

Swiss Hydrogen Association

**Hydropole**  
since 2001



# **HYDROGEN REPORT SWITZERLAND 2026**

25<sup>th</sup> anniversary of Hydropole



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# Hydrogen

## The key element for power-to-X



**Prof. Andreas Züttel**  
Hydropole president

Over the past 25 years, the world's population has grown by 30% and food production has increased by 50%. Demand for hydrogen has more than doubled since 2000 and now stands at little less than 100 Mt per year (less than 4000 TWh/year). Hydrogen has been given colors depending on how it is produced and how much CO<sub>2</sub> is emitted in the process.

Hydrogen plays two very different roles. On the one hand, hydrogen is a chemical product that represents an essential part of organic chemistry, is used as a reducing agent and used to produce ammonia. Alongside oxygen, hydrogen is the second element in water. Hydrogen is used in space travel as fuel in rocket engines and for fuel cells. On the other hand, hydrogen is the link between renewable energy and chemical energy carriers, so it can be used to store renewable energy. The advantage is that hydrogen can be selectively produced from water via electrolysis and has the highest gravimetric combustion enthalpy of all known fuels. Hydrogen contributes 50% to the calorific value of petroleum and 66% to that of natural gas. Analogous to nature, where in plants during photosynthesis the absorbed solar energy is first transferred to hydrogen and then the CO<sub>2</sub> is converted into carbohydrates with the hydrogen, technical processes can also be used to produce hydrocarbons from hydrogen and CO<sub>2</sub>, i.e. to produce synthetic oil. Theoretically, all electrical energy could be converted into hydrogen, but conversely, there is a thermodynamic upper limit of 83% for the conversion of energy into hydrogen in electricity. Today, the technology is still far from this upper limit, with electrolysis at just over 60% and fuel cells at around 50%.

What role will hydrogen play in the future? Most traditional applications will continue to require hydrogen; in refineries, demand depends on the volume of petroleum products produced. With the energy transition, i.e. increasing electrification and production of renewable electricity, the need for storage and synthetic energy sources will increase, and with it the demand for green hydrogen. With each conversion step, some

of the renewable energy is lost, which is why hydrogen is the most efficient chemical energy carrier, but unfortunately it is costly and bulky to store. On the other hand, the production of synthetic oil involves a great deal of energy loss, but the oil is very easy to store and transport, partly because the necessary technology and infrastructure are already in place.

Today, we treat renewable energy in the same way as small farmers did before industrialization. Production is decentralized for self-sufficiency, and in winter there is a shortage of supply, which is still compensated for today by conventional, mostly fossil-based energy. In the future, we will need a renewable energy industry consisting of producers, large distributors, storage facilities and transport systems (grids) that supply local distributors and provide consumers with both electricity and energy carriers reliably and securely at any time as needed. This requires at least national, if not global, coordination. In this coordinated energy industry, hydrogen plays an essential role as a bridge element for synthetic energy carriers.

We are still a long way from a coordinated renewable energy economy. Today, the focus is primarily on decentralized production such as photovoltaic (PV) on rooftops and applications such as heat pumps and electromobility, because these offer significant efficiency gains without, however, ensuring the supply of renewable electricity. This will lead to more and more electricity being produced at midday in summer, exceeding demand and causing prices to fall, while at night in winter, production will be unable to meet demand, causing electricity prices to rise sharply. Whether hydrogen can contribute to seasonal storage also depends on whether it is possible to build sufficiently large hydrogen storage facilities and produce the corresponding quantities of hydrogen.

Due to the low conversion efficiency from electricity to hydrogen to electricity, covering 25% of the winter gap with hydrogen requires approximately the same amount of renewable energy as the 75% direct supply in the remain-

ing nine months. This means that around 150% renewable electricity must be produced.

In Switzerland we are in a very comfortable situation because due to the wise planning of our ancestors all electricity is produced for a low cost of only around 0.05 CHF/kWh by hydroelectric power plants and nuclear power plants without any CO<sub>2</sub> emissions. With the energy transition the electricity demand in Switzerland will approximately double. Since we are consuming more electricity in winter than in summer and photovoltaics produces four times more electricity in summer than in winter, Switzerland needs to shift around 20 TWhel. from summer to winter. This is the key component allowing an energy transition to mainly renewable energy. Without such a seasonal storage Switzerland needs to produce the electricity in winter with nuclear power plants or with thermal power plants.

The coming 25 years will decide on how the world is powered in future. Hydrogen is going to play an increasingly important role with a lot of opportunities for new advanced technology in the hydrogen energy economy. Especially the improvement of the conversion efficiencies and the availability of low cost large scale hydrogen storage has a significant impact on the future role of hydrogen.

Sion, 23. June 2025



## Table of contents

06	History of Swiss hydrogen production and utilization
16	Hydrogen market, application, trade and distribution
18	EPFL Laboratory of Materials for Renewable Energy
22	GreenGas project: Demonstrating the strategic potential of synthetic gases
24	Institute for Energy Technology: Hydrogen and its derivatives
27	DASH Storage & DASH Power: Industrialization of solid-state hydrogen storage
28	Innovative hydrogen fuel station
30	GRZ's HyCo technology: Hydrogen metal hydrides thermal compressor with low operational cost
32	Empa Digital Twin: A model for planning a hydrogen refueling station
35	Status and outlook of the Swiss Green Hydrogen Ecosystem
39	Hydrogen and fuel cells at OPmobility
40	A green hydrogen production plant in Bulle
43	Reversible hydrogen storage: Formic acid hydrogen storage
44	Cracking ammonia for clean, resilient power
46	Hydrogen for seasonal energy storage: The implication of applied education
48	Tube fittings for the energy transition
50	HEIG-VD Institute for Energies: Hydrogen research and activities
52	Decentralized hydrogen hubs to valorise local excess photovoltaic production
54	EasyEnergy's EasyFlex: Innovative hydrogen solution for industrial applications
57	EH Group: Advancing Swiss innovation in fuel cell technology
58	Liebherr Machines Bulle: Developing hydrogen internal combustion engine
60	Nova Werke AG: Shaping the future with high pressure
62	Hydrogen history
70	Hydrogen facts
76	Member introduction

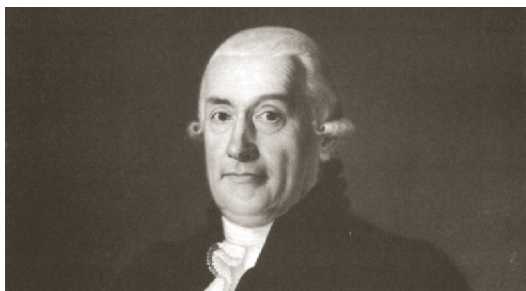
# History of Swiss hydrogen production & utilization



Prof. Andreas Züttel Hansruedi Arnold

## First car running with hydrogen

Francois Isaac de Rivaz served as an officer in the French army and lived in Switzerland after his retirement, where he became a naturalized citizen.



Francois Isaac de Rivaz (1752–1828).

In 1806, Rivaz built an internal combustion engine, for which he was granted Paris patent no. 731 on 30 January 1807. This authorized him to use explosive combustion instead of steam to power his machines.

The engine worked with an ignitable mixture of coal gas, hydrogen and air. It was ignited electrically in the cylinder by a spark and the combustion drove a heavy piston upwards. A rack was attached to this, the teeth of which engaged with a cogwheel when the piston fell. This cogwheel then drove a pair of wheels via a cable. The piston was propelled upwards by the force of combustion; the work was performed by the weight of the falling piston and the air pressure acting on the piston from above.



Painting of the first hydrogen car.

