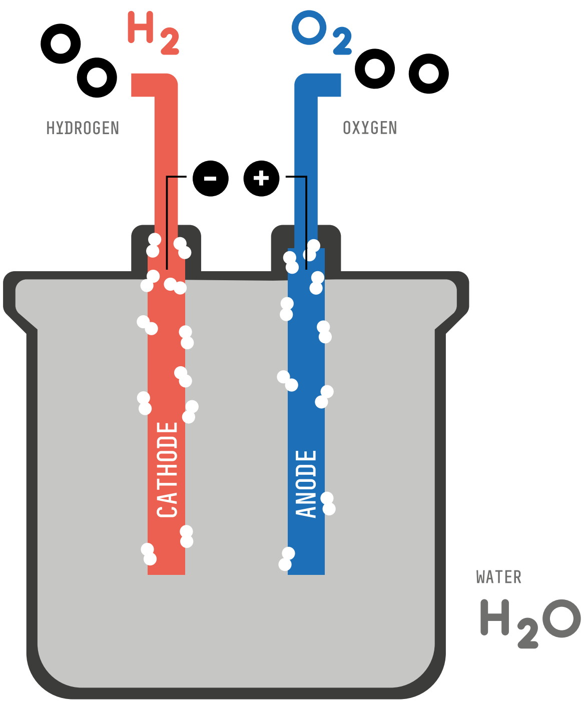
Other possible types of hydrogen are **brown** hydrogen (produced by gasification of lignite), **black** hydrogen (produced from coal using the same process), **pink** hydrogen (generated through water electrolysis powered by nuclear energy), **white** hydrogen (hydrogen in its natural state – very occasionally found in geological strata), **yellow** hydrogen (produced by electrolysis powered by electricity of solar origin or a mix of what is available on the grid: renewable and fossil fuels), **blue** hydrogen (steam reforming of methane with capture and storage of CO_2), and **turquoise** hydrogen, a variation on blue hydrogen (pyrolysis of methane with CO2 capture). In this process, pyrolysis uses heat to split natural gas into gaseous hydrogen and solid carbon.

Worldwide production is made up of 95% grey hydrogen and 5% green hydrogen!

Like electricity, hydrogen is not a primary energy source as oil, gas and coal are, but an energy carrier.

Hydrogen: how does it work?

KEY HYDROGEN TECHNOLOGY: ELECTROLYSIS AND FUEL CELL

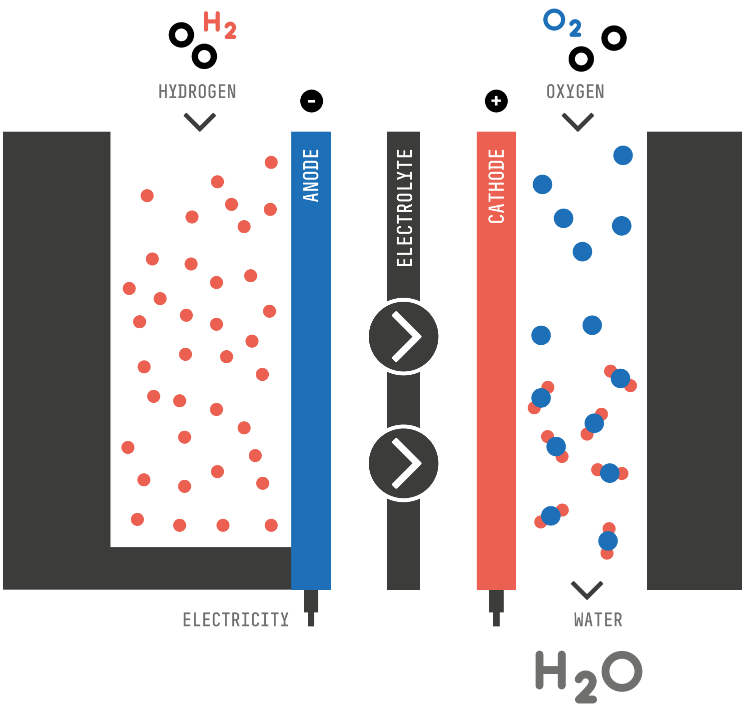


ELECTROLYSIS

The process used to produce green hydrogen is **electrolysis** of water. In this process, an electric current is used to break down water into oxygen and hydrogen. Different methods exist: alkaline, proton-exchange membrane (PEM), high-temperature, and chemical.

Did you know ?

The fuel cell was invented in 1839 by the Swiss scientist Christian Schönbein!
One kilogram of hydrogen generates around one kilogram of CO_2 if the electricity used is from a renewable source (solar, wind or hydro power) and almost 10 kilograms if a fossil fuel source is used.



Source: Efficience 21

THE FUEL CELL

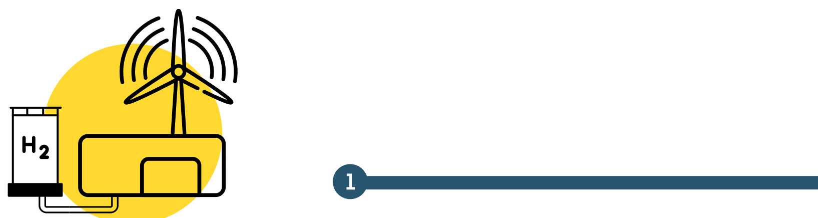
The fuel cell works in the opposite way to the electrolysis of water. It transforms chemical energy directly into electrical energy, acting like a generator in the same way as an ordinary battery.

The international context

When it comes to global warming and the need to reduce greenhouse gas emissions, the solutions currently in place are not enough to meet the 2050 goals. As a storable energy carrier, hydrogen is now considered to be a realistic alternative for reducing greenhouse gas emissions and an effective addition to the storage solutions currently in use in the energy sector. Hydrogen has a huge advantage from the climatic point of view because the only product of hydrogen combustion is water.

As a result, hydrogen offers numerous opportunities as a carbon-free industrial feedstock and a high-temperature heat source, in transport by road, rail and air, in heating buildings, and lastly in helping to balance electricity supply and demand.

Currently, hydrogen is mainly used as a feedstock in the manufacture of other materials, particularly in the petrochemical and chemical industries (including food production), in processes such as hydrocracking and ammonia production.



Enable **large-scale renewables integration and power generation**

A RAPID SWITCH TO GREEN AND BLUE HYDROGEN

The contribution that hydrogen makes to creating a low-carbon society (or its main uses) will depend directly on the way it is produced. According to the International Renewable Energy Agency (IRENA), the CO_2 emissions associated with worldwide production of grey hydrogen (which accounts for more than 95% of the total) is the equivalent of the combined emissions of Indonesia and the United Kingdom.

This being the case, it is essential to switch production over to green and blue hydrogen. The ultimate aim will then be to re-use the captured CO_2 in industrial applications, a process called carbon capture and utilisation (CCU). Blue hydrogen is still uncommon and often considered as a transitional phase to reduce emissions and help build the hydrogen economy. It is, for instance, the solution chosen by South Korea in its energy transition, which aims to begin by developing a suitable infrastructure to transition entirely to hydrogen without initially worrying about its carbon content and then, over time, to switch its hydrogen sources gradually from grey to blue and ultimately to green.

MAJOR CHALLENGES ALL ALONG THE VALUE CHAIN

In this context, the figure below is a very good illustration of the challenges faced by the rollout of hydrogen if it is to live up to its promise and apply to the entire value chain. This diagram shows the essential steps in the hydrogen ecosystem, consisting of power generation (integrating renewable energy sources), the distribution and storage network and, at the far end, distribution to the users in each sector concerned (transport and mobility, energy, industry and processes).

This means that the infrastructure for every link in the value chain and for every application concerned will have to be built or adapted accordingly. Specifically, this will involve expanding the pipeline network and building compression units and hydrogen refuelling stations (HRSs) to transport and distribute the hydrogen.

To store the hydrogen, it will be necessary to develop the technology required and build high-capacity storage installations. To produce and convert it, vast quantities of equipment such as electrolysers and fuel cells will be needed. The cost of this equipment will depend on the production volumes involved and how powerful it will need to be.

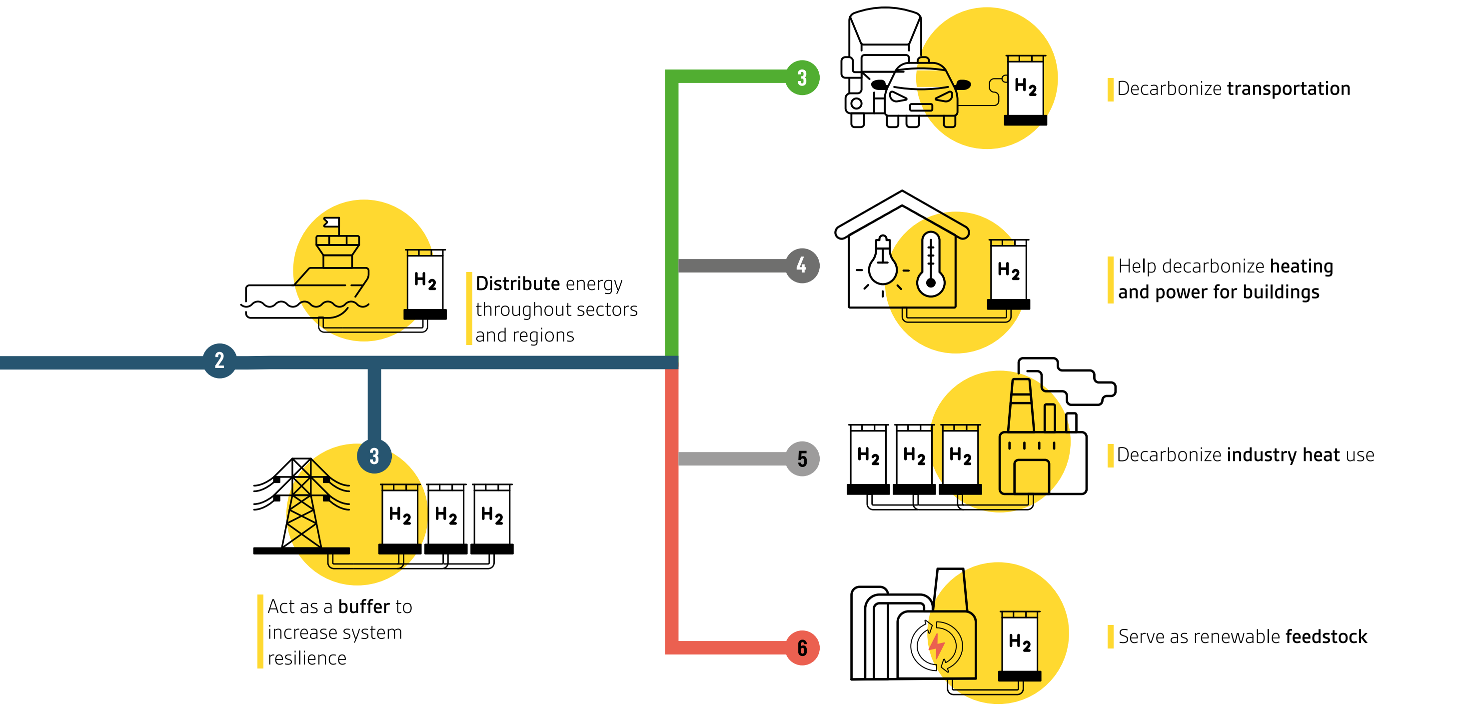


Figure 1
Source: Hydrogen Roadmap Europe: a sustainable pathway for the European energy transition, 2019

Technological solutions do already exist, but most of them will need to go through a commercial production stage before they can be deployed on a wide scale and deliver the vast outputs that will be needed. This also explains why governments are allocating colossal budgets to stay in the race for hydrogen. There is currently a mismatch between the requirements in terms of hydrogen production, and therefore production capacity (electrolysers), and the current capacity of the market. The press may be publishing articles about calls for tender for 100 MW facilities, but in reality, green hydrogen installations are currently producing more like two or three megawatts, with future projects promising around 10 MW.

The predicted growth in capacity requirement is mind-boggling, increasing from 0.1 GW (2020) to 6 GW (2024) and then to 40 GW (2030), in other words a 60-fold increase by 2024 and then another seven-fold increase in the six years after that. In the next 10 years, a 400-fold increase is expected!

The rate of mergers and acquisitions in this vast potential market is accelerating, representing considerable opportunities for Swiss companies, which are clearly not in a strong enough position to take on the market head-on. This being the case, Swiss business needs to anticipate and review the various business model options to secure the key know-how and keep as much value as possible in Switzerland.

To enable them to pursue a properly thought-out and coordinated hydrogen strategy, the relevant players have gradually grouped themselves into a variety of associations and institutions, such as the Hydrogen Council, Hydrogen Europe Industry and Hydrogen Europe Research. In the last five years, we have seen a definite consolidation of the hydrogen scene, with an international ecosystem emerging alongside an increase in activity and initiatives in the sector.

NATIONAL AND SUPRANATIONAL STRATEGIES

The European Union's hydrogen strategy published in the summer of 2020 shows the way forward and stresses that hydrogen must be taken into account throughout the value chain, as much at the production stage as the consumption stage. It clearly states that it is only through stepping up consumption capacity through an adequate distribution infrastructure and using hydrogen in an increasing number of domains that we will achieve the volumes necessary to make the hydrogen society economically viable. This process will result in a significant reduction in the cost of the technologies involved throughout the value chain, from production to distribution and including transformation and storage along the way.

With this in mind, on 23 February 2021, the EU announced that it planned to invest 10 billion euros of research funding in the green and digital transition, pursuing its hydrogen policy through a public-private partnership mechanism: the Clean Hydrogen Partnership for Europe. The EU's objective is to accelerate the development and deployment of a value chain for 'clean' hydrogen technologies, in other words those involving green and blue hydrogen.

For their part, the EU member states are coming up with various hydrogen strategies, working more or less in concertation, but backed by enormous budgets: nine billion euros in Germany and seven billion in France. To some extent, these countries are coming together to work on joint projects aimed at developing specific industries, although a cynical view would be that each country is vying to ensure that the resulting range of demonstration technology ends up on its own territory.

The intention here could well be to reposition certain struggling sectors of industry by adapting them to develop elements of the hydrogen system shown in the figure above. There is nothing wrong with that, but this practice will slow the growth of the European market.

It is therefore no surprise that we are seeing considerable variation in different countries' hydrogen strategies. Australia, for example, took the decision to try to produce green hydrogen right at the beginning of its transition, in an attempt to turn the country into a worldwide exporter of green hydrogen. This country has led the way in producing liquid hydrogen, developing a maritime carrier in a project with Japan. And since there is no single solution when it comes to the energy transition, no strategy can be ruled out. South Korea's approach, for example, seems to have taken the opposite tack to Australia, changing its infrastructure first and its source of hydrogen later. The United Kingdom is somewhere between the two, trialling hydrogen networks in some regions.

Rolling out any and all of the above strategies involves the need for standardisation and regulation at both national and international level. So far, few countries have introduced sufficient regulation of the hydrogen industry and there is precious little standardisation. In this context, what we need is a robust and comprehensive international ecosystem in which every country and sector of industry should be present or represented.

THE IMPORTANCE OF HYDROGEN WORLDWIDE

Hydrogen is currently an important industrial gas, with nearly 75 million tonnes (Mt) supplied annually to the chemicals industry (73.9 Mt in 2018, according to the International Energy Agency, IEA). Whereas demand for the production of ammonia and nitrogen fertilisers has remained relatively stable since 2000 (fluctuating between 26 and 32 Mt), over the same period, its use in oil refining (desulphurisation, methanol production, etc.) has increased (from 21.4 to 38.2 Mt). The other sectors in which hydrogen is used, the food, electronics and metallurgy industries, account for around 6% of the total, of which 1% goes to powering space rockets (which involves the combustion of liquid hydrogen and oxygen), although that remains very much on the margins.

Industry's demand for hydrogen is set to increase in the coming decades. New industrial applications have been developed, with hydrogen now replacing coal in steel production, being used in the manufacture of synthetic fuels and replacing natural gas and coal in high-temperature applications. All these changes are pursuing the same end: to enable industry to reduce its carbon footprint drastically.

It is interesting to note that global consumption can vary enormously by region. In Western Europe, demand from the chemicals industry (ammonia) is almost twice that from oil refineries. Like the way it is used, the way hydrogen is produced depends largely on the context. In this respect it is similar to other renewable energy sources, in which the immediate environment (topology, climate, industrial fabric, etc.) plays an important role and where the energy mix is often a key consideration.

This aspect currently also plays a significant role in the types of projects launched in different countries and regions around the world, in terms of the technologies, applications and output capacities involved. This also explains the point raised above, with everyone trying to validate the technologies and uses that are relevant to their own context. This is hardly surprising in view of the battle that is going on behind the scenes to prepare for the smoothest possible fundamental industrial transition of the sectors under threat (which some commentators are already calling the re-industrialisation of the economic fabric), against the backdrop of the climate crisis.

THE COST OF MANUFACTURING HYDROGEN

When it comes to cost, estimates vary depending on the assumptions made, particularly regarding the cost of the energy used to produce the hydrogen. According to IRENA, by 2050, the levelised cost of hydrogen could be a third of its current cost (see the figure below).

The levelised cost of hydrogen (LCOH) means the full cost of the hydrogen over the lifetime of the equipment used to produce it. This is by analogy with the term LCOE, which applies to energy and electricity costs.

Taking into account the complete production and distribution chain, the current cost of one kilowatt-hour of green hydrogen is about twice that of blue hydrogen and three times that of grey hydrogen. But these costs are changing fast. They are currently around 16 euro cts/kWh for green hydrogen and approximately 6 euro cts/kWh for grey hydrogen, but in the long term, these costs will depend directly on the expansion of production capacity, the effect of scaling up industrial manufacture, and above all future carbon tax policy.

IRENA ESTIMATES OF THE PRODUCTION COSTS OF 'GREEN' AND 'BLUE' HYDROGEN

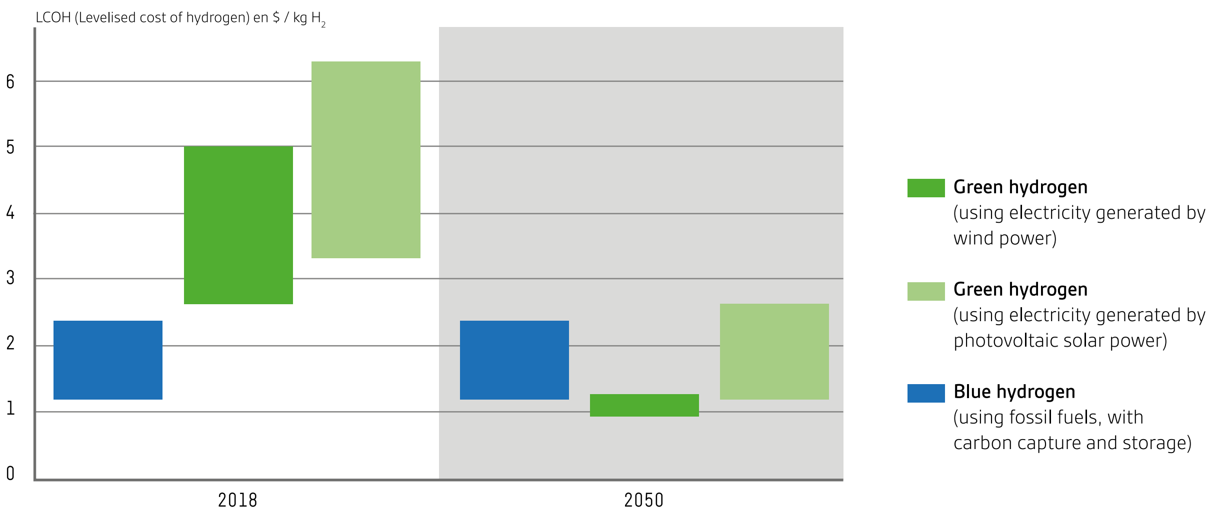


Figure 2 ⏶
Source: analysis by IRENA

The figure 3 illustrates the overall cost structure for some of the most important applications. This clearly shows the relative importance of the impact of production with respect to distribution costs in terms of investment and operational costs.

The development of these applications will be largely dependent on the costs structure of the industry and domain concerned. The Hydrogen Council regularly publishes studies and analyses of the different sectors of industry and their usage scenarios, along with regularly revised projections.

DRIVERS OF HYDROGEN'S COST COMPETITIVENESS

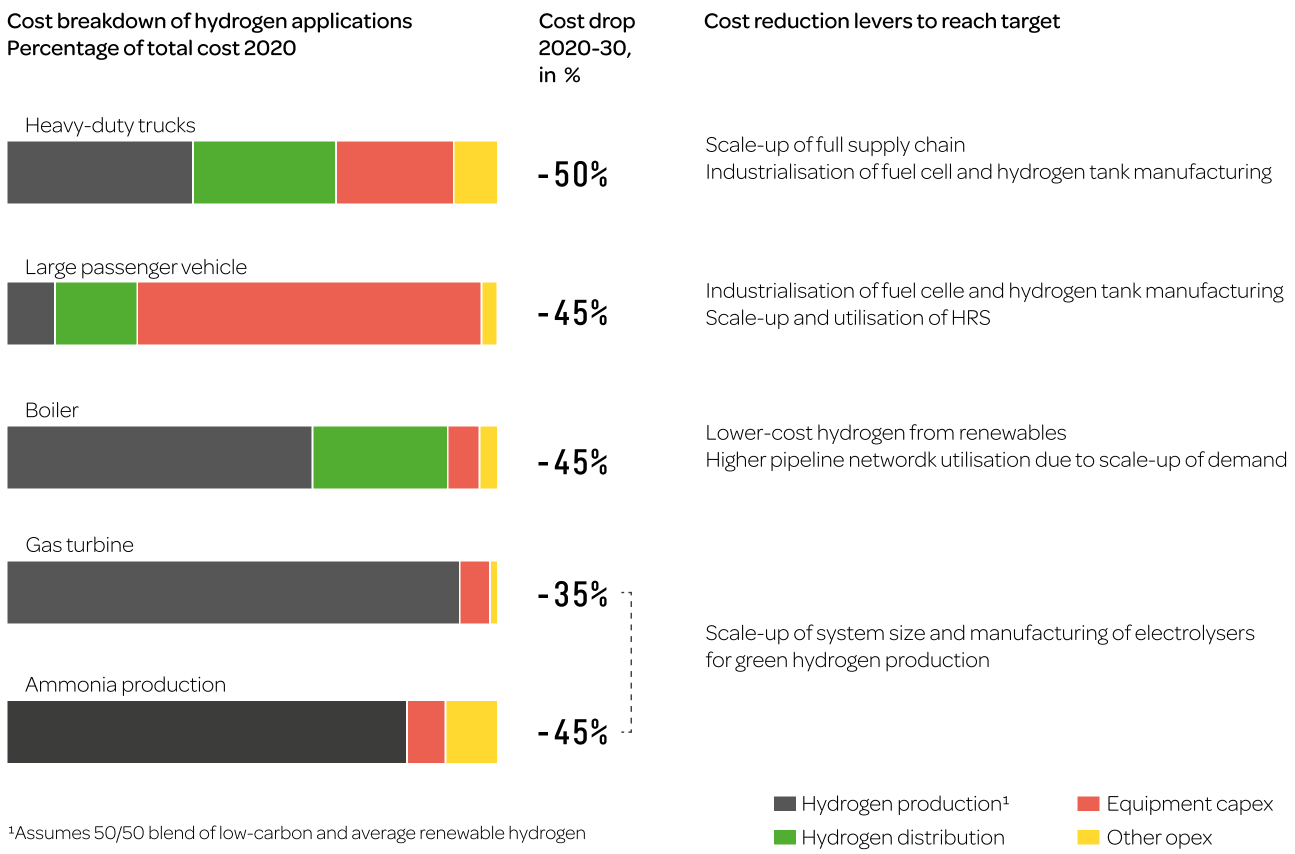


Figure 3
Source: Hydrogen Council, Path to hydrogen competitiveness - A cost perspective, January 2020

DAVID HART
Partner at ERM, Director at E4Tech

The FC & hydrogen industry is entering a crucial positioning phase with dramatic investment in technologies, production lines and partnerships. Stakeholders not moving now will face higher barriers to entry.

The Swiss context

The strategy and scenarios adopted by the Federal Council

In 2019, the Federal Council decided that Switzerland had to reduce its greenhouse gas emissions in order to become carbon neutral by 2050. It laid out the roadmap for reaching this goal in its long-term climate strategy. The Energy Perspectives 2050+ document forms one of the essential foundations of this strategy.
Two scenarios are envisaged: the "Net zero emissions" (ZERO) scenario, consisting of a base variant and three other variants that take into account different possibilities in technological development, and the "Continuation of current energy policy" scenario. The four variants of the ZERO scenario all achieve the net zero emissions target by 2050. These scenarios take into account different rates of growth in the production of renewable electricity.

Source : Swiss Federal Office of Energy (SFOE)

As yet, Switzerland has not set out a domestic hydrogen strategy. However, in the "Net zero emissions" (ZERO) scenario (see page 22), Switzerland is able to transform its energy supply model to achieve climate neutrality by 2050. In the variants of this scenario, hydrogen is earmarked as contributing to the heavy transport sector (trains, road haulage, etc.), mainly thanks to electricity production by hydroelectric power plants.

Internationally, and specifically under the auspices of the Pentalateral Energy Forum (Benelux, Germany, Switzerland, France and Austria), on 20 June 2020, the Swiss Confederation signed a joint political declaration on the role of hydrogen in the decarbonisation of the energy system. This first step is designed to kick-start the market. To build momentum, a regulatory framework that offers appropriate incentives to the market players will be required. The members of the Pentalateral Energy Forum intend to discuss a hydrogen market.

The objectives of this future cooperation are to:

- develop a shared long-term vision for 100% renewable hydrogen in Europe;
- draft common definitions for hydrogen and set down the guarantee-of-origin rules;
- harmonise the hydrogen mix in natural gas networks;
- decide on the technical standards for gas infrastructures;
- define the role of taxes on CO_2, energy taxes and energy levies.

It is clear, then, that Switzerland is actively engaged in efforts to deploy hydrogen on an international level. It is working not only at governmental level through the Swiss Federal Office of Energy (SFOE), but also on an industrial level with the umbrella association Hydropole and on an academic level with two prestigious research institutes: the Swiss Federal Institute of Technology Lausanne (EPFL) and Swiss Federal Laboratories for Materials Science and Technology (Empa).

THE DOMESTIC IMPORTANCE OF HYDROGEN IN SWITZERLAND

The Swiss hydrogen market is very small. In 2021, it was only 1% of the size of the natural gas market. In general, hydrogen is used only for small applications. If larger quantities are required (as in the chemicals industry for example), it is usually produced on site. The extent to which hydrogen is currently used in mobility is also insignificant. As we can see, the Swiss are not familiar with hydrogen and that it is evidently not (yet) part of the country's DNA.

USING EXISTING INSTRUMENTS AND ENCOURAGING PIONEERS

This being the case, the Confederation is applying a pragmatic approach, providing the framework conditions necessary to develop projects through existing instruments (the innovation agency Innosuisse and the SFOE's programme of pilot projects and demonstrations).

As a proponent of the liberal economy, Switzerland has faith in the dynamism of the private sector. It would seem that on this occasion this approach has paid off, particularly when it comes to the XCIENT Fuel Cell truck project launched – in a world first – with the motor manufacturer Hyundai. Switzerland has shown once again that it can provide fertile ground for pioneering minds to develop their ideas.

In this 'Renewable hydrogen cycle for heavy goods traffic' project, which won a Watt d'Or award in 2021, it is clear that H2 Energy and the consortium built around it are extremely well conceived. This consortium is made up of an entity that produces green hydrogen (see on page 54) which supplies a network of service stations set up by the consortium under the aegis of the association H2 Mobility Switzerland. The network fuels the hydrogen-powered trucks of a well-known motor manufacturer which are leased to haulage companies. This business model was carefully thought through to take advantage of the framework conditions provided in Switzerland: an abundance of hydroelectric power to produce green hydrogen, the waiving of the RPLP heavy goods vehicle duty normally payable, and no energy transport tax because the energy is produced directly at the production site. Hats off, too, to the commercial nous of the people involved and the know-how they have developed in the sector through various projects undertaken in the last decade (see pages 44 and 45).

COMING UP WITH THE RIGHT BUSINESS MODEL

This consortium shows that a hydrogen future is possible if one comes up with the right business model and achieves a critical mass of customers. But this is not necessarily the case currently in other sectors or usage scenarios. An analysis of the players involved has shown that Switzerland's economic fabric does not have a critical mass in any particular industry or technology. This observation is typical of the structure of the Swiss economic fabric, except perhaps in the case of pharma/chemicals/biotech and the MEM industries (machinery, electrical equipment, metals and related branches).

In any case, this observation is nothing new when it comes to most of Switzerland's 'cleantech activities', where, even though the country can boast world leaders in their field (e.g. Studer Innotec with its inverters), a fully-fledged industrial sector does not exist. This is also a consequence of Switzerland's federal non-interventionist policy, which deliberately refrains from introducing sector-based industrial policies as such, allowing the laws of the market to dictate how the economy functions.

GROWTH IN THE NUMBER OF PLAYERS

There is strong private sector interest in hydrogen technology, and this has resulted in significant growth in the number of players active in the hydrogen sector in recent years. This is a clear sign of the vitality of an ecosystem that is still in the process of coming together in Switzerland, as illustrated in the section dedicated to the Swiss ecosystem pages 34 and following.

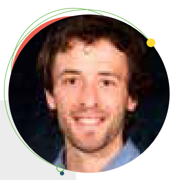
NICOLA ZANDONA
Former Business Director at IHT and current consultant at Sunfire

Electrolysis is the «cornerstone» of the new green hydrogen industry which will contribute to the integration and decarbonisation of several key sectors of the economy.

Seasonal storage of hydrogen: a key part of the puzzle?

As mentioned in the introduction, the purpose of this report is not to provide an analysis of the impact of hydrogen on the Energy Strategy 2050. Discussions about conversion yields may still be ongoing, and rightly so, but hydrogen remains an important solution when it comes to long-term storage, also known as seasonal storage. According to an analysis by the consulting engineers for sustainable development Planair, the mass storage of hydrogen produced using excess renewable energy in the summer could constitute Switzerland's biggest hydrogen market in 15 to 20 years' time.

Thanks to the meteoric boom in electric vehicles and heat pumps, renewable energy sources are becoming a key tool of climate policy. They have the potential to take the country beyond an energy strategy, instead fuelling a fully-fledged and ambitious Swiss climate strategy.



LIONEL PERRET
Director of Renewable Energies and Innovation at Planair, Director of Swiss Eole

On a national scale, the production of hydrogen for seasonal storage of renewable surpluses could constitute the first hydrogen market in Switzerland.

A detailed analysis of the SFOE's Energy Perspectives 2050+ document reveals that in the "Net zero emissions" scenario, it is possible to move towards a fossil-fuel-free energy system. As the figure below shows, by 2050 we will be consuming on average 10% more electricity than we are now, but our total energy consumption will be 31% lower. In this scenario, we see the advent of a category of energy source known as 'Power-to-X' that will provide 56 PJ of energy, equal to nearly a quarter of the contribution to total energy consumption made by electricity (228 PJ). In this, hydrogen is set to play a crucial role, along with other synthetic fuels, no doubt.

The Europe-wide scenarios drawn up by LUT University (Finland) confirm that by 2050, this kind of renewable system could be more competitive than one powered by fossil fuels. (https://www.solarpowereurope.org/100-renewable-europe/)

EVOLUTION OF FINAL ENERGY CONSUMPTION FROM DIFFEREN ENERGY SOURCES

National consumption excluding international air traffic, base ZERO scenario, petajoules (PJ)

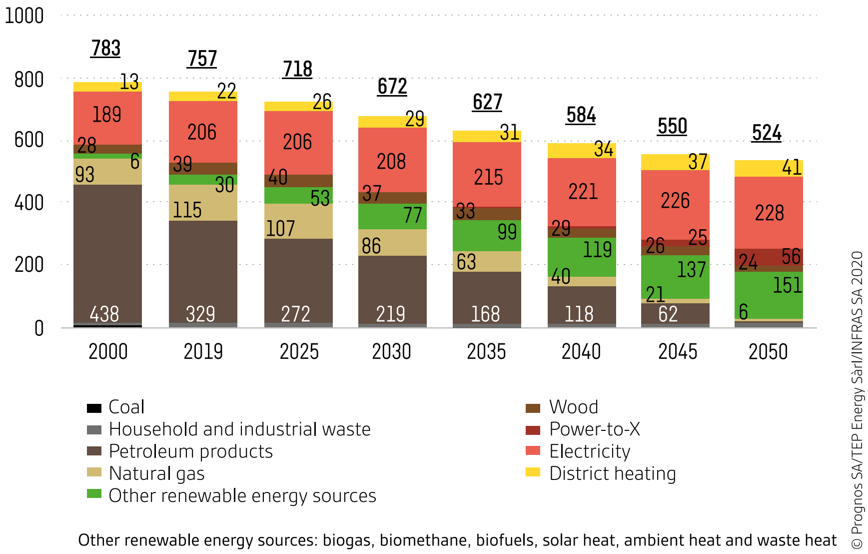


Figure 4
Source: Prognos SA/TEP Energy Sàrl/INFRAS SA 2020
https://www.bfe.admin.ch/bfe/fr/home/politique/perspectives-energetiques-2050-plus.html

A COLOSSAL POTENTIAL MARKET

In Switzerland, these possibilities would require the large-scale development of new seasonal storage resources. Based on dozens of climate/energy strategy scenarios produced for Switzerland, Planair's conclusion is unequivocal: to avoid massive dependence on other countries in winter, Switzerland will need to develop a seasonal hydrogen storage capability that makes use of the excess energy produced by renewables during the summer. This in turn presupposes the large-scale development of renewable energy production as advocated by Roger Nordmann in his book Le plan solaire et climat.

The simulator and algorithms developed for this purpose (see box below) show that it is possible to balance the energy system for every hour of the day. These also demonstrate the extent to which battery storage (which has a daily cycle) and hydrogen storage (which has a seasonal cycle) complement each other.

To avoid having to expand the existing infrastructures, it has been calculated that between 10 and 25 TWh of hydrogen storage per year would be required. Simulations show that this is possible with the production of 300,000 to 750,000 tonnes of hydrogen per year, which equates to the production capacity of electrolysers with a cumulative output of between 2 and 5 GW operating continuously.

Current consumption by industry (not including refineries) is 2,000 t/year and the potential consumption by heavy mobility in Switzerland is approximately 60,000 t/year. This application would therefore make up the hydrogen market for an energy-independent and carbon-free Switzerland.