In 1813, de Rivaz experimented with a carriage powered by this engine. By today's standards, it looked more like a carriage. The engine pro-

duced 25 consecutive ignitions, each of which had to be triggered individually by hand. Rivaz actually managed to drive the carriage a few hundred meters in Sion. It is the first journey by a fuel-powered vehicle with an internal combustion engine in the history of technology.

## Fuel cell invented

The basic principle of later invented fuel cells was described in 1801 by Humphry Davy. The first experimental demonstration of the fuel cell operation was performed by the German-Swiss chemist and physicist Christian Friedrich Schönbein in 1838 and published in the January 1839 edition of the *Philosophical Magazine*. He detected a voltage by dipping two platinum wires into a sulfuric acid electrolyte and applying flows of hydrogen and oxygen gases around them. It should be noted that Schönbein was only demonstrating the concept, while much more work was done after him by Sir William Grove. Grove was a more practice-oriented man: he intended to use the fuel cell effect and designed a "gas battery" between 1842 and 1845. Therefore, the major credit for inventing fuel cells has been given to him, while the original work of Schönbein was forgotten. Notably, the "fuel cell" term was not used at that time and it was coined later in 1889 by Ludwig Mond and Charles Langer.

are combined without detonation, (Schönbein called  
 invisible combustion, the advantages are simplicity  
 & absence of danger & the gases may be combined with  
 too much & diluted & detonate, as it happens with  
 the bombs of an electric machine & the little  
 apparatus (2 of my 2 nicholson elements) which seems  
 to heat the wire also seems to produce by decomposition  
 the required measure of pure hydrogen, the  
 electrodes in the decomposing apparatus are of course divided (a porous  
 & diaphragm) & I think the gases are collected separately  
 the platinum wire should be fine or it will crack the glass  
 should the gases detonate there was danger as the  
 tube is not closed but the extreme light in the bottle  
 shows hydrogen & detonates then it will once before the tube  
 I should like you to try it & give me some opinion on  
 it - I hope you find Schönbein's & your children  
 in good health on your return, my family are thank you  
 well & give their best regards & believe me & ever  
 believe me  
 your very friendly  
 W. Grove  
 of the allegory of the top of the diploma

Letter of Schönbein to Grove.



Christian Friedrich Schönbein (1799–868).

### Hydroelectric power plant in Gampel

The first water rights concessions were granted in Valais in 1890. The Lonza was also an ideal source of water for generating energy. An interest group was founded in Basel to exploit the hydroelectric power of the Lonza. After tough negotiations with the municipalities of Steg and Gampel, the concession was finally granted at the second attempt on 2 March 1897. Shortly afterwards, "Lonza Elektrizitätswerke" was founded for the production of calcium carbide ( $\text{CaO} + 3\text{C} \rightarrow \text{CaC}_2 + \text{CO}$ ) and acetylene. In 1909, the company moved to Visp, where it initially produced synthetic fertilizers from acetylene and nitrogen.

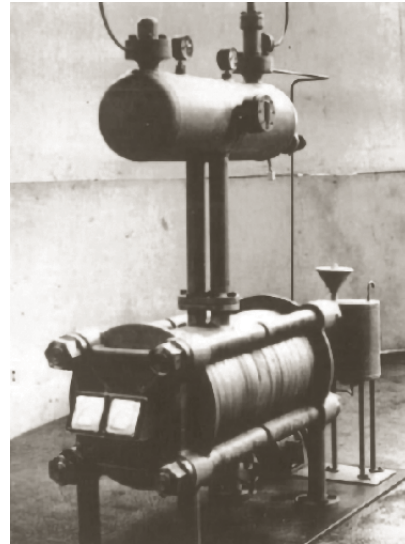


Hydroelectric power plant in Gampel (1898).

### Pressurized electrolyzer

1948, the Swiss company Lonza, based in Visp, having long experience of water electrolysis as a user, decided to build its own pressurized electrolyzers.

Lonza hired Arnold Ewald Zdansky, a Czech engineer who had worked for Bamag-Meguini in Germany before the war, where he patented an electrolyzer in 1937. It had taken him three years to develop a cell 1.6 m in diameter and 13 mm thick, operating at 30 bar. Zdansky was delighted to find that Giovanola Frères SA, in Monthey, had a competent workshop in the Valais to manufacture these large mechanical parts, with the collaboration of his engineers, who built special mechanical machines for themselves and for the inventor's highly complicated parts.



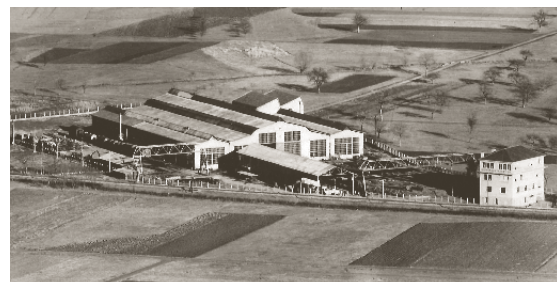
Water electrolyzer in 1937.

In 1951, a pilot plant electrolyzer comprising 25 cells was built. In 1956, the largest pressurized electrolyzer ever was built: 660 cells, 12 m long. All the tests were carried out in Achersand, close to a power plant at the start of the ascent to Stalden in the Vispental, far from the Lonza chemical plant in Visp (danger of explosion!).

### The history of the "Giovanola" company

Joseph Giovanola (1857–1904) hails from the Italian village of Fomarco. As a child, he settled in Monthey with his parents. Joseph became a blacksmith and married Isaline Donnet, a Monthey woman. In 1888, he set up a workshop in a former clock factory to manufacture quarry tools, carpentry tools and building locksmiths' tools.

Like other Monthey industries, the workshop took advantage of its location on the quay of the Vièze, a river flowing from the Val d'Illeiez, by using waterwheel power. With three workers at the outset, the company soon expanded and had to move to another site.



Giovanola site in Monthey in 1946 (top) and 1962 (bottom).

When Joseph died in 1904, the business was taken over by his wife and sons, the eldest of whom, also named Joseph, was only seventeen. In 1913, the three brothers Joseph, Louis and Théodule created the general partnership "Giovanola Frères", specializing in structural steelwork and boiler making. Constantly expanding, the company was forced to relocate, and in 1930 built its new factory at "Clos-Donroux" in Monthey. This site gradually became home to some twenty different halls, representing a maximum workforce of 800 by 1961. The end of dam construction led to a reduction in the company's production volume. On 12 December 2000, a weld in the penstock installed by Ateliers Giovanola in the Cleuson-Dixence hydraulic structure in the Valais region of Switzerland failed, which led to its bankruptcy in 2003.

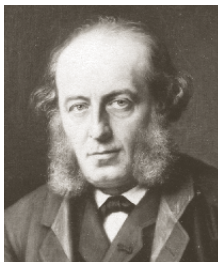
### Production of synthetic sapphire

Hrand Djevahirdjian (1880–1947) was a member of the Mechitaric College in Venice and a diamond cutter and gemstone dealer in Paris. After Auguste Verneuil produced the synthetic ruby in the 1890s and published it in 1902, Djevahirdjian became enthusiastic about it, was able to realize his first ruby synthesis using the Verneuil method the following year and opened the first Djeva Ateliers in Villeurbanne near Lyon in 1905. In 1908, he founded a factory in the canton of Arudy in the Pyrenees. In addition to Djeva, one factory in Switzerland, one in France and one in Japan worked according to this system. In 1914, he built a new factory Industrie de pierres scientifiques Hrand Djevahirdjian in Monthey, where he was initially able to use surplus hydrogen from the local chemical industry (Ciba-Geigy). He later produced the oxyhydrogen himself by electrolysis. His synthetic stones were used in watchmaking as a substitute for real rubies. In 1924, he changed the company into a public limited company, of which he was chairman of the Board of Directors. From 1934, he was assisted by his nephew, the chemical

engineer Vahan Djevahirdjian (1905–1997), who succeeded him after his death. In 1960, Djeva delivered the first laser rubies to the USA. Djeva in Monthey was Lonza's first and only external customer for electrolyzers. In 1957, Djeva purchased a Type Z-500 pressure electrolyzer with 500 cells, a current density of  $1,200 \text{ A}\cdot\text{m}^{-2}$ , a potential of 465 V corresponding to  $1,860 \text{ kW}$  producing  $450 \text{ m}^3 \text{ H}_2/\text{h}$  ( $40 \text{ kg/h}$ ).