AN ECONOMIC MODEL THAT MUST BE CONSTRUCTED NOW

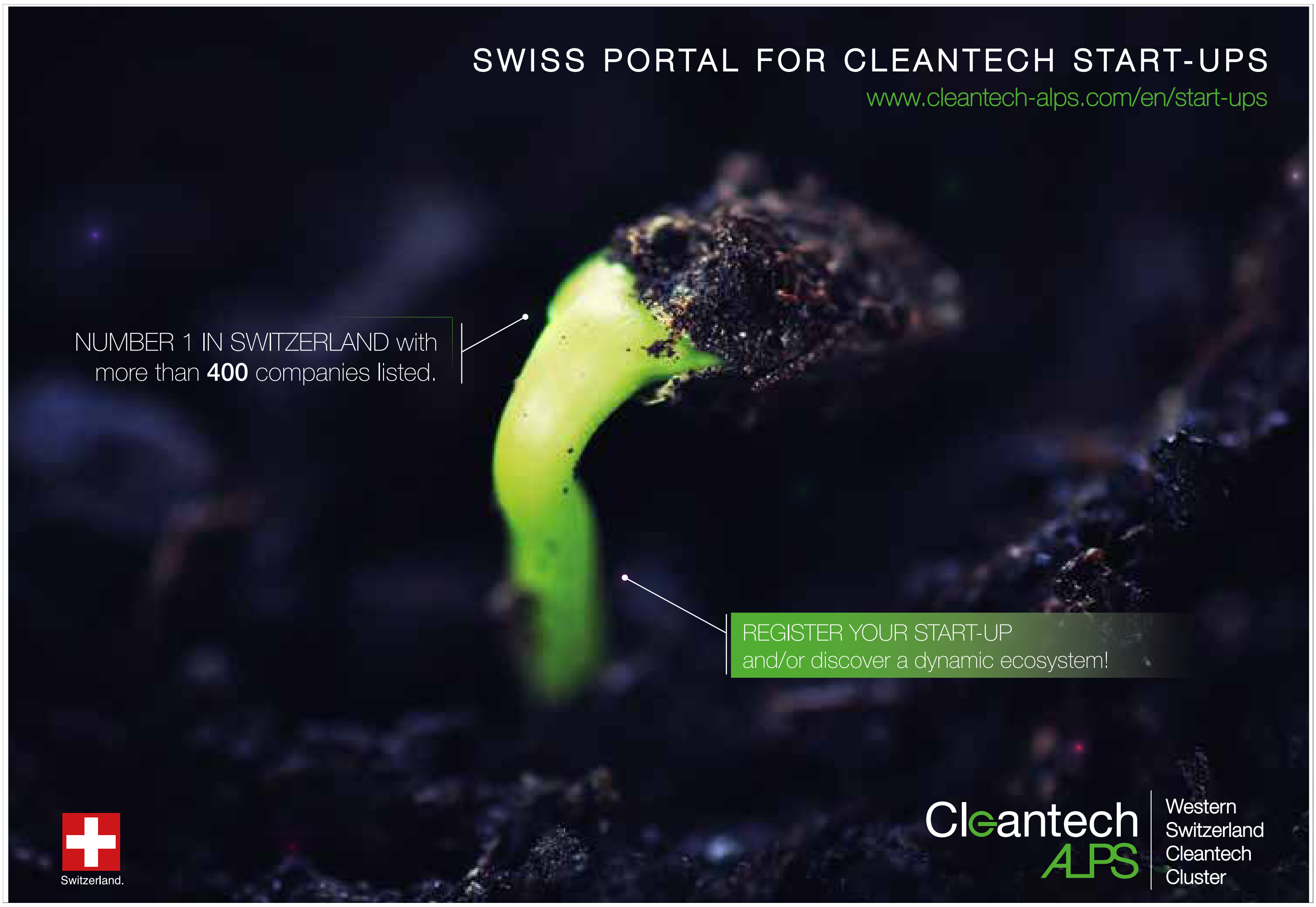
The analyses carried out by Planair with its calculator show that in Switzerland at national level, such a system could be competitive and could for example use liquid hydrogen storage technologies as part of the mix. But this means acting now to develop appropriate market mechanisms that make use of Swiss renewable energy sources that do not bring in much income over the summer. Because of the different conversion losses, the winter electricity supply from seasonal hydrogen storage is three times more expensive than the summer supply (not taking into account system depreciation costs).

Grid View: an easy-to-use energy scenario calculator

This tool developed by the consultancy company Planair provides five reference scenarios and a calculation interface. It can be used to analyse the energy independence outcome and the investment required for a system, providing a flow diagram and an interactive hourly load curve for any system. On request, Planair is also able to generate indicators specific to certain regions or a selection of technologies, along with analyses of the system's sensitivity (costs and grey energy).

For more information and to use the calculator, go to https://gridview.planair.ch


WESTERN SWITZERLAND'S
INNOVATION CLUSTERS
4 DYNAMIC & VIBRANT ECOSYSTEMS
alp ict
info & digital technologies
BioAlps
life sciences
Cleantech ALPS
clean technologies
MICRONARC
micro & nano technologies
SUPPORTED BY


SWISS PORTAL FOR CLEANTECH START-UPS
www.cleantech-alps.com/en/start-ups
NUMBER 1 IN SWITZERLAND with more than 400 companies listed.
REGISTER YOUR START-UP and/or discover a dynamic ecosystem!
Switzerland.
Cleantech ALPS
Western Switzerland Cleantech Cluster

The hydrogen value chains

Because, by its very nature, hydrogen can be used in multiple applications, we need three kinds of information when describing the positioning of a player active in this field. These are:

> *1. the product it makes or service it provides, to enable us to position it on the technology value chain;*
> *2. its business, which provides information about is commercial activity;*
> *3. the sector it operates in (transport, energy or industry).*

The first two of these are value chains in the strict sense, but the third characteristic is more a description of the market segment in which it is active. This is also known as the sector value chain.

The type of technology used is another important piece of information when analysing the sector. This actually has to do with business intelligence, and as such does not come under the scope of this study. It mainly concerns the players in the field trying to garner information about the competition, or the public sector, to help them decide whether it is appropriate to set out a targeted development programme, and if so, in which area of technology.

BENOÎT REVAZ
Director of the Swiss Federal Office of Energy (SFOE)

The integration of renewable energies into the energy system is a major challenge, which is why we are currently examining the role that «green» hydrogen can play in the future.


ECO
H
2
BIO

THE TECHNOLOGY VALUE CHAIN

The technology value chain is outlined in Figure 5. This ranges from the materials used through to system integration and includes the various subsystems required to create the finished product (a vehicle or production facility, for example). Operators in the fields of production equipment, storage and distribution are represented in the last link in the chain: Services. Service providers with specialist knowledge of hydrogen technology, such as technology consultants and organisers of specialist conferences, are also included in this link right at the end of the chain.

By showing the way the different players are distributed along this value chain, we can measure the density of the economic fabric and identify the areas of expertise available in the ecosystem. This is shown in (Figure 9) in the following section.

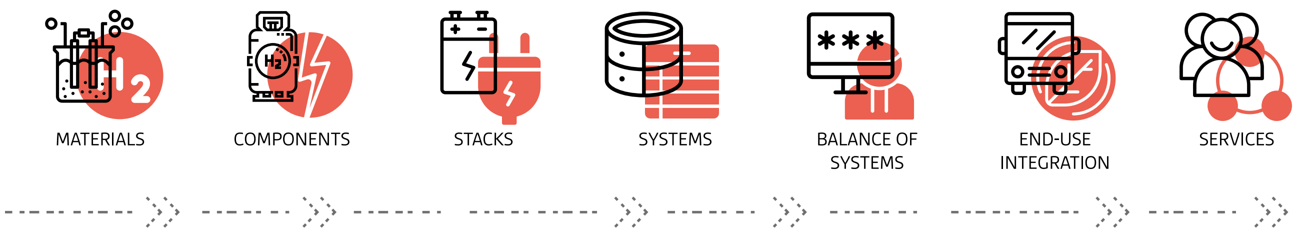


Figure 5 ▲
The technology value chain for hydrogen (source: E4tech, 2014)

BERTRAND PICCARD
Initiator, Chairman and Solar Impulse Pilot

Some say that hydrogen is the future; I say that hydrogen is already the present.

THE BUSINESS VALUE CHAIN

The business value chain shown in Figure 6 covers the players' activities. This value chain is made up of three generic links running from production to distribution. Other stages such as purification or conversion do not provide additional information relevant to our analysis and have not been included. The distribution stage is understood to mean distribution in the broad sense of the term, covering all the activities involved in supplying the end customer or user with hydrogen.

This value chain applies to the three sectors of applications required to complete the positioning of a player in the hydrogen ecosystem.

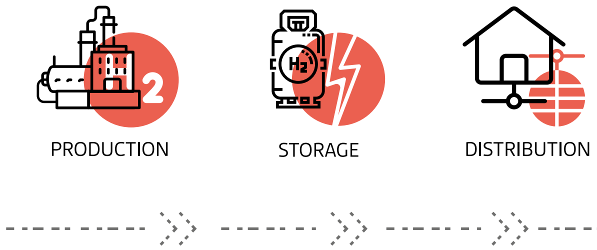


Figure 6 ▲
The business value chain for hydrogen (source: CleantechAlps, 2020)

THE SECTOR VALUE CHAIN (SECTOR OF APPLICATION)

In practice, in this case it is preferable to talk about sectors of application or industries rather than a value chain. This is because this aspect describes the sector of application in which the business operates. A system or facility can potentially be used in several different segments or industries. For example, a high-power fuel cell can be used in transport (trucks, trains, etc.) but also in a stationary facility requiring a high-power input. In essence, this applies to the three following sectors of application or industries:

- Transport (mobility/haulage)
- Energy (energy systems – heat)
- Industry (feedstocks and processes)

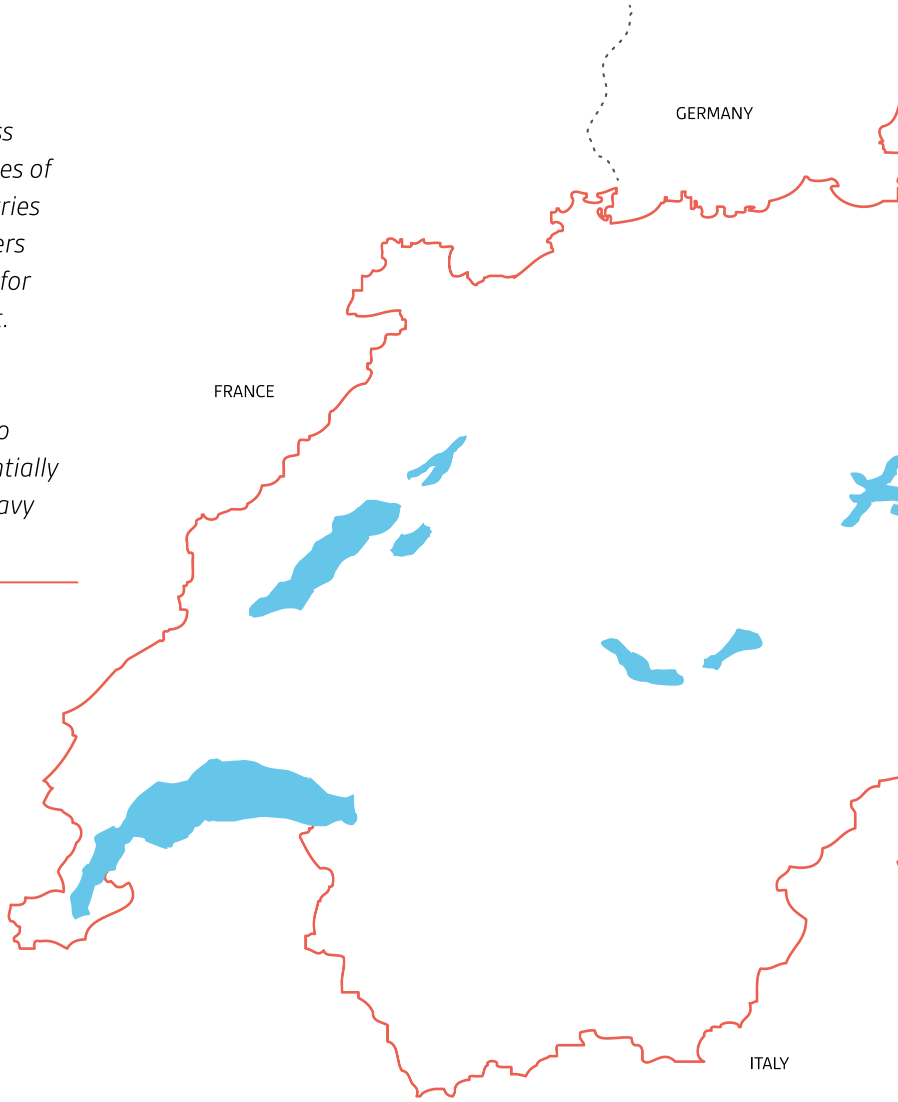
DAVID HART
Partner at ERM, Director at E4Tech

There is a significant opportunity in building fuel cell & hydrogen value chains. Europe can play a major role, with thoughtful support to both demand and supply-side, as well as development of people and skills.

The Swiss hydrogen players

Here, we present a systemic overview of the Swiss hydrogen ecosystem. This describes the categories of players making up this ecosystem and the industries in which they operate. The major industrial players in each category are explicitly mentioned, but – for practical reasons – individual businesses are not.

It would not have been relevant to publish here an endless list of company names, and this is also problematic in a context where companies potentially belong to more than one sector, such as both heavy mobility and industrial processes.



ASSOCIATIONS AND LOBBIES

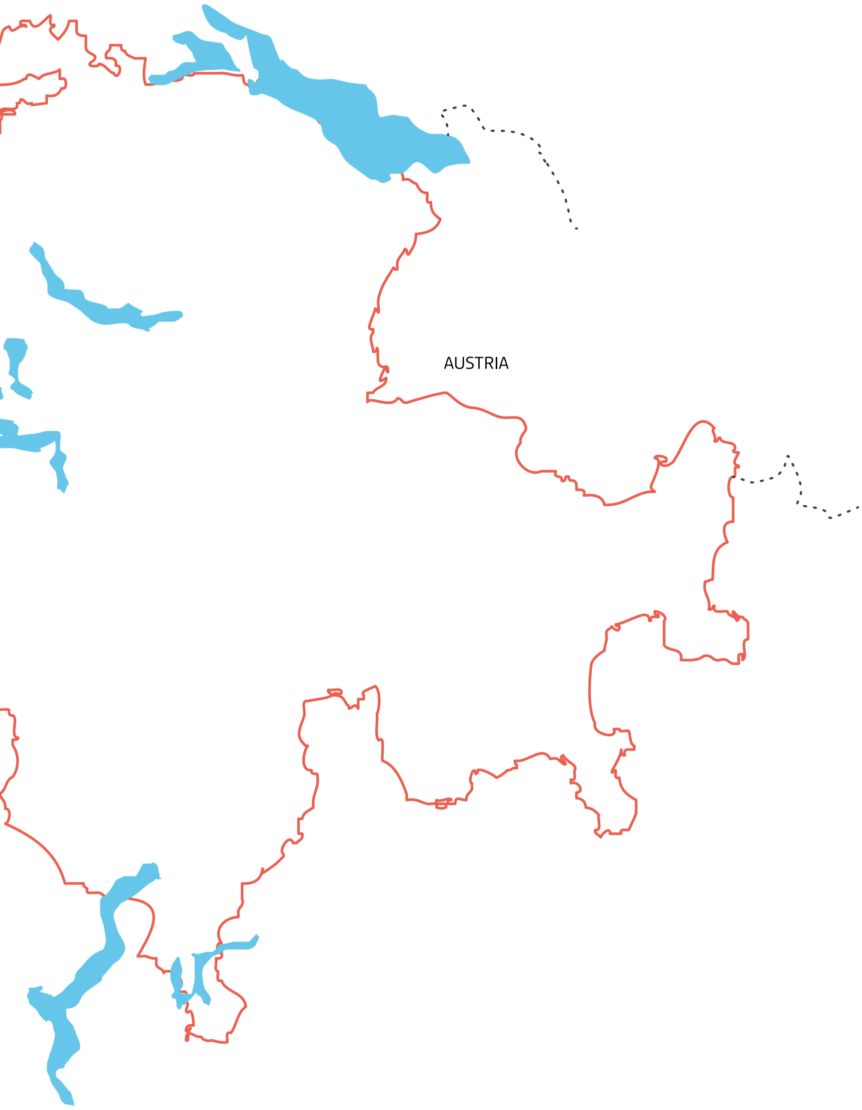
H2 Mobility Switzerland
Hydropole
Association des producteurs de H2
Nomads Foundation
Swisspower
AEE
swisscleantech
SSIGE/ITIGS
ASIG

SWISS CONFEDERATION

FEDRO
FOT
SFOE
Innosuisse
SERI
METAS
FCA
FOEN

PUBLIC/PARAPUBLIC PLAYERS

Cantons
Public transport
Public service companies



CONNECTORS

- CleantechAlps
- Netzwerk Wasserstoff

AMBASSADOR PROJECTS

- Hyundai XCIENT FuelCell
- Mission H24
- The Victoria project

PIONEERING REGIONS

- Zurich/Aargau (GZA)
- Lake Geneva Region/Valais

INDUSTRY

- SMEs
- Start-ups
- Large businesses
- Engineering firms
- Design consultants

FLAGSHIP PROJECTS

- GOH
- Hydrospider
- Demo4Grid
- Limeco
- H2Bois
- SATOM

FUNDING PROGRAMES

- Pilot and Demonstration programme
- Horizon Europe
- SWEET

DEMONSTRATORS

- Move
- ESI Platform
- Energypolis
- InnovationLab

ACADEMIC INSTITUTIONS

- EPFL
- ETHZ
- UAS
- Empa
- PSI
- UNIGE, UNIL, UNIBE and UNIBAS
- CSEM
- CREM

FIGURES AND TRENDS

What makes up the economic fabric that uses hydrogen technology? This question comes up again and again, and this section provides some answers in terms of the size of the businesses concerned, their distribution along the value chains and the changes that have occurred in recent years. The main findings are illustrated in a series of charts. Reminder: this analysis is of the private sector players only; public research institutes are not included. The Portal of technology actors (see page 38) provides an overview of the academic players active in the field and past and current research projects.