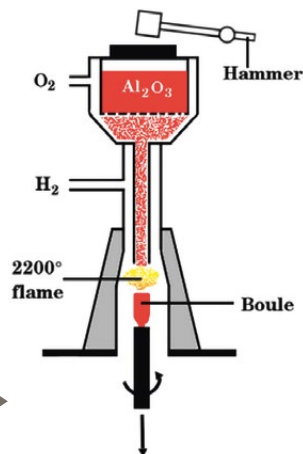
### From Zero Gap to the New Lurgi Pressure Cell

Lonza sold the exclusive license for its process to the German engineering company Lurgi in Frankfurt in 1958. Later Lurgi also made a contract with Giovanola in 1968. The development work on the electrolysis was then carried out in close cooperation with the laboratories of Metallgesellschaft AG (Chemetall and Metall-Laboratorium) and patented in 1979. The catalyst structure is achieved by coating a metal sheet with metal powder and subsequent cold roll cladding. Work on the development of a new generation of pressure electrolyzers for the production of hydrogen from water was started in 1982 and from 1989 the development program was carried out as part of the BMFT project "Development of an advanced water electrolyzer". The Metall-Laboratorium is a subcontractor of Lurgi, which transferred the electrolysis activities to its subsidiary Lurgi Bamag GmbH in Butzbach in 1992. The development of an advanced alkaline pressure electrolyzer for hydrogen production was aimed at replacing the diaphragm and other components made of asbestos-containing materials, the processing or use of which is no longer permitted in many countries after 1995, and increasing the efficiency of electrolysis by up to 20% by increasing the electrode surface area through micropores and reducing the electrode gap from 5 to 0.5 mm. In January 1984, Lurgi signed a license agreement with Forschungszentrum Jülich (KFA) for the use of nickel oxide diaphragms in water electrolysis plants.



Auguste Victor Louis Verneuil (1856–1913).

Process for synthetic Sapphire after Verneuil. ▶



Hydrogen storage tanks (30 bar) at Djeva in Monthey.



Serie of furnace for the production of synthetic sapphire at Djéva in Monthey.

### Import of electrolyzers from Lurgi

DEJVA purchased 1982 and 1991 two Lurgi type S-556 electrolytors (S= Safe, and electrolytor denomination by Lurgi to differentiate the pressurized electrolyzer from the atmospheric electrolyzer) Electrolytors type S-556, four blocks (4 × 139 cells) for 556 cells with a voltage of 542 V and a current of 6600 A, leading to a power of 3.6 MW and a production of 760 Nm<sup>3</sup> H<sub>2</sub>/h with a H<sub>2</sub> purity of 99.8%, corresponding to an energy efficiency of 84%. Technically, these are actually two two-block electrolytors, each mounted back-to-back and electrically connected in the middle, which means that the maximum current for each electrolytor is 3300 A. The advantage of this construction is that the peripheral modules (transformer, rectifier, pumps, gas separator, control valve and all control and safety equipment, etc.) are housed in a single room.



Electrolytors type S-556, four blocks (4 × 139 cells) for 556 cells with a voltage of 542 V and a current of 6600 A.



The Lurgi-test-ectrolyser with 100 SE-cells in the production.

### Hydrogen powered house and mobility

The hydrogen-powered house of Markus Friedli in Zollbrück, Switzerland, is a pioneering project in renewable energy and hydrogen technology. Markus Friedli, an architect and self-taught solar energy expert, converted his house into a hydrogen-powered building in 1990. At the time, it was the only such residential building in Europe. The house is equipped with photovoltaic panels that generate electricity from solar energy. Excess electricity is used to produce hydrogen through electrolysis. The hydrogen produced is stored in specialized tanks for later use. The stored hydrogen powers household appliances and a minibus owned by Friedli. The minibus can switch between hydrogen, gasoline, and liquid gas as fuel sources. The system allows the house to operate largely independently from external energy sources. This project demonstrated the feasibility of using hydrogen as a sustainable energy source for residential purposes. It showcased how renewable energy could be stored efficiently and utilized for both stationary and mobile applications. Friedli's work remains a notable example of early innovation in integrating solar and hydrogen technologies



House and minibus of Markus Friedli in Zollbrück.

### Lurgi decides to close the electrolysis department

Heinz Schimmelbusch discontinued in the year 2000 the development of electrolyzers due to a shift in focus toward other business priorities, particularly in the field of advanced materials and renewable energy solutions. After his tenure at Metallgesellschaft AG, Schimmelbusch concentrated on ventures such as AMG Advanced Metallurgical Group N.V., where he emphasized technologies that contribute to CO<sub>2</sub> reduction, including lithium refining for electric vehicle batteries.

The decision to halt electrolyzer development likely reflects strategic business considerations, including market demand, profitability, and alignment with emerging industries like electromobility and energy storage. Schimmelbusch's current focus on lithium hydroxide production underscores his pivot toward materials critical for the energy transition rather than hydrogen technologies.

### The Dixence accident

On 12 December 2000, the underground pressure pipe that transports water from the Grande Dixence dam to the Cleuson-Dixence plant burst. The rupture occurred along a 9-meter length, with a split width of up to 60 cm, and was exacerbated by additional weaknesses in the material. Investigations revealed deficiencies in the welding seams and overall construction quality. These structural issues ultimately led to the catastrophic failure when subjected to high water pressure. Approximately 27,000 m<sup>3</sup> of water escaped, causing significant destruction, including landslides, damage to infrastructure. Three people lost their lives. The plant was subsequently shut down. The repair work then took a total of four and a half years. According to the electricity company Alpiq, 600 employees were working around the clock. More than 1,300 prefabricated steel cylinders were transported from Linz in Austria to Valais – around 12,500 tons of steel. The costs amounted to 365 million Swiss francs.

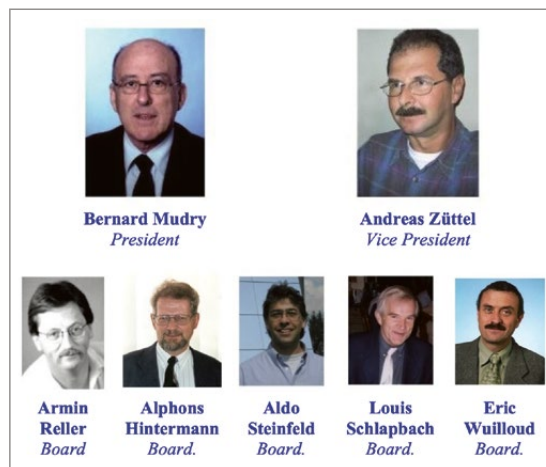


Below the water lock Tracouet, where the accident happened.

The cause of the rupture in the pressure pipeline at the Dixence power plant in December 2000 was primarily attributed to structural failures in the steel lining of the pipeline. Specifically, a longitudinal seam burst, leading to a crack that extended over multiple sections of the pipe. The rupture occurred along a 9-meter length, with a split width of up to 60 cm, and was exacerbated by additional weaknesses in the material.