Overall, nearly 99% of Switzerland's economic fabric is made up of SMEs. It is therefore no surprise that SMEs top the list in the different categories in the hydrogen sector too. The figure below clearly illustrates the situation.

This chart shows that start-ups also play a significant part in this sector, with the greatest number being in activities related to hydrogen production. On the other hand, few start-ups are active in storage, where their presence is only just beginning to be felt. It is worth noting that although network operators are more active in distribution, they are showing a growing interest in all the links in the value chain.

NUMBER OF PLAYERS PER BUSINESS TYPE IN EACH CATEGORY

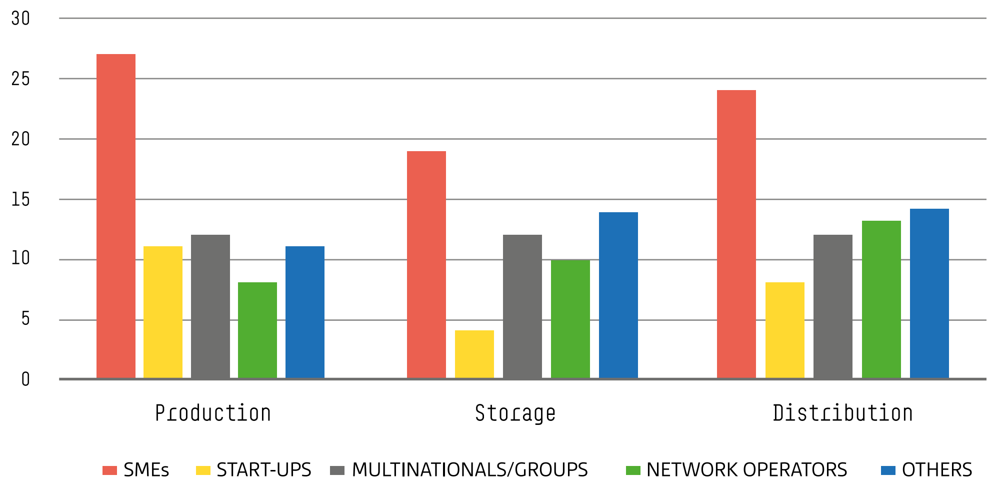


Figure 7 ▲

The chart showing the number of players per business type in each sector completes the picture, indicating the areas that are currently of most interest:

NUMBER OF PLAYERS IN EACH SECTOR PER BUSINESS TYPE

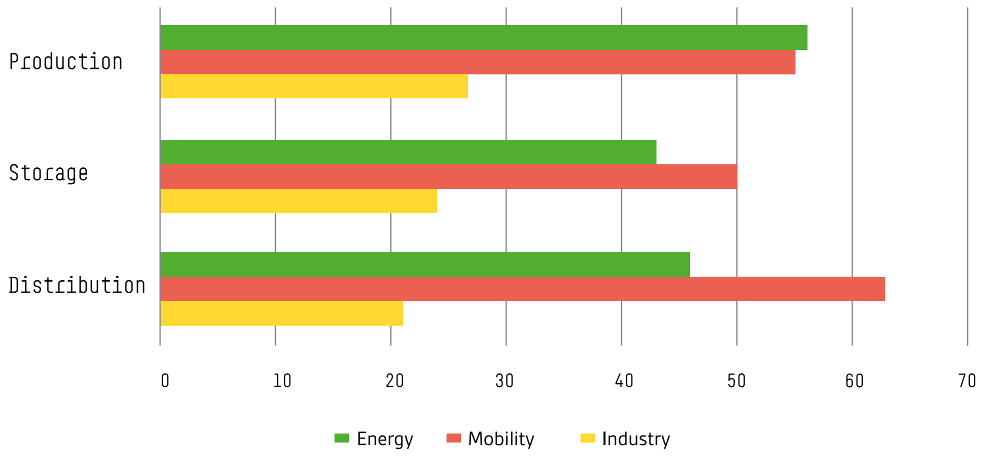


Figure 8

Figure 8 clearly shows that mobility is the leading sector of application in Switzerland in terms of critical mass. The biggest differences between mobility and the other sectors are in storage and, as one would expect, distribution, given the development of hydrogen service stations and related logistics. On the other hand, when it comes to production, there is no appreciable difference between the energy and mobility sectors. This seems to suggest that the players producing green hydrogen are less likely to focus on one specific application, favouring a range of applications to ensure there is a market for their output. The diversity of sources of consumption is one of the keys to keeping the system balanced. The industry sector is lagging behind the two others, illustrating the low volume of the hydrogen market in this sector, with only a small number of industries having so far embraced hydrogen technology.

An analysis of the distribution of players along the technology value chain (figure 9) reveals potential centres of gravity in terms of the technology and expertise on offer in Switzerland.

DISTRIBUTION OF PLAYERS IN THE TECHNOLOGY VALUE CHAIN

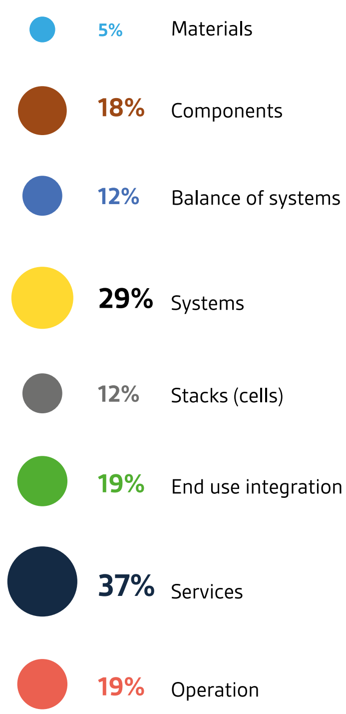


Figure 9

This chart clearly shows the dominant areas of the economic fabric, with a marked centre of gravity in systems creation. Growth in this link is to be expected, since it is supported by the expertise and products developed in the preceding links (components and stacks), which themselves benefit from the developments achieved by research institutes. Leaving aside services (which accounts for roughly a quarter of all businesses), it is also interesting to see that integration comes second in terms of the number of players. The concentration of players in this link illustrates these businesses' ability to innovate and develop new products in response to a specific need. It is also a demonstration of the richness of the ecosystem in terms of cross-sector skills. This clearly illustrates the quality of the labour force and expertise available in Switzerland.

Comparing the number of players in 2012 and 2020 shows that the centres of gravity in the value chain have become more marked in services, systems and integration. We can see also that services has also increased significantly, in contrast to the more technology-based links. This trend has continued over 2021.

In addition, since 2012, the number of players has almost doubled. This is a sign of how healthy the ecosystem is. This finding is not apparent in Figure 10, which is based on the date when each company was founded and not the date when it began showing interest in hydrogen technology. This is particularly true of network operators and public service companies, which have been around for several decades.

To complete our analysis of Switzerland's economic fabric, we also looked at the categories of players in the value chain (Figure 11). This confirms the dominance of SMEs throughout the value chain, with the exception of the extremities (materials and operation). The capacity for innovation shown by start-ups can be seen in the technological aspects (components and systems), supported by SMEs, while the network operators are where one would expect to find them: at the end of the chain, involved with operational activities associated with managing facilities and installations. It should be noted, however, that their activities do extend along the chain towards integration, and this is partly to do with the network convergence strategy that is starting to become more popular with energy distributors.

Portal of technology actors

This portal presents an overview of research and technology activities and the first commercial applications in Switzerland.

More specifically, it provides details of the different hydrogen and fuel cell projects in Switzerland, listing the major industry players (multinationals, SMEs and start-ups) and universities involved. Data on the Swiss hydrogen and fuel cell market is also available on this portal, along with information about the current hydrogen mobility situation in Switzerland.

https://h2.energyresearch.ch/

CHANGE IN THE NUMBER OF PLAYERS IN THE TECHNOLOGY VALUE CHAIN

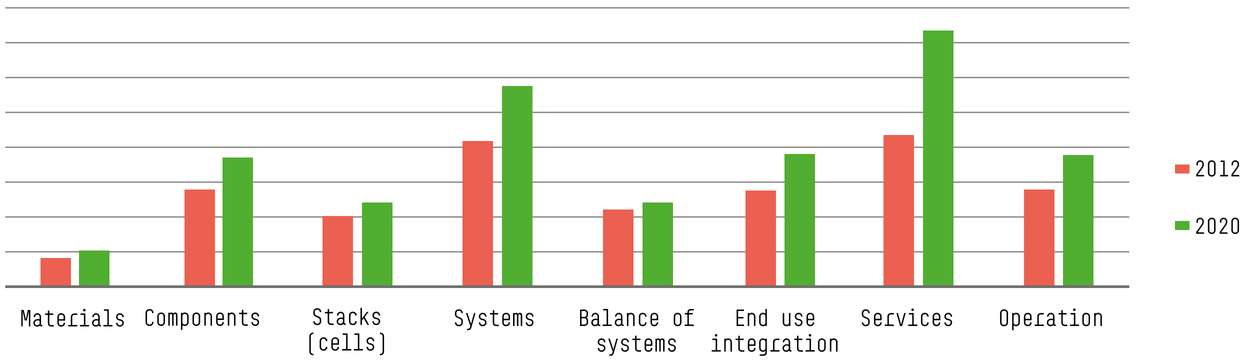


Figure 10

NUMBER OF PLAYERS IN THE TECHNOLOGY VALUE CHAIN BY CATEGORY

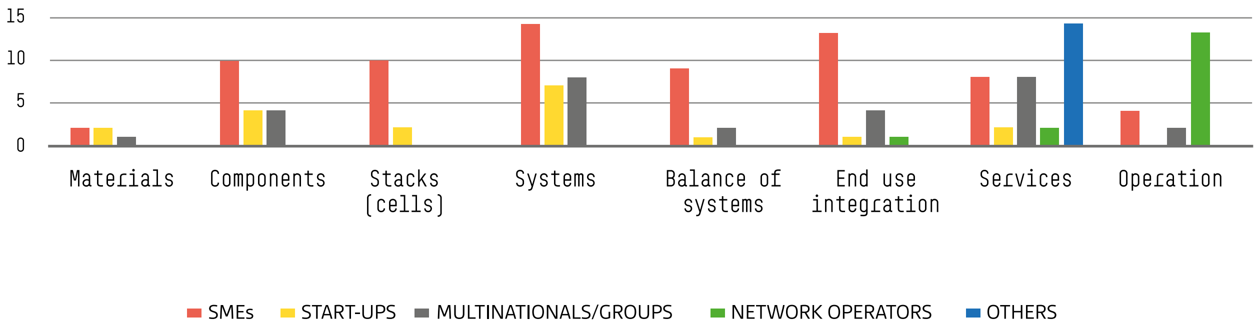
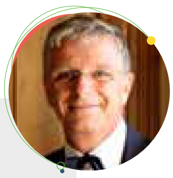


Figure 11

HUBERT GIRAULT
Prof. EPFL



Hydrogen is an energy vector to import green energy in gaseous or liquid form into Switzerland, and to replace the import of carbon products.

SWITZERLAND GLOBAL ENTERPRISE (S-GE), SUPPORTING SWISS SMES INTERNATIONALISE AND FOREIGN COMPANIES TO BECOME ESTABLISHED

Switzerland global enterprise (S-GE) the official export and investment promotion agency of Switzerland, present in all of Switzerland and in more than 27 countries, supporting Swiss SMEs, especially cleantech companies with international business development and helping innovative internationally active companies become established in Switzerland. Providing value to customers and creating prosperity for Switzerland through a unique national and global network of partners.

EXPORT PROMOTION

Working on behalf of the Swiss Confederation, represented by the State Secretariat for Economic Affairs (SECO), S-GE uses its expertise in internationalisation to help Swiss companies, especially SMEs, identify and develop new business potential on a worldwide basis. It provides regular information about relevant trends in the global markets, as well as professional advice and support in finding contacts and partners, and identifying new business opportunities.

SWISS CLEANTECH COMPANY DATABASE CUBE

This database of Swiss cleantech companies, known as the Cleantech CUBE, is a basis for communicating services and for promoting companies both in Switzerland and abroad. Registration is free. www.s-ge.com/cube

INVESTMENT PROMOTION

As part of its remit from the Swiss Confederation and the cantons, S-GE provides potential foreign investors with information about Switzerland as a business location. Its services for foreign companies include assessing the potential of their projects before they are presented to the cantons. S-GE assists the cantons with the relocation of foreign companies, providing market and trend analyses and coordinating the activities of all the bodies involved.

SWITZERLAND GLOBAL ENTERPRISE
enabling new business

www.s-ge.com/cleantech

As the official investment promotion agency for Western Switzerland, **GGBa** advises and assists **innovative international companies** in setting up business operations in the region. Our support is tailor-made, free of charge and confidential.

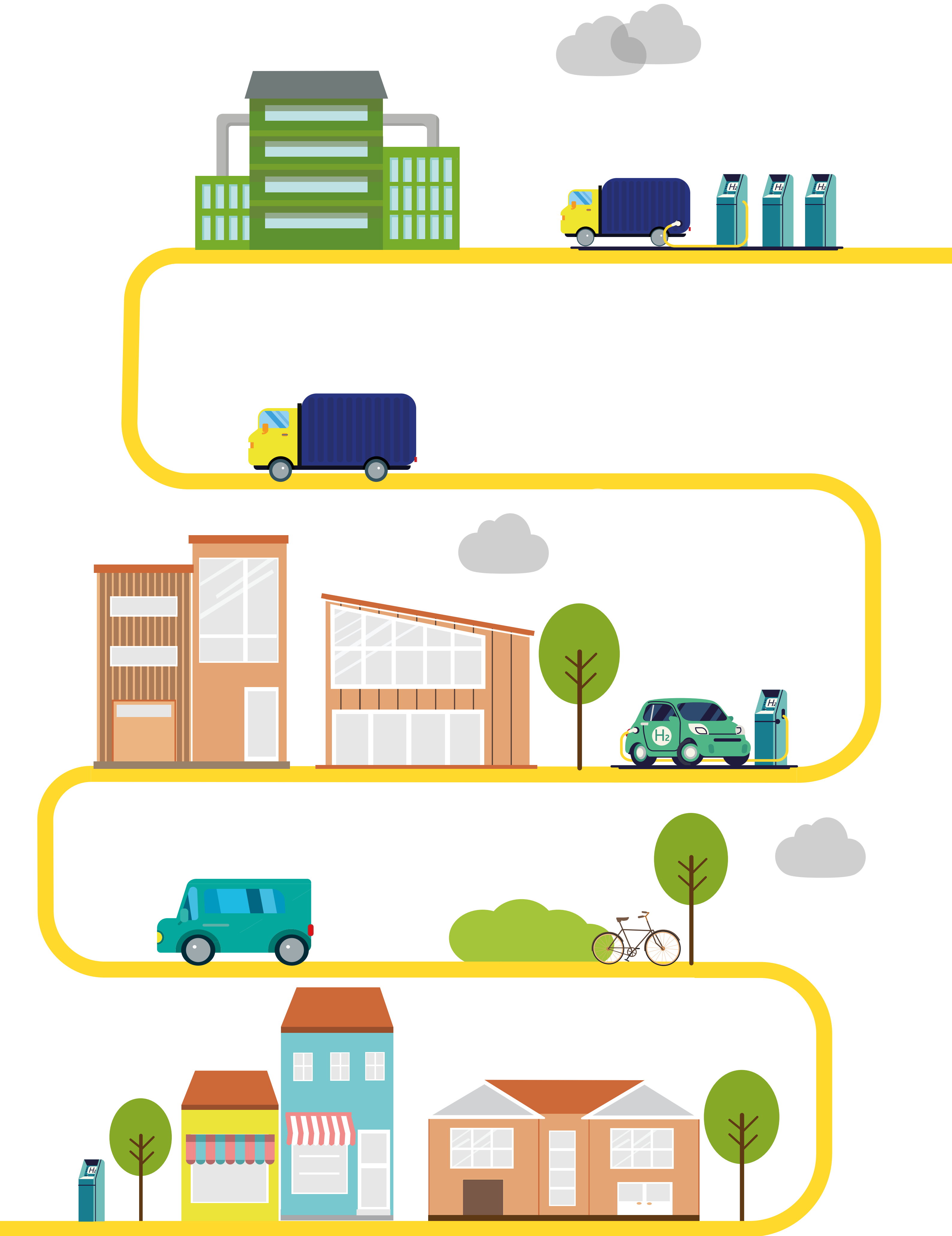
Switzerland is among the global leaders in sustainability and the issue is of clear importance to us as we strive to attract new investors. Our region actively contributes to solving the world's sustainability challenges: the **Oeschger Center for Climate Research** at the University of Bern is one of the most important hubs for international climate research; **CLIMACT**, a joint initiative between EPFL and the University of Lausanne, promotes integrated economic, social and environmental resilience; in Valais, **ALPOLE** studies high-altitude and high-latitude environments, which are sentinels of climate change.