### The founding of Hydropole

After Lurgi's decision Hansruedi Arnold, working at Djéva, realised the importance to unite the hydrogen activities in Switzerland. On 23 November 2001 the Swiss hydrogen association named Hydropole was founded at the Paul Scherrer Institute (PSI) in Villigen. Bernard Mudry (president), Andreas Züttel (vice president), Alphons Hintermann (member of the board), Eric Wuilloud (member of the board), Armin Reller (member of the board), Louis Schlapbach (member of the board), Aldo Steinfeld (member of the board). From 26 November 2004 on Prof. Dr Andreas Züttel is the president of Hydropole and after solving the initial difficulties with the administration Hydropole became the National Hydrogen Network bringing academia, industry and economy together.



Hydropole funding board members, 23 November 2001 at PSI in Villigen.



General assembly on 26 November 2004 at Djéva in Monthey.

### The funding of a new electrolyzer company

After the closure of Giovanola Frères S.A. in 2004, the young engineers of GTECH, a sub-enterprise of Giovanola since 2000, founded the company IHT (*Industrie de Haute Technologie*) on 1 September 2003, which started operations one year later. A group of fifty clients around the world were already in possession of Lurgi electrolyzers. The big challenge was to return the machines to the workshop, which had not been in service for many years. A few revisions of electrolyzers were carried out abroad, but in order to build new electrolyzers, the specialists, know-how and financial support were missing. IHT was able to put the manufacturing workshops back to operation.

### First snow groomer with an ICE and Postbus with Fuel cells.

The first Ratrac running with hydrogen in an internal combustion engine was demonstrated on Kleine Scheidegg in Switzerland on 15 March 2004. The 120kW gasoline engine was modified by Mr Jakob Hertig in Zollbrück to run on hydrogen. The vehicle carried the hydrogen in a metal hydride storage system with water cooling/heating developed by Dr Andreas Züttel and the mechanical workshop at the University of Fribourg. The heat from the combustion was transferred through the water cooling system of the engine into the metal hydride tank in order to desorb the hydrogen. The Ratracs in Switzerland consume ten million liter Diesel every year, therefore, running them with hydrogen has a big impact on the air quality in the Alps.



Ratrac running with hydrogen in an internal combustion engine was demonstrated on Kleine Scheidegg in Switzerland.



Water cooled metal hydride storage for 5 kg of hydrogen was built in the mechanic workshop of the Physics department at the University of Fribourg (2003).

### First fuel cell street sweeper powered by hydrogen

The first hydrogen-powered street cleaning vehicle in Switzerland, the CityCat H<sub>2</sub>, was developed by researchers at the Swiss Federal Laboratories for Materials Science and Technology (Empa) and the Paul Scherrer Institute (PSI). It is a emission free (water vapor) machine equipped with a fuel cell drive with a compressed hydrogen storage and electric motor compressing the oil for the hydraulics.

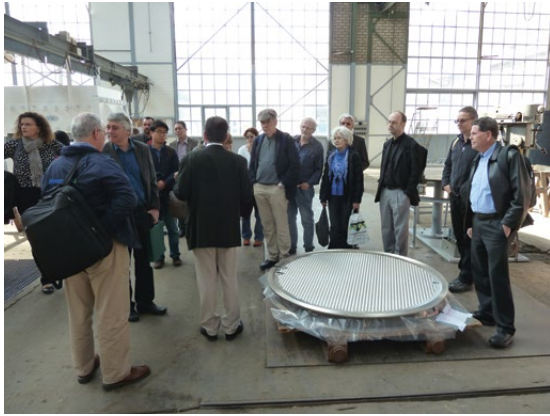
The CityCat H<sub>2</sub> was first tested in Basel in 2009 and was later used in other cities such as St. Gallen. The vehicle can run for up to eight hours on seven kilograms of hydrogen. The aim of the project was to bring fuel cell technology out of the laboratory and into everyday use and to demonstrate its practicality. Despite technical feasibility, the high price of fuel cells and hydrogen storage systems remains an obstacle to widespread market introduction.



CityCat H<sub>2</sub> with compressed hydrogen storage and fuel cell in 2009.

### Hydropole celebrates 10th anniversary on the site of IHT in Monthey.

The Hydropole association celebrated its 10th anniversary in Monthey last year. After the general meeting at IHT, we were able to visit the production facility for the world's largest electrolyzers. In addition to the press for manufacturing the checker plates and the hydraulic lift for assembling the cell stacks, we were also able to visit the somewhat antique-looking but perfectly functioning electroplating facility. We then drove to Djeva and were given an impressive tour demonstrating hydrogen production, storage, and use in the manufacture of synthetic sapphires. What particularly stuck in our minds was the ignition of the many furnaces, which all start burning with a small oxyhydrogen explosion and melt the aluminum oxide. The plant ticks as evenly as a Swiss watch and allows the sapphires to grow from seeds into candle-like crystals. After dinner, Bernard Mudry vividly recalled the history of the association in his presentation. More than thirty members of Hydropole participated in the event.



Presentation of the electrode production in IHT at the 10<sup>th</sup> anniversary of Hydropole in 2011.

### First buses with fuel cells running on Hydrogen in Switzerland

In 2011, Postauto AG put five hydrogen fuel cell Postbuses into operation in the Brugg region. The project, led by Nikoletta Seraidou, represents the first commercial passenger transport using hydrogen in Switzerland, which also has international significance as part of the European project "Clean Hydrogen in European Cities" (CHIC). A hydrogen filling station was built in Brugg to ensure the supply of fuel for the Postbuses. This project was awarded with the Watt d'Or price by the Federal Office of Energy (BFE) on 10 January 2023.



One of five Postbuses in Brugg (2011).



Hydrogen refilling station in Brugg (2011).

### Energieautarke Mehrfamilienhaus in Brütten

The apartment building with nine apartments in Brütten, Canton Zurich, is a globally unique showcase project in the field of sustainable construction. It was initiated by the Umwelt Arena Schweiz foundation and inaugurated on 6 June 2016. The building shows how modern living is possible without external energy sources.

The façade and roof of the building are equipped with highly efficient photovoltaic modules. The modules on the roof are monocrystalline solar cells that achieve an output of 160 W/m<sup>2</sup> and produce around 100 MWh of electricity per year. Lithium-iron-phosphate batteries store the surplus solar power for short to medium-term use (two to three days). They are characterized by high cycle stability, a long service life and an efficiency of over 85%. For long-term storage, excess electricity is converted into hydrogen by electrolysis. This hydrogen is stored under pressure and converted back into electricity and heat by a fuel cell in winter. Part of the solar energy is used to generate heat for heating and hot water with a heat pump. Excess heat is temporarily stored in thermal storage units. An energy management system monitors and optimizes energy production, storage and consumption in the building to ensure maximum efficiency.



Schematics of the energy conversion with PV on the roof and facades and storage in batteries (153 kWh) and hydrogen.



Energy self-sufficient apartment building in Brütten from René Schmid Architekten.

## Fuel cell developments in Switzerland

Switzerland has been at the forefront of fuel cell and hydrogen technology development, leveraging its strong research institutions, innovative companies, and government support. Institutions like ETH Zurich, EPFL, and the Paul Scherrer Institute (PSI) have been pivotal in advancing fuel cell research. They focus on materials, components, and system modeling, as well as hybrid concepts. PSI collaborated with Michelin to develop a light hydrogen-powered vehicle called Hy-Light, which gained international attention. Empa contributes to fuel cell research, particularly in materials testing and efficiency improvements. Swiss Hydrogen SA was a leader in fuel cell technologies, the company has developed systems for diverse applications. Achievements include a 100 kW system for Switzerland's first hydrogen truck and a hydrogen chain for a 100-ton solar boat, a 300 kW system for grid management projects. Sulzer Hexis are early pioneers in stationary solid oxide fuel cell (SOFC) systems.