Thomas Bohn

Executive Director, Greater Geneva Bern area (GGBa)
www.ggba-switzerland.ch

Major projects and test benches in Switzerland

This section presents the major projects in Switzerland's hydrogen sector, including those already completed, currently underway and planned (non-confidential). To these we have added details of the demonstrators currently being used to test the new developments under real-world conditions.


H₂
H₂
H₂
H₂
H₂
H₂

PROJECTS

PROJECTS

VICTORIA *202x*
Constructing Jules Verne's balloon Victoria, a balloon containing 2,500 m3 of hydrogen designed for a five-day flight

AURORA *2021 (20xx)*
Incorporating hydrogen into the energy mix used to power buildings

H2BOIS *2021 (2023)*
Hydrogen produced from wood for hydrogen mobility, local industry and supporting the energy transition

SATOM *2021 (20xx)*
Optimising the overall energy efficiency of the site and supporting the ecological transition

USC-FLEXSTORE (Underground Sun Conversion - Projet EU ERA-Net Smart Energy Systems) *2020 (2023)*
Geological seasonal storage of gaseous hydrogen in deep wells (1,000 m)

LIMECO *2020 (2022)*
Economic demonstrator – supporting the energy transition (P2X contributing to the generation of renewable electricity).

NATIONAL ROAD HAULAGE ECOSYSTEM – HYUNDAI XCIENT FUEL CELL TRUCK *2019 (2025)*
Development of a renewable hydrogen-cycle ecosystem for heavy goods traffic
Rollout of 50 trucks (36 t) in 2021 and 1,600 by 2025
Various green hydrogen production projects currently in the planning stage by the consortium and partners

GOH (GENERATION OF HYDROGEN) PROGRAM *2018 (2022)*
Establishment of a complete, local, and sustainable energy industry that covers every aspect of the energy transition in the heavy mobility sector (40-tonne trucks powered by fuel cells). A pioneering experiment accompanied by a major hydrogen industry training initiative. A pilot project that aims to provide solutions to the new challenges facing the haulage industry.

MISSION H24 – HYDROGEN AT THE 24 HOURS OF LE MANS IN 2025… *2018 (2025)*
Launch of a hydrogen class at the 24 Hours of Le Mans in 2024, 653 hp engine (Pmax: 480 kW at 13,000 rpm)
GreenGT electric-hydrogen propulsion module producing a constant 250 kW.

DEMO4GRID (EU FCH JU PROJECT) *2017 (2022)*
Demonstrator for the supply of grid balancing services under real-world operating and market conditions.

FIRST ENERGY-SELF-SUFFICIENT APARTMENT BLOCK – BRÜTTEN *2016 (2020)*
Demonstration of the technical and economic feasibility of building energy-self-sufficient dwellings. Contribution to the energy transition

METHANATION REACTOR, PILOT & SCALE-UP *2016 (2020), 2020 (20xx)*
Making a regulating station carbon neutral through a pilot scheme for highly efficient conversion (>99% of CO_2) into sustainable syngas

STORE&GO (Projet EU H2020) *2016 (2020)*
Network convergence demonstrator

THE BEE *2016*
Hydrogen-powered truck with trailer

CHIC (EU, FCH JU H2 project – Clean Hydrogen in European Cities) *2010 (2016)*
26 buses in 5 towns and cities, including 5 hydrogen postbuses in Switzerland

	PRIZES AND DISTINCTIONS	
	Worldwide audience in terms of communication on the subject of sustainability with a strong human and social dimension	6
		15
	The first installation of its kind in Switzerland	14
		13
		11
	Switzerland's first industrial power-to-gas installation	9
	- First mass-produced fleet of trucks powered by green hydrogen - 2021 Watt d'Or - 2021 Swiss Logistics Award	5
	The first 40-tonne hydrogen-powered truck	4
	First hydrogen class at Le Mans	3
	Europe's largest pressurised alkaline electrolyser (PAE)	12
	2021 Watt d'Or	10
	First methanation reactor inside a metering and regulating station (MRS)	8
		7
	- First public hydrogen service station in Switzerland - First hydrogen-powered semi-trailer truck	2
		1

DEMONSTRATORS

The hydrogen players also have access to four test bench infrastructures located in various parts of Switzerland. These demonstrators can be used to test and validate various technologies and combinations of technologies in surroundings very close to real-world conditions.

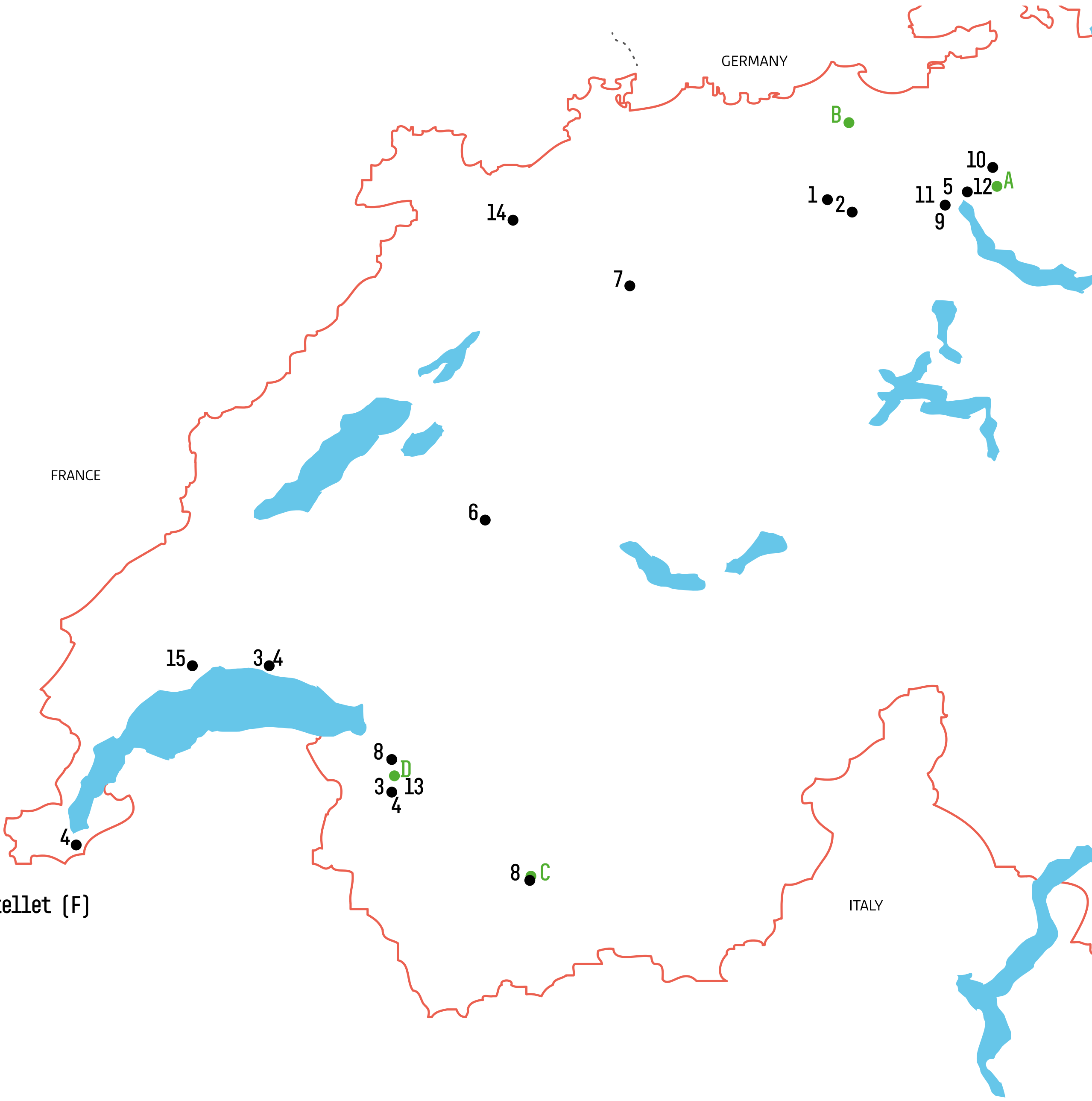
MOVE : EMPA – DÜBENDORF/ZH
Move, the mobility-of-the-future demonstrator, showcases three examples of the use in mobility of excess renewable electricity (electricity that cannot be used directly on the electricity market): hydrogen, synthetic methane, and storage in the network. The hydrogen part of the demonstrator involves its use as a fuel, both as pure hydrogen and when added to biogas.

ESI PLATFORM (ENERGY SYSTEM INTEGRATION): PSI – WÜRENLINGEN/AG
With the ESI Platform, PSI provides research scientists and industry with access to a test platform on which even highly complex solutions with potential can be tested. It can be used for example to examine in detail the storage and conversion processes in the context of power-to-gas.

ENERGYPOLIS – DISTRICT DEMONSTRATOR : ENERGYPOLIS CAMPUS – SION/VS
The purpose of this demonstrator district is to test and validate the technologies and energy systems developed by EPFL and HES-SO Valais/Wallis and their partners. Hydrogen takes centre stage here in, for example, developing new fuel cells, testing new materials and working on next-generation synthetic fuels. The experience of hydrogen mobility developed at Electromobilis in Martigny is part of this.

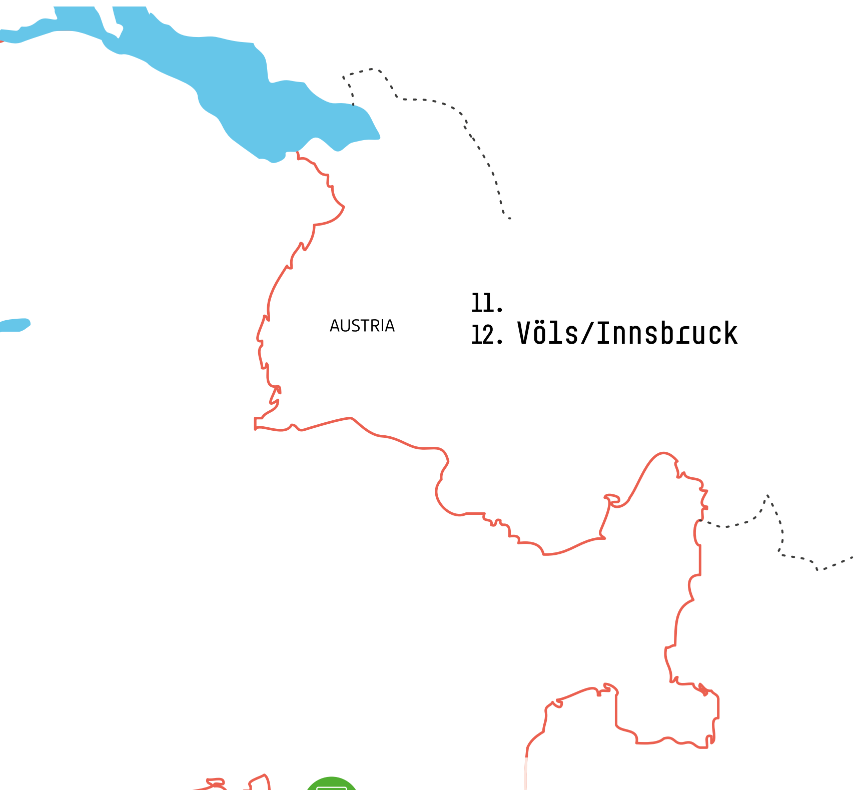
INNOVATION LAB: GAZNAT - AIGLE/VD
A test bench in an industrial environment for energy pilot projects, mainly the production of renewable gases (hydrogen, carbon-neutral synthetic methane, etc.). This platform is used to test technologies such as power-to-gas, fuel cells and CO_2-capture membranes in an industrial setting in preparation for their large-scale rollout.

MAPPING OF PROJECTS AND TEST BENCHES IN SWITZERLAND



DEMONSTRATORS

A. Move : Empa
B. ESI Platform (Energy System Integration) : PSI
C. Energypolis – District Demonstrator: Energypolis Campus
D. Innovation Lab : Gaznat



MOBILITY

1. CHIC (Projet EU, FCH JU H2 – Clean Hydrogen in European Cities)
2. The Bee
3. Mission H24 – hydrogen at the 24 Hours of Le Mans in 2025...
4. GOH (generation of hydrogen) program
5. National road haulage ecosystem – Hyundai XCIENT fuel cell truck
6. Victoria

POWER-TO-GAS

7. STORE&GO (EU H2020 Project)
8. Methanation reactor, pilot & scale-up
9. Limeco

STORAGE

10. First energy-self-sufficient apartment block - Brütten
11. USC-Flexstore (Underground Sun Conversion - Projet EU ERA-Net Smart Energy Systems)

MULTI-USE

12. DEMO4Grid (Projet EU FCH JU)
13. SATOM
14. H2Bois
15. Aurora

Experts views

Hydrogen is a vast subject, as seen in the preceding pages. To open up the debate and the range of possibilities, we interviewed two personalities who give us their view on the subject.

3 questions for...

« Thanks to the dynamism of the private sector, Switzerland already has a pioneering role. »

▸ STEFAN OBERHOLZER
Hydrogen Program Manager
Swiss Federal Office of Energy (SFOE)

Touted as a practical response to global warming (as a carbon-free energy source), hydrogen is now the subject of renewed interest. What role can hydrogen play in Switzerland?

In addition to measures that address efficiency, our energy strategy is heavily reliant on electrification in various sectors, along the lines of what's happening in transport. For example, according to Energy Perspectives 2050+ published at the end of 2020, indigenous production of green hydrogen (from run-of-river hydroelectricity) for use in the road haulage sector is set to total around 2 TWh/year by 2050. Today, thanks to the dynamism of the private sector, Switzerland already has a pioneering role globally in this industry.
Green hydrogen can help to reduce greenhouse gas emissions in the industrial sector. In the future, it will also play a major role in the transport of and trade in renewable energies, both globally and within Switzerland. We are not yet sure to what extent electricity from other renewable sources, such as photovoltaic energy for example, could be used to produce hydrogen in Switzerland.

Nearly 30 countries and the EU have already published their hydrogen deployment strategies. Is Switzerland planning to publish its own strategy, too?

Up to now, Swiss energy policy has been based on sensible framework conditions rather than industrial policy measures. In meeting our energy and climate goals, we need to be open to all the different developing technologies. That said, the Federal Office of Energy is currently looking at greater depth into the specific potential of hydrogen in helping to meet our energy and climate goals and improving security of supply for Switzerland.

What contribution do you think Switzerland can make to the development of the hydrogen sector?

As mentioned above, Switzerland is today a pioneering market, particularly for Europe, in the use of hydrogen in the road haulage industry. An important factor here is the incentive provided by the exemption from the heavy goods vehicle service duty (RPLP) granted to electric trucks. Currently, no such regulatory incentive exists in Germany, for example. When it comes to technology, Switzerland has a large number of innovative start-ups and well-established SMEs that offer cutting-edge hydrogen and fuel cell technology, backed by excellent cooperation between industry and the country's higher education sector.

3 questions for...

« The main factor limiting the development of hydrogen is economic. »

▸ **FRANÇOIS VUILLE**
Director-General of the Department of Energy (DGE-DIREN), Canton of Vaud

What contribution can hydrogen make to a successful energy strategy, at national and/or cantonal level?

Since hydrogen is an intermediate energy carrier that is not available in its natural form on Earth, it can only play a role in optimising the energy system. There are various ways in which hydrogen can be of use to us, including putting the excess electricity generated in the summer to good use in storage and powering heavy trucks. Under certain conditions, the latter may already prove to be economically viable.

How do you explain the fact that there are so many hydrogen players concentrated in the Canton of Vaud?

I'm not so sure that the Canton of Vaud does have a higher concentration of players than anywhere else. I suppose it is possible, though, that because we have top universities like EPFL here, this generates a certain number of start-ups and projects in the region. It's true that Vaud is home to some real technology gems like GreenGT and SOLIDpower, along with pilot projects in hydrogen-powered vehicles and power-to-gas, in other words transforming excess electrical energy into gas or hydrogen.

In your opinion, what is holding back the large-scale deployment of hydrogen in Switzerland?

The main factor limiting the development of hydrogen technology is the difficulty of developing the production and consumption markets at the same time. Investors are being put off by the lack of clarity about the future.
In addition, we definitely still lack the excess renewable energy required for hydrogen production, and there is a need to introduce standardisation, particularly in safety, the different applications possible, and infrastructures.

However, the main aspect holding us back is economic. The cost of equipment such as electrolysers and fuel cells is still high, because as yet there is no mass market. Also, hydrogen producers can benefit from very cheap electricity, but the cost of transporting this electricity (the network tariff) is by comparison very high, which means that only hydrogen production plants located next to hydroelectric dams can be economically viable, and this limits the opportunities available.
Hydrogen's calorific value, which is lower than methane's, and the perception of the risk posed by its high flammability, are also still putting operators off.

Conclusion: the hydrogen dilemma

Hydrogen is not the new kid on the block, but what is new is that the environmental issues and their attendant threats to the global climate and public health are converging with the political and economic issues.

Hydrogen shows that network convergence is the way to go, in particular when it comes to power-to-gas, or more broadly, power-to-X technologies. However, the reality is that the players involved are not (yet) coming together quickly enough.