## Hydrogen storage and compression in metal hydrides

GRZ Technologies SA is an innovative Swiss company specializing in the development and application of hydrogen technologies. GRZ Technologies uses solid-state metal hydrides to store and compress hydrogen. These materials enable safe and efficient storage of hydrogen gas in a highly compressed form that can be released when needed. The company offers modular DASH solid-state hydrogen storage systems for renewable energy storage as well as thermal hydrogen compressors for industrial applications. GRZ has developed a solution that converts raw biogas into almost 100% synthetic methane, doubling the yield of conventional biogas plants. GRZ was founded in 2017 as a spin-off from EPFL and builds on decades of research since the 1990s. The company works closely with partners such as Gaznat and EPFL to promote substitution of fossil fuels with renewable energies.



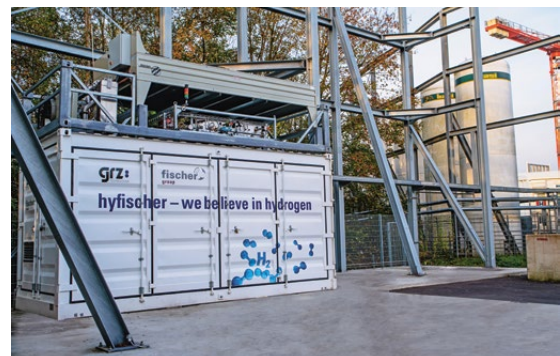
PAC-Car II during the Shell Eco-marathon in Nogaro on 21 May 2005. Using hydrogen as the fuel, PAC-Car II covers a distance of 5385 km with the energy contained in 1l of gasoline.



Metal hydrides hydrogen compressor HyCo with a capacity of 30 kgH<sub>2</sub>/h up to 200 bar developed by GRZ Technologies SA and installed in 2022 on the premises of Messer Schweiz AG on the site of Lonza/Arxada in Visp (Switzerland).



The 30 kW fuel cell powered VW Bora was created 1998. The system was realized in a collaboration of Volkswagen, PSI and ETH Zürich.



DASH Power with an outlet peak power capacity of 500 kW and a storage capacity of 3.5 MWhel installed in 2024 on the site of fischer Edelstahlrohr (Achern, Germany).

### Hydrogen powered trucks from Hyundai

Hyundai Hydrogen Mobility (HHM) has deployed hydrogen-powered Xcient Fuel Cell trucks in Switzerland in 2020. The initial fleet consisted of ten units, later expanded to fifty vehicles. By 2025, Hyundai plans to deliver a total of 1,600 trucks to Switzerland through HHM, a joint venture with Swiss company H<sub>2</sub> Energy AG. The Xcient trucks have collectively driven over 10 million kilometers in Switzerland, saving approximately 631 tons of CO<sub>2</sub> emissions compared to diesel trucks. Powered by a 190 kW hydrogen fuel cell system, these vehicles can travel up to 400 km on a single charge of 30 kg hydrogen. Hyundai is also developing models with ranges up to 1,000 km. Despite initial success, there have been complaints about fluctuating prices for green hydrogen and concerns about supply reliability. Some contracts were reportedly canceled due to rising hydrogen costs.



Import of the first Hyundai Xcient fuel cell trucks to Switzerland (2020).

### IHT was acquired by Sunfire

On 12 January 2021, the company Sunfire of Dresden, Germany, manufacturer of high-temperature, atmospheric-pressure solid oxide electrolyzers (SOEC), announced to acquire Swiss alkaline electrolysis company IHT. With this expansion of the product portfolio, Sunfire strengthens its position as electrolyser producer in the green hydrogen revolution.

At Sunfire, the Lurgi S-556 electrolyzer now bears the name AEL. On 19 February 2025 (four years after the purchase) Sunfire took the decision to close the Giovanola site in Switzerland, information which was passed on 20 February 2025 directly to the 69 employees.



Sunfire's production site in Monthey (2021–2025).



Launch of Kvyreen 80 charger with CE compliance and installation in Avia Volt public charging network in Saint Gallen.

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# Hydrogen market, application, trade and distribution



Dr Hans Michael Kellner  
Messer Schweiz AG

## Short introduction into the history of the gas hydrogen and its applications

Hydrogen is used since the beginning of the industrialization as a burning gas or a lifting gas (Zeppelin) for mobility and weather research purposes. Its actual name is based on the result of a burning process, realized in the late 18th century. Burning of hydrogen generates water: Hydro (water) + gen (generation).

In 1800 hydrogen was produced for the first time with an electrolysis instead of reaction between metals and acids. And few years later in 1806 the first hydrogen combustion motor was developed, which few years later was already tested for mobility purposes. And in the 1830-ies the principle of a fuel cell to produce electricity out of hydrogen was described, in a time when electricity started to be useful for industry and society. This shows, that the most important applications from the actual point of view already existed in the beginnings of the discovery of hydrogen in 1766.

But this gas was too expensive compared to the upcoming fossil fuels and got forgotten. Only at the beginning of the 20th century was hydrogen used again to produce synthetic ammonia. Hydrogen came back into focus of interest as a fuel for rockets and applications in space in the sixties.

## How Messer Schweiz became market leader for hydrogen in Switzerland

C. A. Scharpf Cartonfabrik in Lenzburg, a producer of paper and cardboard since 1891, decided to step in in the gas market in 1911 with an own production, in a time, when oxygen became an important gas for a new joining technology: autogenous welding.

To offer a burning gas the first electrolysis plant to produce 40 m<sup>3</sup>/h hydrogen was installed 1955, followed by a second one in 1960. Both driven by an own hydropower plant. Hydrogen became an alternative to propane and acetylene for the industry. The success of the gas business led to a renaming to Sauerstoffwerk Lenzburg (SL).

Messer Griesheim, a significant and leading gas company in Germany founded 1898, acquired 49% of the company 1971 to expand the gas business with additional gases and processes.

A third electrolysis for hydrogen in 1986 raised the production rate significantly up to 200 m<sup>3</sup>/h.

In that time Solvay in Zurzach was the biggest producer of hydrogen in Switzerland since 1944, with a capacity of 1200 m<sup>3</sup>/h, mainly for own use in a soda factory. But it was also the backup for SL.

16

Hydropole



Hydrogen transport in the 50-ties at Lenzburg site.



Standard hydrogen trailer of gas suppliers.

Towards the market, Carbagas was the biggest hydrogen player, although they hadn't an own production on that time. They got their hydro-gen from various chemical companies, when available, not having a reliable supply. Pangas, the third gas company in Switzerland had a hydrogen production of 120 m<sup>3</sup>/h with two electrolysis. After the failure of one of them, they started to import hydrogen.

The former EMS-site in Dottikon announced their need of a second supplier in addition to Solvay, to ensure their growth. Some other industrial companies were also interested to be supplied with hydrogen. SL started up in 1998 a steam reformer with a capacity of 500 m<sup>3</sup>/h. The process is based on cracking natural gas and can produce hydrogen at far lower costs, giving a big advantage in the market. Only the latest electrolysis remained running for cylinder filling, while the steamre-former with its trailer station supplies till today customers with hydrogen in tube trailer.

In 2003 Messer took over the rest of the shares of the company. After the insolvency of Solvay in 2004 SL advanced to the market leadership for of hydrogen in Switzerland. With the additional sourcing site at Djeva in Monthey with 165 m<sup>3</sup>/h Messer was able to supply the demands of the industry as the successor of Solvay.

Messer initiated the implementation of a network of sources and production sites all over Switzerland. This network enables a stable supply of all kinds of demands, including mobility. With about 4000 t/a of hydrogen Messer Schweiz is the largest provider of hydrogen in Switzerland of all time.

### **From a simple burning gas via numerous industrial applications to mobility**

Since the first delivery, Messer developed different technologies for several branches to promote hydrogen and showed to the industry the ad-vantages of this gas to optimize production processes. Starting as a simple welding gas, the uses of hydrogen find their way in numerous branches. Today hydrogen is a standard gas in the metallurgy, welding technologies, food industry or chemical productions.

Since the nineties Messer participate in single projects of mobility outside their core business. The first fuel station for the first fuel cell car Esoro in Switzerland was built. And from then designing and building pilot H<sub>2</sub> fuel stations for a FC-sweeper (EMPA), busses and forklifts, becoming so an expert in this field.

Together with EPFL and GRZ technologies an innovative fuel station based on metal hydride technology was designed and made market-able. The big advantages of this material started a new era of sustainable refueling and opened ways to further possibilities of use.

Following the principle "demonstration is the best way to convince", Messer invests in newest technologies with focus on economics, safety and sustainability, making hydrogen more attractive to the market and preparing the break-through for hydrogen as the leading energy provider in the coming years.



Hydrogen metal hydride based fuel station for forklifts at Messer in Lenzburg.

### **Summary**

The history of Messer Schweiz AG is coupled to the history of hydrogen when hydrogen started to be popular for industry. The company advanced to the market leadership and accompanied the industry with the development of related new technologies and processes. Promoting innovation Messer prepares step by step the breakthrough of hydrogen as the leading energy supplier.

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# EPFL Laboratory of Materials for Renewable Energy



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## RESEARCH

### Hydrogen storage in metal hydrides

Metal hydrides which consist of Ferrovandium and crystallize in a bcc structure, absorb up to 5 mass% of hydrogen. Around 50% of the hydrogen desorbs at >1bar pressure below 100°C, the other hydrogen only desorbs at temperatures above 300°C. The goal of the ongoing research is to reach the highest possible gravimetric hydrogen density in alloys, where Vanadium is partially substituted by Iron and to destabilize the more stable hydride in order to lower the desorption temperature (figure 1).

### Hydrogen physisorption in nanomaterials

The gravimetric and volumetric hydrogen density in porous and non-porous nanomaterials is determined with a model only based on two material parameters, the material density and the specific surface area. Materials as small particles after synthesis exhibit a packing density of 50% of the crystal density, which significantly reduces the volumetric hydrogen density.

Very few metal organic frameworks (MOFs) exceed the gravimetric and volumetric hydrogen density at 100K of compressed H<sub>2</sub> at 700 bar and 298 K (red area in figure 2). However, some reported data are erroneous, the pore volume in the material is not large enough to host the reported amount of hydrogen, due to overestimation of the packing uptake and the excess hydrogen uptake (figure 2).

### CO<sub>2</sub> reduction

Hydrogen for CO<sub>2</sub> reduction leads to hydrocarbons, e.g. methane, methanol and alkanes. The

products can replace directly there fossil versions in storage and in the application. Only the reactions to the C1 products, i.e. gaseous synthetic methane and liquid methanol are selective reactions with a high carbon yield. The reactions to longer hydrocarbons, for example the Fischer-Tropsch synthesis, suffer from low carbon yield to a specific product. In any case the energy efficiency is low due to the formation of water in the oxygen reduction in CO<sub>2</sub>.

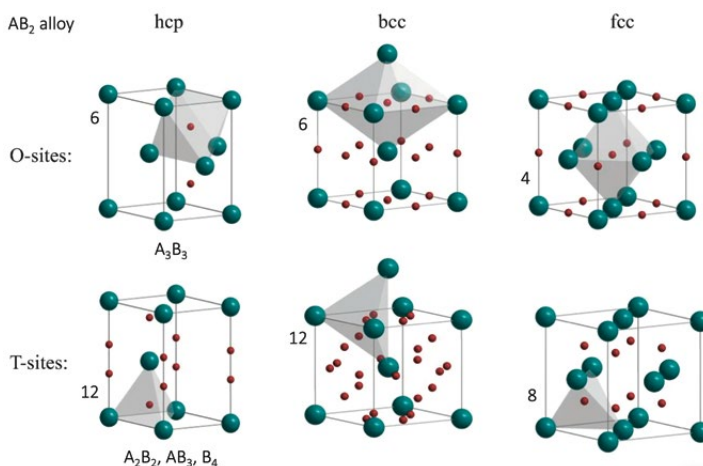


Figure 1 | Interstitial sites occupied by hydrogen in hexagonal, body centered cubic and face centered cubic structure [1].

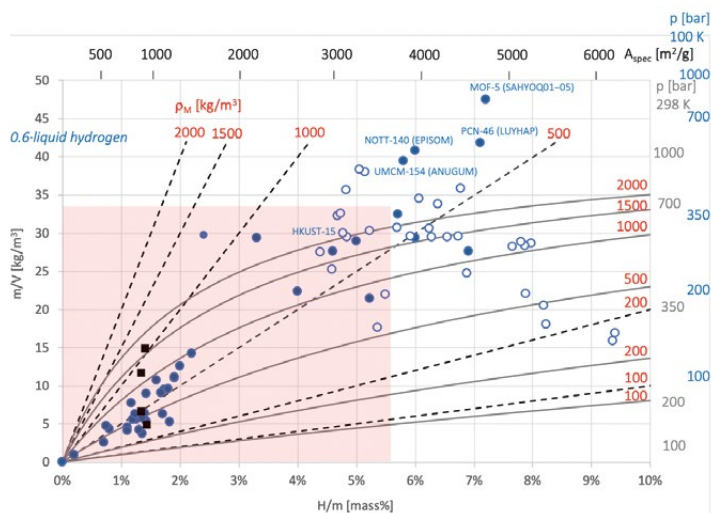


Figure 2 | Volumetric versus gravimetric adsorbed hydrogen density in nanomaterials. Dotted constant density lines are for porous and solid lines for non-porous materials. The red area indicates the range covered by compressed hydrogen at 298 K.

A high yield of >99% was achieved for the Sabatier reaction by a new highly efficient catalysts and a reactor design with a high radial temperature gradient.

Electrochemical CO<sub>2</sub> reduction allows to synthesise a variety of products. The selectivity of the reaction is partially controlled by the electrochemical potential and high yield (Faradaic efficiency) are achieved for some products. The energy efficiency remains a challenge. At the catalyst scale, tandem and alloy catalysts were developed and hydrophobic polymer overlayers regulate the local concentrations of reactants and intermediates (figure 3).

### Bio-oil hydrogenation

The reduction of CO<sub>2</sub> with hydrogen suffers from the large energy consumed to form water, two H<sub>2</sub> molecules are sacrificed in water and only one is bound to the carbon. Bio-oil already contains 90% of the energy of the final product, e.g. alkane, therefore, only 10% of the energy is provided by hydrogen (figure 4).

In order to produce the bio oil for a complete substitution of the fossil fuels worldwide approximately 8% of earths land area (25% of the agricultural area) would be needed for the plantation of Palm oil. This represents by far the most feasible global solution for the reduction of CO<sub>2</sub> emissions from fossil fuel combustion [3].