Hydrogen divides opinion in every sector of society, and that is not about to change. The contribution that (green) hydrogen can make to the energy transition towards a carbon-free society is now undisputed and universally accepted. However, the timetable and the source of the electricity used to make it remain major stumbling blocks.

No one denies that hydrogen will make an important contribution in the long term, and its utility in seasonal storage makes it very attractive, but the matter of conversion efficiencies is less clear cut. This debate would, however, be irrelevant if there was enough renewable energy in Switzerland. Currently, this is clearly not the case, and the renewable electricity needed to produce green hydrogen depletes the supply earmarked for other uses. This opens the door to imported electricity sourced from fossil fuels or potential new gas-fired, CO_2-generating power stations.

On another front, there is pressure on industry to reduce its greenhouse gas emissions. Because the transport sector is a major contributor to these emissions, hydrogen is a tempting proposition for businesses keen to work towards carbon neutrality, such as haulage companies.

It is therefore quite possible that we will see rapid growth in demand for green hydrogen production in Switzerland. It is projected that a fleet of 1600 Hyundai XCIENT Fuel Cell trucks will be operating in Switzerland by 2025. Announcements are regularly made about new hydrogen trucks on the market, such as the GOH project and the first 40-tonne hydrogen truck (see page 58). Currently, Switzerland's indigenous production of hydrogen, from a 2 MW installation, would be enough to power around 50 trucks. A second installation, this time 10 MW, has been announced for the end of 2022, and production capacity will probably have to be increased to at least 100 MW by 2025.

Clearly, it is not going to be possible to square up the interests of the private sector and Switzerland's commitments to carbon neutrality by 2050 unless, at the same time, the country accelerates its rollout of renewable energy production capacity, particularly from photovoltaic solar power.

Private and public players may have the same long-term goal, but it will take considerable effort on both sides to ensure their interests converge in the short term. Pragmatism, not dogmatism, is the order of the day. The key will be to align the interests of both parties, ensuring they are not at odds.

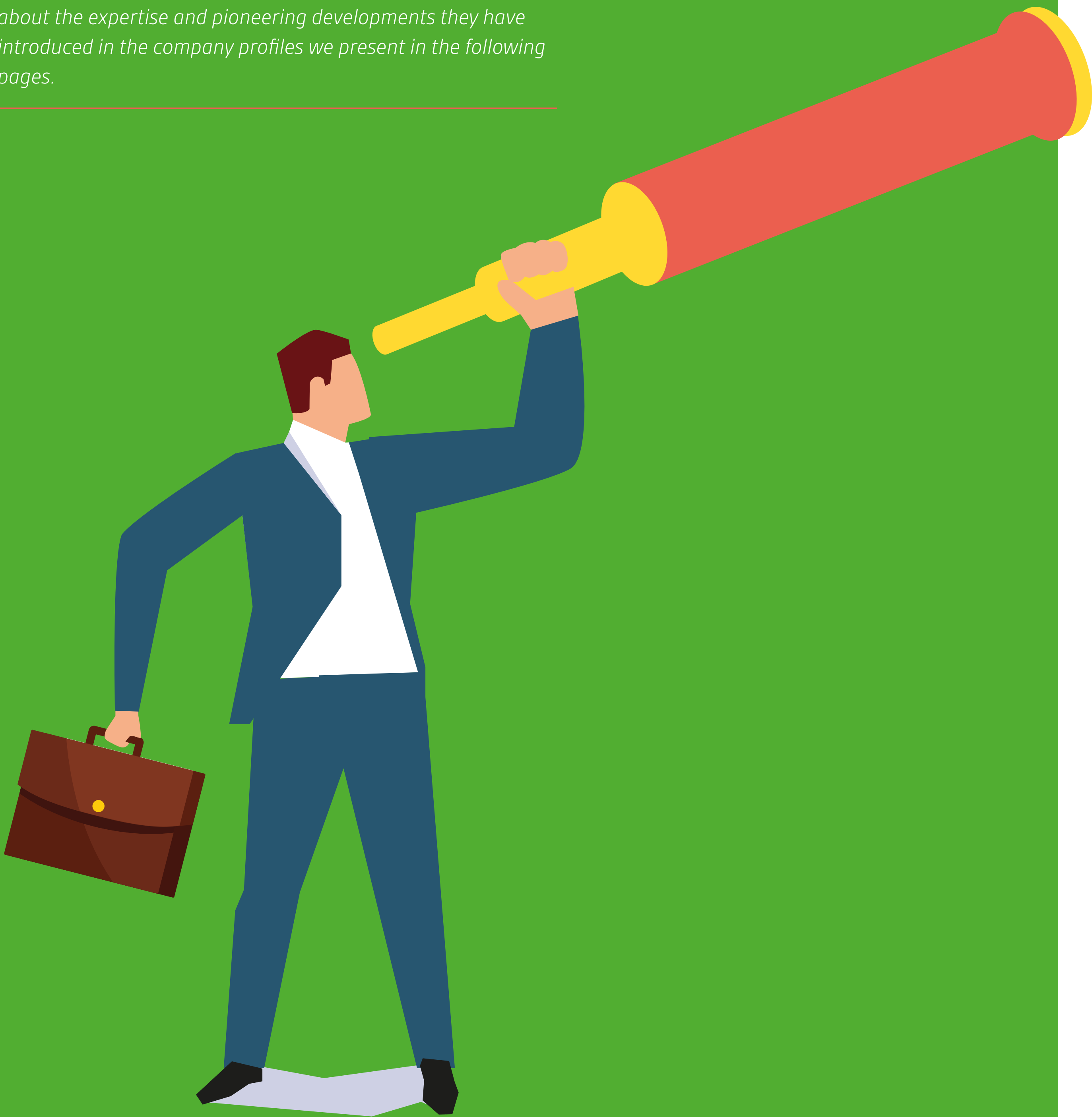
From the point of view of technology businesses, it is essential to keep in mind that the hydrogen sector is growing very fast globally, in particular in Switzerland's European neighbours. The market opportunities are real – and considerable. The expertise offered by Switzerland's economic fabric, as shown in the portfolio of business and project profiles (see page 54 and following), is a perfect illustration of how good Swiss players are at offering solutions in this rapidly growing sector.

To allow this to happen, it is imperative that changes are made quickly to the regulatory framework so that pre-industrial-scale demonstration installations can be built in Switzerland to win over future customers. After all, is it not often said that your first export market is your local market?

By applying this approach, Switzerland can come full circle and benefit on both fronts, building up the country's economic fabric of multiple businesses developing complex solutions all along the hydrogen value chain, and contributing to both the energy and the environmental transition at the same time.

Company profiles

We thought it would be a good idea to shine a light on some of them, mostly innovative start-ups and SMEs. You can read about the expertise and pioneering developments they have introduced in the company profiles we present in the following pages.



HYDROSPIDER AG

A world first – a mass roll-out of trucks entirely powered by green hydrogen

Around 50 hydrogen-powered trucks are already out on Switzerland's roads. This is the result of an unprecedented collaboration between Hydrospider, Hyundai Hydrogen Mobility and the many companies partnered with the H2 Mobility Switzerland Association, which aims to encourage vehicle development together with green hydrogen production and its delivery to filling stations.

Hydrospider is part of a green hydrogen mobility ecosystem focusing on heavy-duty truck transport. "In this sector, we're confronted with the limits of electric batteries," says Amédée Murisier, Head of Hydropower Generation at Alpiq, a Hydrospider shareholder along with Swiss hydrogen pioneer H2 Energy and Linde/PanGas, a specialist in industrial gases. "The weight of the batteries needed to power a truck reduces the payload too significantly." Hence the solution of using hydrogen – green, naturally. Hence, also, the relevance of locating the project in Switzerland, a pioneer in matters of hydroelectric power. Alpiq has many years' experience in producing renewable electricity from this source, essential to producing sustainable hydrogen. That's who is behind the fuel production and its supply to filling stations. As for the vehicles, Hyundai Hydrogen Mobility is a partnership between the Korean Hyundai Motor Company (which produces the XCIENT Fuel Cell heavy-duty trucks) and H2 Energy and is providing the trucks and handling their leasing.

1600 TRUCKS BY 2025

A first electrolysis plant, with a capacity of 2 MW, was commissioned by Hydrospider in the summer of 2020 on the site of Alpiq's hydroelectric power station in Gösgen, in the canton of Solothurn, while a first XCIENT fully hydrogen-powered truck toured around the country's roads. Further hydrogen production sites will be built to meet the demand for the 1600 trucks that are to be rolled out on Switzerland's roads by 2025. "They'll require 100 MW," says Murisier. "We won't be producing all of it, but we will have to ensure a minimum quantity to develop the ecosystem." The power already installed will produce enough hydrogen to fuel the 50 XCIENT trucks that are operated in Switzerland this year. These vehicles will be used for local distribution by various transporters and retailers, including Coop and Migros. Eight filling stations are currently in operation along major roads to supply the trucks with hydrogen.

What's next? Switzerland will continue to be the priority market for now. In addition to a large capacity for generating renewable electricity, the country supports carbon-free mobility through exemption from the tax on heavy goods vehicles. This is the ideal context in which to firmly anchor the ecosystem before expanding into the European market.

HYDROSPIDER AG
www.hydrospider.ch
amedee.murisier@alpiq.com

CELEROTON

Taking the route of electric mobility

A strong vision and true technical innovations are needed to create the mobility of the future. Based in Volketswil, Zurich, Celeroton develops compact, powerful turbo compressors for electric engines in commercial vehicles.

Electric engines run on electricity, of course, which can be produced from hydrogen, using a fuel cell. And a fuel cell requires a compressor to work efficiently. Compressors for industrial applications have been around for some time, but not with a compact design and very high speeds. It was precisely this gap in the market that led scientists Martin Bartholet and Christof Zwyssig, from the Swiss Federal Institute of Technology in Zurich, to set up Celeroton in 2008.

Today the company employs 38 people. It supplies turbo compressors to manufacturers of fuel cell systems for lorries, buses, cars and boats. The compressors are also used to clean the lenses of inspection systems or to supply compressed air. Celeroton's end market is European manufacturers of light commercial vehicles, from forklifts to lorries. The company does not supply directly to the vehicle manufacturers but to fuel cell manufacturers in Europe and Asia.

"What's truly innovative is that we offer a system that integrates the turbo compressor and the control electronics," explains managing director Martin Bartholet. What is particularly striking about this technology is that the compressors work without the need for lubricant: the shaft "floats" on a gas bearing. The Celeroton engineers took their inspiration from electronic chip production: compressors need to become ever smaller and more efficient. The overall system, which combines both compressor and control electronics, is the product of a research and development process that started several years ago and still continues today.

When it started, the company built prototypes and mainly fulfilled engineering orders. Since then, it has become an SME manufacturer able to solve the issues arising in series production. A new industrial cleantech company is currently being developed in Volketswil. Hydrogen vehicles have enormous potential in the sustainable transport sector, and Celeroton supplies a key component for this promising technology.

Celeroton
www.celeroton.com

A company that doesn't rest on its laurels – next on the list: hydrogen

Satom SA is positioning itself as a player in the transition towards sustainable energy and has unveiled an ambitious vision, broken down into five major projects. One of these is its H2 pilot project, which will enable it to produce and supply hydrogen to a fleet of rubbish trucks.

Satom SA has long since established its role as a power plant operator. At its Valais site in Monthey, the heat produced in the waste-to-energy plant is already being used to produce electricity and supply the remote heating network that serves the communes of Monthey and Collombey-Muraz. In a spirit of innovation, the public utility company wants to go even further by developing five projects that meet the objectives of the 2050 Energy Strategy. The company's objective is to reduce the environmental footprint of waste while diversifying energy production in order to test out the market and choose the most profitable energy carrier. "Our core business isn't changing; it's the market that's changing, with its very rapid variations in supply and demand, the types of energy produced and the way we're going to manage and use them," says Daniel Baillifard, engineer and Managing Director of Satom SA. It is against this background that the company is launching its H2 project. A credit of 4 million francs has been approved for the installation of a 1 MW pilot electrolyser and an H2 filling station, which will enable it to gain experience in the production and storage of hydrogen.

UP TO 1200 TONNES OF CO_2 SAVED EACH YEAR

Demineralised water will be electrolysed on site, using electricity generated by waste incineration, to produce around 120 tonnes of hydrogen a year. The aim is to decarbonise the transport of waste to the energy recovery plant. With a captive fleet of heavy-duty trucks on the roads in 77 shareholder communes in Valais and Vaud, Satom is ideally placed to install a hydrogen charging station. A production rate of 120 tonnes of H2 a year would supply 40-tonne trucks with enough fuel to cover approximately 1.5 million kilometres, thus saving 1200 tonnes of CO_2 a year (compared with diesel emissions). A partnership is being set up with H2Valais (Hydrogène du Valais), which wants to earmark hydrogen to supply a fleet of trucks to be deployed in the transport sector.

Eventually, the surplus hydrogen could be combined with the CO_2 captured after combustion to produce methane (CH4) – another of Satom SA's five projects.

SATOM SA
www.satomsa.ch info@satomsa.ch

Powerful electrolysers that have prove their worth

With an impressive track record built up around the world, IHT developed, manufactured, marketed and installed high-pressure electrolysers for the industrial production of hydrogen. Early 2021 IHT joined Sunfire, a german company and is now targeting large-volume production in Europe, with the aid of its alkaline electrolyser technology.

The stack, where water is split to produce hydrogen forms the heart of the electrolyser and is built in Switzerland. What is so special about the stacks developed by this company is their large size and consequently their high production capacity. Their power varies between 4 and 5 MW; they weigh around 60 tonnes and have a diameter of about 2 metres. Production capacity can be easily increased by installing and operating several stacks of this type on the same site. This flexibility, coupled with the stacks' size, power and pressure level, makes them particularly suitable for industrial applications. This technology has become highly attractive, especially in calls for tender at a European level, including projects in the very promising sector of hydrogen energy applications.

READY AHEAD OF TIME

IHT started operating in 2003; the company already had the technology to manufacture large stacks then, but the European market was not ready for new applications such as transport and energy. "At the time, we had very little visibility in the market, and the series of projects funded by Europe was aimed at deploying small-scale electrolysers," says Nicola Zandonà, former Business Director at IHT and current Sunfire's advisor. They were projects that suited the competition, but not IHT, based in Monthey, in the canton of Valais. "Not being able to respond to Europe's calls for tender for installations that were much smaller than what we were producing was a bit frustrating, but we still continued our development programmes, and we have been able to get ahead of the competition as a result," says Zandonà.

Europe is now aiming higher, and Sunfire has entered the race through the front door with the Demo4Grid project in Innsbruck, Austria, with the support of the Swiss State Secretariat for Education, Research and Innovation (SERI). Under the terms of the project, the company is responsible for building the largest pressurised alkaline electrolyser ever used to date, both for the demonstration of grid services and the production of green hydrogen for industrial and transport purposes. The next step is to construct electrolysis facilities with even greater power and capacity. Sunfire has acquired IHT to complete its product range (high temperature electrolysers based on SOEC technology). Now the company is increasingly being called upon to build hydrogen production plants capable of generating several tens – or even hundreds – of megawatts.

Sunfire
www.sunfire.de
laura.ziegler@sunfire.de

Hydrogen solutions – from racing cars to heavy-duty trucks

GreenGT is the inventor of the hydrogen-powered racing car and produces high-power electric-hydrogen propulsion solutions. The Vaud-based company is also developing a consulting activity covering the entire hydrogen value chain.

GreenGT was founded in 2008 on the initiative of Jean-François Weber. Drawing on his knowledge of the automotive industry, Weber had developed a battery-based electric propulsion system for auto racing in 2005, but had soon seen its limits with respect to weight and recharging time. Recognising the potential of the fuel cells used in the aerospace industry, in 2011 he launched a 100% hydrogen-powered racing car under the GreenGT banner.

Since then, the company has developed high-power systems to improve the performance of heavy-duty vehicles. Initially for motor sports, of course, particularly as part of the Mission H24 project to introduce a hydrogen category at the 2024 24 Hours of Le Mans, in partnership with ACO (Automobile Club de l'Ouest). However, in 2015, GreenGT also turned its attention to industrial applications, with a first fuel cell project integrated into a Renault Maxity truck, followed by GOH at the end of 2020, a 40-tonne truck that runs solely on hydrogen.

ENORMOUS POTENTIAL FOR HYDROGEN TRUCKS

"The technology developed by GreenGT is at the cutting edge of high-power integrated hydrogen systems, in terms of both weight and compactness," says Frédéric Veloso, the company's Director of Strategy and Business Development. GreenGT is now structured around three core businesses. The first is motor sports, a business division that draws its resources from sponsoring. "It's also an excellent communication channel to demonstrate the technology's relevance," says Veloso. The second business division is engineering and systems, which is responsible for the design, integration and manufacture of hydrogen propulsion systems. A new third business division brings together the company's consulting and strategy activities. These are focused on large companies and regions wishing to set up their hydrogen ecosystems, for production, distribution or applications, whether these be mobile, static or industrial.

GreenGT successively doubled its workforce in 2020 and 2021. It has many projects underway in Switzerland and France, in collaboration with several companies, including Migros, Carrefour, Total and Michelin. Having outgrown its workshop in Aclens, the company moved into its new factory in Valais at the start of 2021, to meet the "enormous demand for trucks". GreenGT has also set up a branch at the EPFL Innovation Park for its research activities.