### Renewable energy solution for Switzerland

Energy system analysis for Switzerland was carried out in order to estimate the future renewable electricity demand and the technical and economic challenge in order to replace all fossil fuels with renewable energy. Switzerland in 2023 consumed 215 TWh·y<sup>-1</sup> of energy, from which close to 57 TWh·y<sup>-1</sup> are already renew-

able. All 66 TWh·y<sup>-1</sup> electricity is produced without CO<sub>2</sub> emission. In order to replace the 112 TWh·y<sup>-1</sup> of fossil fuels, mainly used in mobility, heating and industry, we estimate the demand for electricity to increase by at least 38 TWh·y<sup>-1</sup>, mainly produced by photovoltaics (PV) and wind (figure 5).

If 65% of the additional renewable electricity is produced in the summer season but 55% is consumed in the winter season a storage of 20 TWhel. is necessary to shift the electricity from summer to winter (figure 6).

Increasing the hydroelectric storage capacity has several advantages. It provides 9 TWh flexible electricity in winter and it reduces the electricity production from hydroelectric in summer, allowing more PV electricity to be consumed. In addition six times 4 TWh hydrogen storage (24 TWh hydrogen) is needed in order to produce 12 TWh electricity in combin cycle power plants in winter. For the production of the hydrogen, beside the excess electricity in summer of 20 TWh an additional 28 TWh need to be produced, increasing the needed additional renewable energy in 2050 to 66 TWh·y<sup>-1</sup>. Alternatively, four new nuclear power plants (1.6<sup>-1</sup>GW) would make the additional PV and storage superfluous. If they are built in mountain caverns or underground energy security is increased the plants become intrinsically safe as well as protected from outside threats and they are invisible (figure 7).

The reduction of the overall energy consumption due to the efficiency increase by electrification leads to a lower overall energy cost in case of the nuclear power plants and at least doubles the energy cost in case of the seasonal storage with hydrogen.

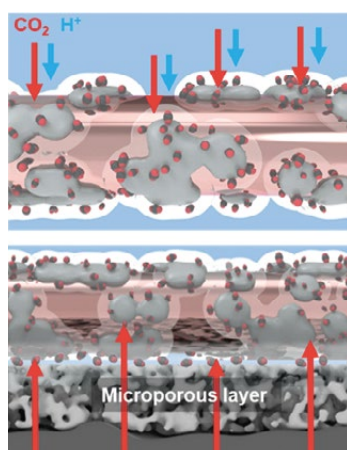


Figure 3 | Gas diffusion electrodes with a solid-liquid-gas interface for the electrochemical CO<sub>2</sub> reduction.

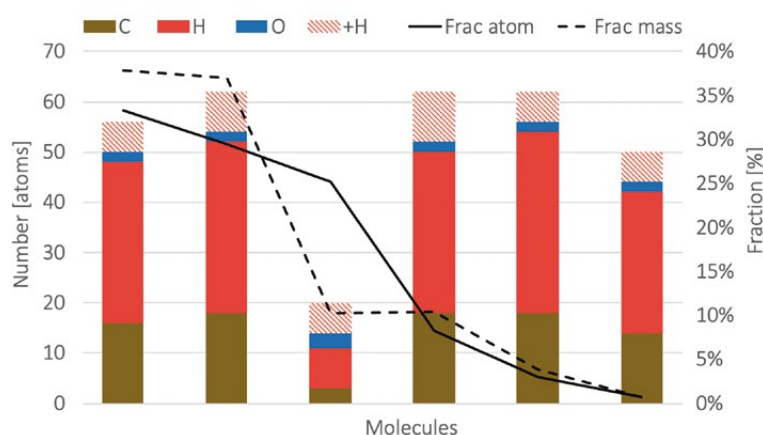


Figure 4 | Composition of the Palm oil, the molecules and the corresponding atomic and mass fraction.

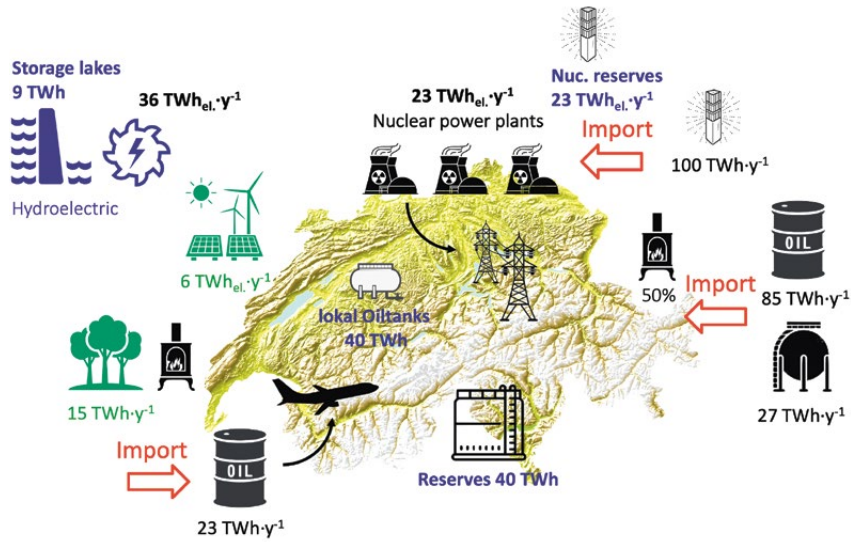


Figure 5 | Current (2023) Swiss energy map. The energy consumption is 215 TWh $\cdot$ y $^{-1}$ , 66 TWh $\cdot$ y $^{-1}$  is electricity.

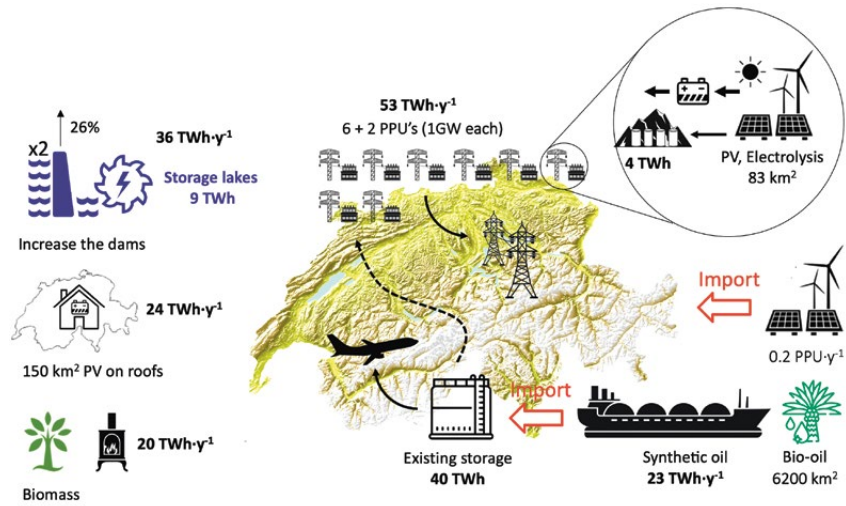


Figure 6 | The replacement of the 112 TWh $\cdot$ y $^{-1}$  fossil fuels requires 38 TWh $\cdot$ y $^{-1}$  additional renewable electricity. The storage for the shift of electricity from summer to winter is realized by doubling the hydroelectric storage capacity and underground compressed hydrogen storage. For the aviation hybridized bio-oil is imported.