GREENGT
www.greengt.ch f.veloso@greengt.com

INERGIO TECHNOLOGIES SA

A mini fuel cell for a whole array of applications

Inergio manufactures high-performance autonomous mini fuel cells. The company was established in the second half of 2020, and a product validation and certification phase is now underway, in preparation for a market launch in 2022.

The Inergio team has developed a power source for off-grid and mobile applications. This solid oxide fuel cell (SOFC) is compact and lightweight. One of its advantages is that it can use different types of gas: hydrogen, of course, but also propane or natural gas. "Our solution provides users who do not yet have access to hydrogen with some flexibility: they are able to use more easily accessible fuels, but already have the infrastructure in place for a transition to hydrogen," explains Inergio's Chief Operating Officer (COO).

The start-up is offering a solution that is 80 to 90% lighter than those proposed by its competitors. The technology is also capable of producing 20 times more energy per kilo than lithium-ion batteries and can reduce CO2 emissions by 60 to 90% compared to solutions using fossil fuels.

IDEAL FOR LOW-POWER MOBILE APPLICATIONS

The SOFC developed by Inergio comes in the form of a one- to two-litre container. And the company, an EPFL and HEIG-VD spin-off, has plenty of applications for the fuel cell in mind – remote measuring stations, pipelines, mobile monitoring systems, telecommunication units, autonomous robots and drones, to name just a few. "Most systems are pretty bulky and therefore suitable for large applications, such as powering data centres or private homes, but not many are designed for mobile and low-power applications," says the COO.

The SOFC also has plenty of advantages, according to Inergio. Not least of which is the absence of particle emissions, since the gas is transformed into electricity via an electrochemical reaction so does not cause any combustion. No noise is produced during operation, either, and the fuel cell requires minimal maintenance as it has no moving parts. In addition, the solution offers greater autonomy than a lithium-ion battery, as well as a competitive price and lower weight. This fuel cell is the culmination of ten years of research stemming from the doctoral thesis conducted at EPFL by Mahmoud Hadad, one of the start-up's founders.

INERGIO TECHNOLOGIES SA
www.inergio.ch Mahmoud.hadad@inergio.ch

Connecting the players in the hydrogen sector

Created in 2001, Hydropole, the Swiss hydrogen association, brings together the participants in this fast-developing sector. It enables them to exchange knowledge and information and to work together on research projects or on developing commercial products.

Based in Valais, Hydropole has sixty members and more than a hundred associate members. While, in its early days, the association was mainly made up of people from academia, most of its members are now involved in industry. As a result, the association has become a platform that networks people who work with hydrogen in all its forms, from research to industry, including consultants, companies and policymakers. Hydropole draws on this wide perspective to publish the biennial Hydrogen Report Switzerland.

The association's evolution reflects the enormous development of the hydrogen sector in recent years. "We've moved from a world based on fossil fuels to a world based on renewable energies," says Andreas Züttel, EPFL professor and President of Hydropole. "This change is essentially brought about by the question of storing renewable energies."

SWITZERLAND LEADING THE WAY

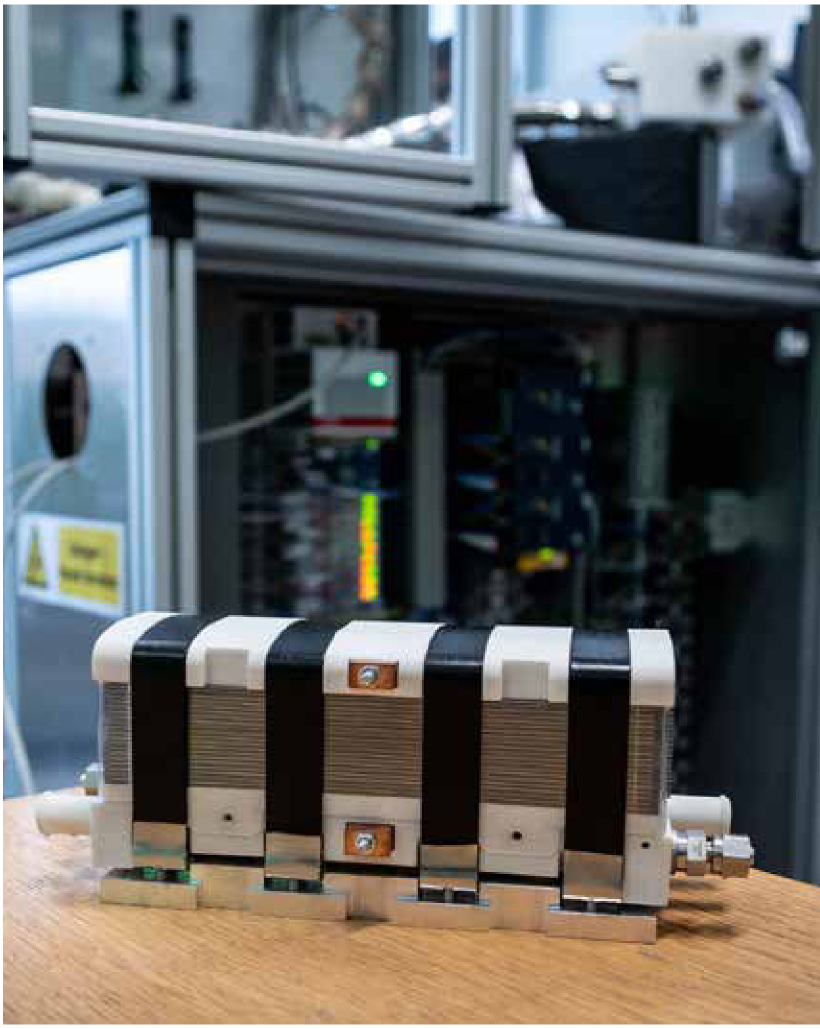
Switzerland is one of the world leaders in hydrogen research. With the construction of the first hydrogen-powered car in 1807 by Isaac de Rivaz, the country had positioned itself as a player in the field well ahead of its time. The same was true in 1987, when the first Swiss self-sufficient house was built. Designed by the architect Markus Friedli, it integrated solar panels, electrolysis and a hydrogen supply for the washing machine, heating, cooker and car. The members of Hydropole also make an internationally recognised contribution to research and are major suppliers of instruments and equipment for producing, measuring, controlling and using hydrogen.

And this gas has a very promising future ahead of it! "Hydrogen is gaining importance as an energy carrier for transport," says Züttel. "Many new products are coming onto the market, from technologies for electrolytic hydrogen production to hydrogen tanks, fuel cells and vehicles." The association, itself a member of the European Hydrogen Association, celebrates its 20th anniversary in 2021. This is an opportunity to share exemplary achievements across the country with the general public, to democratise the subject and strengthen its momentum.

HYDROPOLE
www.hydropole.ch
andreas.zuettel@epfl.ch

EH GROUP ENGINEERING SA

Compact, light and efficient fuel cells



EH Group has reworked the concept and design of fuel cells and is now supplying this technology to several Swiss and European industry players. The company based between Lausanne and Geneva has set its sights on two areas: mobility and backup power for data centres.

A promising clean energy technology, fuel cells are currently the subject of considerable research and are set to play a key role in the near future in powering vehicles and infrastructures with high energy demands. EH Group is active in this field and has made some big improvements to this technology with a view to making it available commercially on a large scale. After years of laboratory research, the team at EH Group have come up with a new fuel cell design that will be easier to manufacture, making a more compact, lighter and more efficient device. Its product is for example 20 times more powerful than a lithium battery of the same size. Another advantage is that this fuel cell features a modular design with a power output of anything from 10 kW to more than 100 kW. This makes it is suitable for a wide range of vehicles, from forklift trucks to heavy goods vehicles and including cars.

AUTOMATING THE PRODUCTION PROCESS

EH Group's first customers are in Switzerland, but also in Croatia and the Netherlands, where its devices are destined to be used in eco-friendly construction machinery and electric buses for use in public transport respectively. "We are also working in partnership with several Swiss universities, including EPFL, in microgrid technology research," says Christopher Brandon, co-founder of the company. One of the aims of this collaboration is to develop a backup energy supply system for data centres.

In February 2020, EH Group pulled off a coup in Europe by securing a grant of 1.5 million euros awarded by the EU's innovation and research support programme, a boost that should enable the company to grow more rapidly and significantly reduce the production costs of its hydrogen fuel cell. It currently uses a semi-automatic process to make this fuel cell, but from next year this should be fully automatic thanks to a partnership with an industrial production machinery manufacturer based in St Gallen.

EH Group Engineering SA
www.ehgroup.ch
christopher.brandon@ehgroup.ch

A revolutionary reactor with the power to decarbonise the

Gaznat has been putting a methanation reactor through its paces at the Sion metering and regulating station (MRS) since September 2020. It has a record conversion rate of 99% and could well give a major boost to Power-to-Gas technology.

With Power-to-Gas, excess renewable electricity can be stored in the form of synthetic methane (CH4). This is produced by converting the current into hydrogen through electrolysis and then injecting it into the reactor with a source of CO_2. The technology also contributes to the decarbonisation of the economy, as it allows industrial CO_2 to be converted into synthesis gas (syngas). “It is a component of Gaznat’s strategy to transport CO_2-neutral gas by 2050,” says Gilles Verdan, Director of the company’s Network Department.

This pilot project evolved from a discussion with EPFL Valais Wallis, which was working on a new methanation reactor. Gaznat expressed its interest on two counts: for the production of CO_2-neutral syngas and because the Power-to-Gas process generates heat. This heat can be used in an MRS (an installation that extracts natural gas from the high-pressure network, reduces its pressure and measures the quantity of gas delivered), in the gas expansion process. Developed in collaboration with EPFL and OIKEN, the largest energy player in the canton of Valais, with the support of Innosuisse, the Swiss innovation agency, the pilot reactor has a power output of 10 kW and an annual production capacity of 90,000 kWh. Its innovative edge is its ability to convert more than 99% of the CO_2 inject in a single step, a rate never before achieved on the market.

INDUSTRIALISING THE TECHNOLOGY

“The installation is operational and is intended to supply OIKEN’s distribution network, with the necessary adjustments,” says Verdan. The next step will be to develop a larger project, based on a reactor with a power output of around 200 kW, with a view to industrialising the technology for other applications. Gaznat’s objective is to deploy this type of installation on a larger scale – for example near hydroelectric power stations, wind farms and solar photovoltaic installations – as the technology shows great promise as a storage solution for the surplus electricity produced in summer.

At the same time, the company is working on a project to store this excess energy in the form of gas and hydrogen in Upper Valais. In the future, the production of renewable syngas, combined with the development of decentralised CHP (combined heat and power) plants, should make it possible to partially compensate for the shortfall in electricity production, particularly during the cold season, and thus contribute to Switzerland’s energy autonomy.

GAZNAT
www.gaznat.ch
g.verdan@gaznat.ch

MEMBRASENZ

A composite membrane that boosts electrolyser productivity

Membrasenz, a company based at the EPFL Innovation Park in Lausanne, is developing an efficient membrane for alkaline electrolysers. A good example of the importance of developing new materials to boost the booming hydrogen production sector.

In the green hydrogen cycle, surplus electricity generated by renewable energy sources is used in electrolysers to split water into hydrogen and oxygen. The membranes that separate the gases generated are the main components of electrolysers. "One of Membrasenz's objectives is to increase the ionic conductivity of these membranes to improve the efficiency of the electrolysis process and bring down the cost of hydrogen to the end user," explains of the R&D engineers. "Reducing the operating expenditure of the electrolysis process by using more efficient membranes enables us to make substantial savings."

"IT WAS THE RIGHT TIME"

The team at Membrasenz is also working on improving thermal resistance to meet the needs of an expanding market. CEO and founder Jelena Stojadinovic previously carried out research on membranes at Ruhr University Bochum in Germany and Empa (the Swiss Federal Laboratories for Materials Science and Technology) in Dübendorf. At that time, she could see that the product her start-up is developing today would meet a need of industry buyers. "The membranes used originally were made of asbestos, which was due to be banned in 2007. It was the right time to come up with a new material."

With its product still at the development and optimisation stage, Membrasenz has already begun a series of industry tests. The next hurdle is scaling up to industrial production, which the team is working on currently. At the same time, the company is busy with R&D, developing new membranes for other energy systems. At the cutting edge of innovation, Membrasenz receives part of its funding from three European projects.

MEMBRASENZ
www.membrasenz.com
j.stojadinovic@membrasenz.com

LIMECO

Green gas on an industrial scale

Household waste and wastewater contain a lot of energy. To convert this energy into renewable gas, Switzerland's first industrial and commercial gas-fired power plant will come into operation in the winter of 2021–22, in Dietikon, canton of Zurich.

In the Middle Ages, alchemists tried to produce gold from natural substances. Inspired by this, the city of Dietikon will itself be producing a valuable commodity from natural substances. It will use a multi-stage process to do so. It is reminiscent of alchemy, but with one important difference: this process works. A wastewater treatment plant (WWTP) supplies the sewage gas, which is converted into high-quality green gas by the addition of renewable hydrogen. This gas is a renewable energy source because the hydrogen used to produce it is generated from renewable electricity from a waste incineration plant. The hydrogen is produced by an electrolyser with a capacity of 2.5 MW.

Pilot plants have already converted renewable electricity into storable gas (using Power-to-Gas technology). Now, in Dietikon, Limeco will be doing this on a commercial scale for the first time. A full 18,000 MWh of green gas will be produced each year, covering the energy needs of around 2,000 households. This will prevent the emission of 5,000 tonnes of CO_2, which are particularly harmful to the climate. "Eight Swiss energy suppliers already support the Limeco power station. They buy gas at production cost and supply their customers with renewable gas," explains Thomas Di Lorenzo, head of wastewater management at Limeco. The project is also supported by the Swiss Federal Office of Energy (SFOE).

This particular power plant was instigated by Swisspower, a strategic alliance of 21 Swiss municipal utilities and regional utility sector companies. Its location near Limeco, in Dietikon, proved to be ideal as it provides the plant with sewage gas from the WWTP as a source of CO_2, a nearby electricity producer (incineration plant), and a gas pipeline to distribute the green gas to households. The natural gas network acts as an expandable reservoir in which this renewable gas can be stored until it is required. Excess electricity from photovoltaic installations, for example, can be converted into synthetic gas using Power-to-Gas technology and stored in the gas network until winter. "With our project, we want to demonstrate the effectiveness of the technology for converting energy into gas and set the stage for many more installations of this type," says Di Lorenzo.

LIMECO
www.limeco.ch
thomas.dilorenzo@limeco.ch

SOHHYTEC

Making fuel from the sun

SoHHytec specialises in optimising the production of solar energy and fuel with technology that is set to help various industrial players step up their ecological transition.

Producing hydrogen, electricity and heat using only water and energy from the sun might seem like magic, but the Lausanne-based company SoHHytec is close to achieving this scientific feat. The technology is promising, and the company's CEO estimates that this new hydrogen production process will reach break-even point in two to four years. Producing industrial quantities of hydrogen is nothing new, but as it stands, the sector is far from exemplary in terms of its sustainability and energy efficiency: more than 95% of current worldwide production (still) relies on the use of fossil fuels.

In its new approach to the production process, SoHHytec has come up with a game changer. The company is advocating a paradigm shift, calling into question the mass production of hydrogen in huge production plants for transport to its final destination. "The transport costs are two to three times higher than the production costs," says Saurabh Tembhurne, CEO and co-founder of SoHHytec. "Our approach takes the opposite tack, making use of lighter production infrastructures that favour a decentralised system in which hydrogen is produced as near as possible to where it will be used, using a completely clean, green method."

A PROTOTYPE ON AN INDUSTRIAL SCALE

SoHHytec is going even further by basing its production process on an environmental approach. The principle involves using a parabolic collector to concentrate sunlight, which is then used to separate the chemical elements of water in the revolutionary photo-electrochemical device developed by the company. This device produces hydrogen and oxygen along with electricity and heat – and zero CO_2 emissions.

The industrial-scale prototype built by SoHHytec has been successfully tested at EPFL since 2019 and could be installed in urban areas to supply electricity to homes. It could also be used in industrial operations and to supply production machinery and infrastructures, particularly on mining sites and in steel production plants.

After winning several Swiss competitions encouraging innovation, SoHHytec has now embarked on a number of partnerships with industrial groups in Switzerland and India.

SOHHYTEC
www.sohhytec.com
saurabh.tembhurne@sohhytec.com

STOR-H BY AAQIUS

Hydrogen in a can

Stor-H has developed a storage standard for green hydrogen in the form of a plug-and-play cartridge. A unique solution for carbon-free and battery-free mobility.

Through its work on gas storage, Aaqius has been piloting research into non-pressurised (and therefore explosion-risk-free) hydrogen storage in small cartridges. Some 155 patents later, its spin-off Stor-H was established in 2017 to take the development of a technology set to considerably speed up the transition to carbon-free mobility to the commercial production stage. “Stored in a gaseous state in a complex solid matrix, the hydrogen is converted into electricity in a fuel cell to power an electric vehicle,” summarises Stéphane Aver, CEO of Aaqius. The whole thing fits inside a can-sized cartridge that will slot into any electric vehicle fitted with the ‘Powered by Stor-H’ module.

The options for recharging the cartridges will be centralised chargers (for example in Geneva, in collaboration with the utilities company SIG), cartridge dispensers, or a home charger the size of a large espresso machine that uses demineralised water. “No charging terminals, no service stations and no constraints for the local authority,” says Stéphane Aver. With a lifetime of about 10 years (5,000 charge/discharge cycles), the cartridges will be available in two formats depending on the size of the vehicle and how intensively it is used.

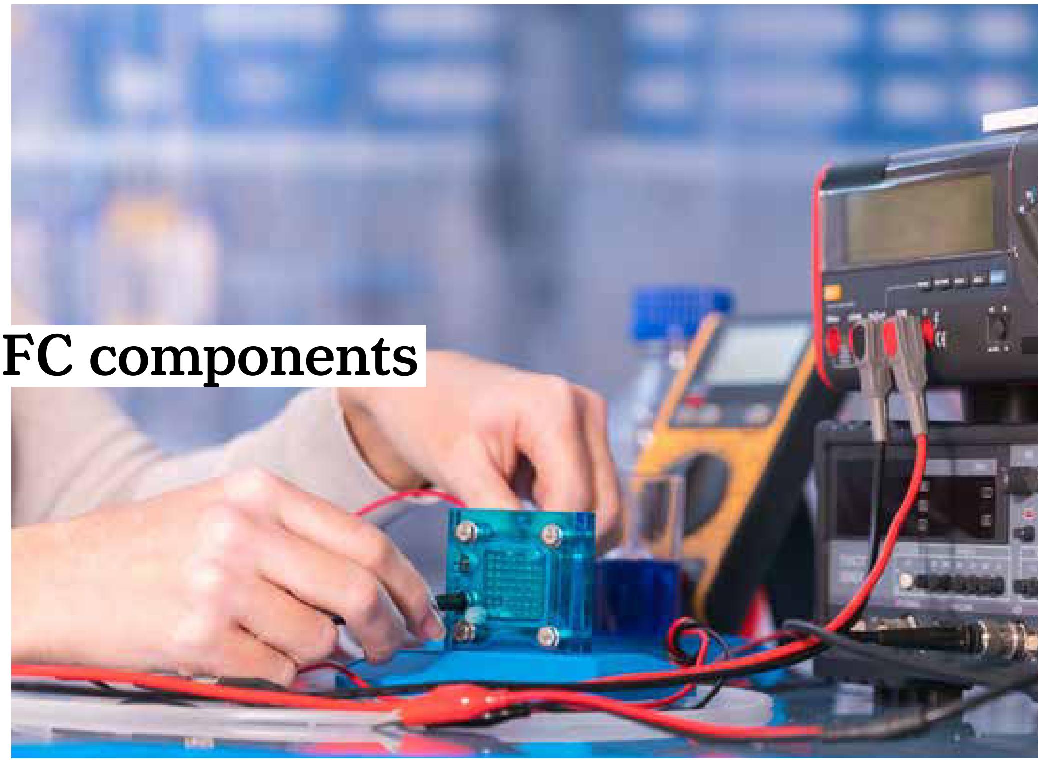
2021: INTERNATIONAL ROLLOUT BEGINS

For now, the technology can be used only in urban vehicles weighing less than a tonne. A three-wheeler cargo bike project, in partnership with the manufacturer Cycleurope, was unveiled in Geneva in 2019. This will be followed by bicycles, three-wheeled stand-up scooters, motorcycles, scooters, cars and even small utility vehicles, developed in collaboration with a dozen manufacturers, including Peugeot Motocycles (PMTC), No Smoke and Mob-ion. Distribution agreements have already been signed in several countries, with more to come in time for the big rollout in 2021 in various locations including Geneva, Morocco, Dubai, France and even China, where Stor-H signed agreements with several municipal councils at the end of 2020.

At the beginning of 2020, the company finalised a 10-million-euro funding campaign, with a second one – for 20 million euros – in the pipeline for 2021/2022. This will fund the investment required to accelerate development and triple the company’s workforce from the ten or so people it currently employs. “We will gain momentum as the numbers of cartridges manufactured grow and the commercial production of suitably equipped vehicles steps up,” says Stéphane Aver confidently. Stor-H is targeting a turnover of CHF 400 million in 2026.

STOR-H
www.aaqius.com
anne.mandron@aaqius.com

FIAXELL



Optimising SOFC components

Having thus far made most of its income from selling fuel cell testers, Fiaxell is now focussing its R&D on optimising solid oxide fuel cell components.

Solid oxide fuel cells (SOFCs) use air and a gaseous fuel to produce both electricity and heat. This technology is very promising for stationary applications, particularly in the field of high-efficiency combined heat and power production. One advantage of these systems is that they will take most fuels and have a high tolerance to carbon residues. “Unlike polymer electrolyte membrane (PEM) fuel cells, SOFCs directly convert a renewable fuel – usually biogas or bioethanol – into ‘clean’ electricity with a high yield of around 60%,” explains Raphaël Ihringer, Director of Fiaxell. This EPFL spin-off founded in 2008 is focusing its R&D on optimising the different components of SOFCs (cells, interconnectors, protective layers and seals) to maintain performance at temperatures of between 600 and 900°C and for power ranges of 0.5 to 5 kW. “It’s a niche market that has not yet reached maturity. We are looking for the Holy Grail that will ensure our expertise comes out on top!” Fiaxell is targeting high-efficiency electricity production with the use of residual heat in smart heating systems.

WINNING OVER INDUSTRY

The company is currently making most of its money marketing its fuel cell testers. Well established internationally (with 99% of its customers abroad), it is collaborating with several universities and research institutes that use its testers on their test benches. In a market shared with 10 to 15 serious competitors, Fiaxell is now keen to convince the major industrial players that its technology really works. The company recently signed its first collaboration contract, with a British company. Its objective for the coming years is to develop fully digital testers with higher power outputs. In parallel, Fiaxell is conducting research on new components and materials in a major project in collaboration with several European universities in France, Norway and Poland.

FIAXELL SÀRL
www.fiaxell.com
raphael.ihringer@fiaxell.com

RÉALINOX

Electrolysis cells with high potential

Réalinox develops ammonia electrolysis cells (AECs) for very-high-pressure electrolysers, a new and very promising link in the hydrogen production chain.

Laurent Escoffier, Director of Réalinox, says that stacks are old hat and AECs are the new thing! Not a field of research one would expect from the boss of a sheet metal working company that specialises in making industrial equipment. Laurent Escoffier began his foray into hydrogen in 2019. "I was working on a prototype electrolyser for a customer and we were short of one part to make it work. So I developed it, and then patented it." In March 2020, his electrolysis cell – a mechanical part made of metal capable of withstanding pressure of 150 bar – won the innovation prize for the Nyon region. That same year, he was also awarded funding by the canton of Vaud's economy and innovation promotion department.

KEEPING UP THE PRESSURE

Réalinox's objective is clear: using high-pressure technology to boost efficiency while reducing hydrogen production costs. "Most stacks don't operate at very high pressure," says Laurent Escoffier. If you're aiming for the mobility market, that's a problem: trucks use hydrogen at 350 bar, and in cars that figure can be as high as 700 bar. Conventionally produced hydrogen therefore has to be fed through big compressors, which increases both energy consumption and production costs. Another issue raised by Laurent Escoffier is that stacks get hot – unlike AECs. "These cells can maintain a pressure of 30 bar at constant temperature," he adds.

To carry out the validation tests that will enable him to sell his product, the entrepreneur is going to have to be creative, because there's no machine powerful enough to withstand tests at that pressure. Or at least, not yet! So, for now Laurent Escoffier is looking at selling his cells for applications at below their actual capacity, for use in new electrolysers or to replace existing stacks. He plans to invest the money he makes from this into manufacturing his test machinery. Laurent Escoffier is aiming specifically to produce green hydrogen using renewable energy sources such as photovoltaic energy and steam from deep boreholes.

RÉALINOX
www.realinox.ch
realinox@realinox.ch

SOLIDPOWER SA

Compact and extremely efficient

SOLIDpower SA develops, manufactures and markets a micro-CHP (combined heat and power) system. Based on high-temperature fuel cell technology, it enables electricity and heat to be produced in residential and commercial buildings.

The BG-15 system from SOLIDpower SA is installed in almost the same way as a regular boiler: it just needs to be connected to the gas and water to produce continuous electricity. It could be of particular interest to small shops and hotels, where appliances such as freezers need to be powered around the clock. Antonello Nesci, the company's General Manager, says it has an energy efficiency of 60% (or even 85% if waste heat is used to heat water), a level unmatched by any other system anywhere. "As a comparison, a gas turbine has an efficiency of 30%. What's more, our system halves CO_2 emissions compared to a conventional gas boiler," says Nesci.

While the company's main target markets are Germany, Italy and Belgium, it also has its sights on Switzerland, where it is targeting electricity producers: they are then responsible for installing the systems and reselling the electricity to their customers. The fuel cells are produced in Italy (with a capacity of 50 MW, this country is one of the largest manufacturers in Europe); assembly and sales are in Germany; and research and development activities, in Yverdon-les-Bains. The EPFL spin-off, created in 2000, develops and tests the fuel cells of the future there, with modules of 25 kWe and more, against today's 1.5 kWe. "By 2022, we aim to be ready for industrial applications that require more power, with fuel cells that can be assembled in parallel," says Nesci.

REVERSIBLE FUEL CELLS

SOLIDpower (still) uses natural gas. Nesci argues pragmatically that a transitional solution is needed to reduce electricity production from fossil fuels, given that Switzerland still imports German electricity from coal-fired power stations in winter. For the future, he is counting on the EU's vision of eventually replacing all natural gas pipelines with hydrogen: "Our machines will be ready, with minor adaptations, to run on green hydrogen."

On that note, these fuel cells also work in reverse mode by transforming water vapour into hydrogen (electrolysis), thanks chiefly to excess electricity produced by solar panels. The hydrogen is then stored in the grid for reuse by the cell. Current tests already allow an efficiency of 95%.

SOLIDPOWER SA
www.solidpower.com
antonello.nesci@solidpower.com

Hydrogen on land and sea

Swiss Hydrogen SA is an important player in PEM fuel cell technologies. Acquired by the French automotive supplier Plastic Omnium, it now focuses its activities on rechargeable hybrid vehicles.

The fifteen or so employees of Swiss Hydrogen have carried out projects as diverse as they are emblematic, such as the delivery of the fuel cell system for Coop's very first hydrogen truck and the installation of a hydrogen chain on the Race for Water catamaran. "Our strength lies in designing a specific system that will be integrated into the final application, whereas most of our competitors develop standard systems," says Alexandre Closset. The former CEO of Swiss Hydrogen, Closset has held the position of Business Line Director Fuel Cell Systems since the company was acquired by Plastic Omnium, a major player in fuel systems for automobiles.

"Since then, we have set aside our electrolysis and marine activities to focus on fuel cells for road transport," says Closset. They have their sights set on plug-in hybrid utility vehicles (battery/hydrogen): "I am confident of hydrogen's potential for logistics companies. They are doing well and want to reduce their CO_2 emissions. Hydrogen cars also have some significant advantages over batteries: weight and charging time. You can fill up in a few minutes."

A HYDROGEN PIONEER

And, when it comes to hydrogen, Closset knows what he is talking about: as early as 2010, he was responsible for developing fuel cells for the hydrogen-powered car so dear to the heart of Nicolas Hayek, head of the Swatch Group. In 2016, Swiss Hydrogen entered into a technological partnership with the Race for Water Foundation, whose boat is the largest solar-powered vessel ever to be equipped with a hydrogen system of this kind. "It was a sort of 'mission impossible' to design such a complex system in just a few months when it normally takes us two years," says Closset. "Everything had to be done from scratch, but we succeeded! We were the first to produce a hydrogen system certified for a boat." With the acquisition of Swiss Hydrogen by Plastic Omnium at the end of 2017, the company has found the industrial power needed for the large-scale production of fuel cells for land vehicles.

SWISS HYDROGEN SA
www.swisshydrogen.ch
info@swisshydrogen.ch

40-ton trucks switch to green hydrogen

GOH! is a 100% Swiss hydrogen initiative. The people behind the programme are working to set up a local, integral and sustainable energy industry that covers every aspect of the energy transition in the heavy mobility sector (40-ton trucks powered by fuel cells).

Encompassing production, distribution and consumption, GOH! is a pioneering experiment accompanied by a major hydrogen industry training initiative. Four Swiss companies in a consortium led by a foundation are involved in this pilot project, which aims to provide solutions to the new challenges facing the haulage industry.

Stepping up the use of locally produced green hydrogen by the road haulage industry: this is the ambition of the GOH! (Generation Of Hydrogen) project. And hydrogen is something that Jean-François Weber, Managing Director and R&D Director at GreenGT – a company that specialises in high-power electric-hydrogen propulsion solutions – knows a great deal about. Realising the limited capacities of batteries in powering heavy goods vehicles, he began looking into hydrogen solutions as early as 2010.

In 2014, Jean-François Weber met the managing director of the Migros supermarket chain in Geneva, who expressed an interest in this alternative way of delivering goods. Together, they analysed the costs involved in operating a local integrated system with a 40-tonne truck. They worked out that by 2030, hydrogen will be more profitable than diesel, partly because it is exempt from the heavy goods vehicle tax. In November 2018, they launched a pilot project through a consortium – "to be as efficient and convincing as possible," says Jean-François Weber.

UP TO 100 TRUCKS A YEAR

The utilities company Services industriels de Genève (SIG) will produce and supply the green hydrogen, Migrol (a Migros subsidiary) will distribute it, and LARAG will manufacture the trucks equipped with a drivetrain powered by a hydrogen fuel cell, technology conceived, developed and integrated into a Kamaz chassis by GreenGT. Nomads Foundation's role has been to bring skills training professionals into the programme and identify all the skills training and professional conversion aspects of this new sector.

A first truck was unveiled at the Swiss commercial vehicle show in Bern at the end of 2021. After six months of operation in 2022, manufacture of the first trucks will begin, and they should be out on Swiss roads by late 2022 to early 2023. "There's big demand," says GreenGT's R&D Director. "At the moment, we're the only ones producing for the 40-tonne hydrogen market." LARAG says it will be able to manufacture up to 100 trucks a year.

GOH!
www.goh.ch
info@goh.green

Bibliography

- OFEN, Perspectives énergétiques 2050+, novembre 2020, actualisé 30 mars 2021
- OFEV, Stratégie climatique à long terme de la Suisse, 27 janvier 2021
- Communiqué de presse Gaznat, 25 septembre 2020
- Communiqué de presse Fondation nomads/GreenGT/Romande Energie/Realstone group, 21 septembre 2021
- Communiqué de presse Groupe Corbat, 9 juin 2021
- Hydrogen Council, Path to hydrogen competitiveness - A cost perspective, January 2020
- Hydrogen Council, Hydrogen Insights – A perspective on hydrogen investment, market development and cost competitiveness, February 2021
- Project USCFlexstore : Underground Sun Conversion (underground-sun-conversion.at)
- Dossier Hydrogène, Efficience 21, no35 Hiver 2021
- E4tech, Swiss Hydrogen & Fuel Cell Activities – Opportunities, barriers and public support, October 2014
- Roger Nordmann, Le plan solaire et climat, 2019
- Dossier Hydrogène PME magazine, décembre 2020
- IEA, The Future of Hydrogen – Seizing today's opportunities, June 2019
- IRENA, Hydrogen : a renewable energy perspective, September 2019
- Greenpeace Energy, Blauer Wasserstoff – Perspektiven und Grenzen eines neuen Technologiepfades, Januar 2020
- AFHYPAC, Pour un plan national hydrogène ambitieux et cohérent, 21 juillet 2020
- OFEN, Recherche énergétique et innovation, rapport 2020
- LUT University/SolarPowerEurope, 100% Renewable Europe – How to make Europe's Energy System Climate-Neutral Before 2050, April 2020
- Agora Energiewende, Making renewable hydrogen cost-competitive – Policy instruments for supporting green H2, July 2021
- Grid View : gridview.planair.ch
- Portail des acteurs hydrogène suisse : Recherche et technologie suisses sur l'hydrogène et les piles à combustible (energyresearch.ch)
- Eniwa AG, Bioboost Flexibler Biogas-Booster, Zwischenbericht vom 15 Juni 2020
- ADEME Magazine, l'hydrogène en transition, Avril 2021 #144
- GREENTECH Cluster, Green Tech Radar, Oktober 2020
- E4tech, Swiss Hydrogen Production and Demand – an overview, July 2018
- WEC, Hydrogen Study : International H2 Strategies, 22 September 2020
- Swissquote magazine 64, septembre 2020
- E4tech, The Fuel Cell Industry Review, 2020
- Projet CHIC : Clean Hydrogen in European Cities | CHIC Project | Fact Sheet | FP7 | CORDIS | European Commission (europa.eu)
- Projet The Bee : https://www.coop.ch/fr/entreprise/medias/communiques-de-presse/2020/coop-met-d-autres-camions-a-hydrogene-sur-les-routes.html
- Projet Mission H24 : https://www.missionh24.fr/
- Projet STORE&GO, https://www.storeandgo.info/
- Projet Limeco : https://www.powertogas.ch/
- Projet DEMO4Grid : https://www.demo4grid.eu/
- FCH JU, Hydrogen Roadmap Europe, 2019 : Hydrogen Roadmap Europe_Report.pdf (europa.eu)

DOWNLOAD PUBLICATIONS
OF CLEANTECHALPS !

ARI–SO
Association Réseau Innovation
Suisse Occidentale

CleantechAlps is an initiative of the Cantons of
Bern, Fribourg, Vaud, Valais, Neuchâtel, Geneva and Jura.
Supported by the SECO under the New Regional Policy (NRP).

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Economic Affairs SECO

INNOVAUD

SWITZERLAND GLOBAL ENTERPRISE
enabling new business

Cleantech ALPS
Western Switzerland Cleantech Cluster

www.cleantech-alps.com
info@cleantech-alps.com