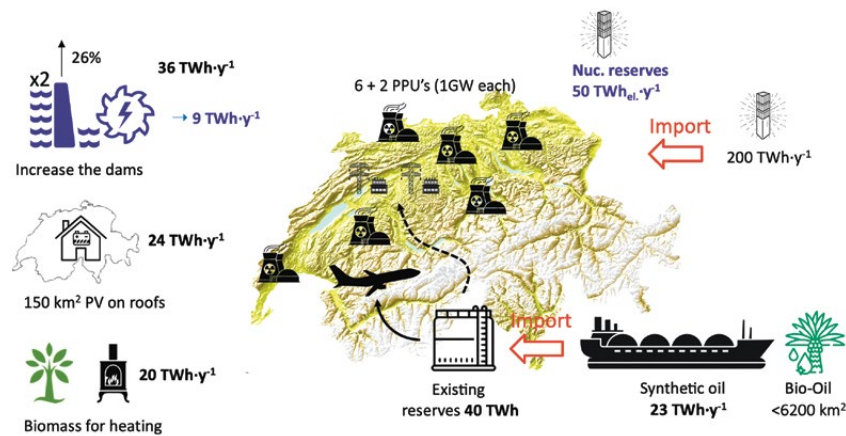


Figure 7 | The replacement of the 112 TWh $\cdot$ y $^{-1}$  fossil fuels requires 38 TWh $\cdot$ y $^{-1}$  additional electricity. The six 1 GW or four 1.6 GW nuclear power plants produce electricity during the whole year. An additional two combined cycle power plants for backup are fuelled with imported hybridized bio-oil as well as the aviation.

## DEMONSTRATIONS

### Small Scale Demonstrator in Sion (SSDS)

In the building I17 of EPFL Valais-Wallis a demonstrator is installed showing the complete conversion of solar energy into hydrogen and hydrocarbons. The demonstrator corresponds to the average fossil energy demand of a Swiss person and allows a direct comparison of the various energy storage technologies e.g. Pb acid- and Ni/MH batteries, metal hydrides, compressed methane and liquid methanol (figure 8).

The demonstrator is entirely on renewable energy and is able to process the energy day and night. Several components of the demonstrator plant have been developed in house and are unique e.g. the perovskite photovoltaic panels on the roof, the metal hydride storage, the metal hydride hydrogen compressor, the methane and the methanol reactors, the energy management system and the data management system incl. the real time display of the energy flow through the plant on the internet.

### Innovation Lab (Gaznat)

A new reactor was designed and built for the reduction of CO<sub>2</sub> with hydrogen to methane in a collaboration with Gaznat. The reactor converts >99% of the CO<sub>2</sub> in one stage of fixed bed catalyst (Ru/Al<sub>2</sub>O<sub>3</sub>) into methane due to the very high radial temperature gradients. This allows a fast reaction at the hot part of the catalyst bed continuing in the gradient along the equilibrium curve (figure 9).

The reactor was upscalled from initially 2 kW to 20 kW to 500 kW and finally 1 MW and represents the central unit in the Innovation Lab of Gaznat in Aigle producing methane from renewable energy.

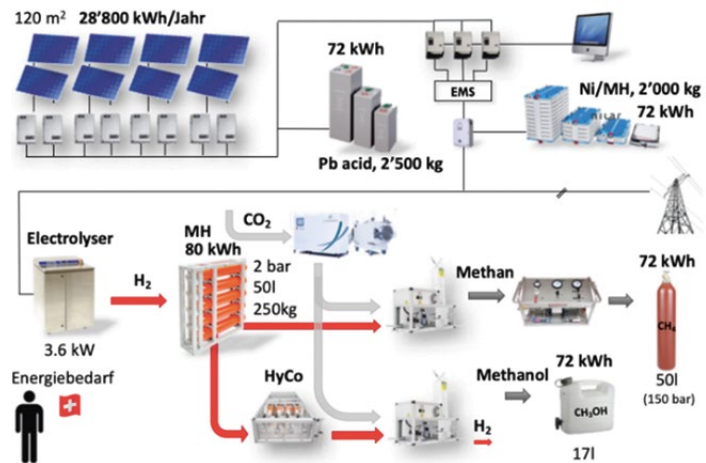


Figure 8 | The small scale demonstrator for Sion (SSDS) is converting solar energy into electricity, has a battery storage, a hydrogen production and storage and finally produces synthetic hydrocarbons (methane and methanol).

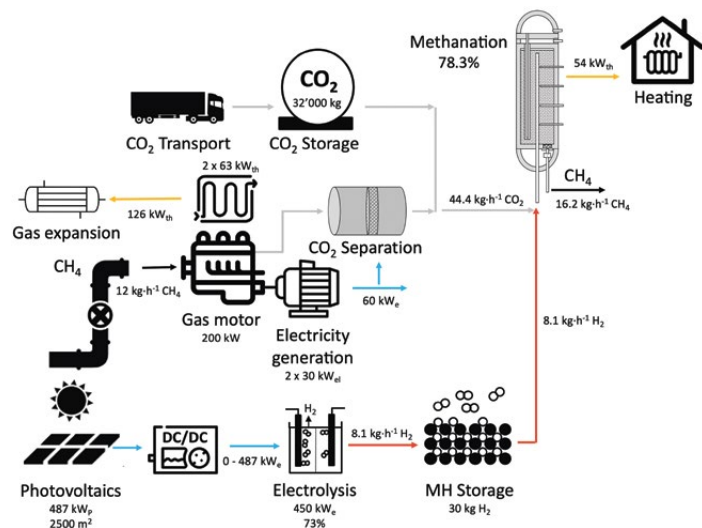


Figure 9 | The innovation lab of Gaznat consists of all essential components for the synthesis of methane, e.g. CO<sub>2</sub> capture, photovoltaics for renewable electricity, electrolyzer for hydrogen production, hydrogen storage in metal hydrides and a methanation reactor producing synthetic natural gas.

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Gilles Verdan  
Gaznat SA

# Demonstrating the strategic potential of synthetic gases

## GREENGAS PROJECT

The GreenGas project took shape around the methanation reactor and CO<sub>2</sub> capture membranes, whose research Gaznat has been supporting and monitoring for several years. Based on these two promising innovations, GreenGas was developed to meet the electrical and thermal energy needs of the Aigle site by integrating a Power-to-Gas installation.

Nanoporous graphene membranes enable the capture of CO<sub>2</sub> from combustion gases emitted by combined heat and power plants used to produce thermal and electrical energy. They represent a world first as they have been produced on an industrial scale as part of the GreenGas project. The captured carbon dioxide is used to produce synthetic methane.

The catalytic methanation reactor produces synthetic gas from a combination of hydrogen and CO<sub>2</sub>, according to the Sabatier reaction. This is also a major technological advance, as it is highly efficient, converting 99% of CO<sub>2</sub> in a single pass.

The GreenGas project aims to demonstrate the essential role that carbon-neutral renewable gases (hydrogen and synthetic gas) could play in the future. Various studies show that there will be an increasing surplus of renewable electricity during the summer months. It will also be necessary to prepare for the intermittency of these energies, particularly in winter, by finding ways to store large quantities of energy.

Storing this electricity in the form of synthetic gas is a major challenge in achieving a carbon-free energy mix. This will aim to adjust supply to demand in order to manage seasonal fluctuations, but also to balance production during the day and cover nighttime demand.

## INNOVATION LAB

On 30 August 2023, Gaznat inaugurated the Innovation Lab at Aigle (VD), the largest industrial-scale laboratory in French-speaking Switzerland for the development of CO<sub>2</sub>-neutral renewable gases. At the heart of Gaznat's new energy project, called GreenGas, and developed on the site of Gaznat's dispatching center at Aigle, the Innovation Lab is home to two major innovations that have reached maturity, and are supported by Gaznat through its chairs at EPFL.

The prototypes of the methanation reactor and new types of membranes for CO<sub>2</sub> capture, both developed in the EPFL Valais-Wallis laboratories in partnership with Gaznat, are now being tested on an industrial scale in the new Innovation Lab.

The Innovation Lab is also providing space for other innovations in the energy sector originating from EPFL, the universities of applied sciences or start-up companies. The investment budget for the GreenGas project and the Innovation Lab is CHF 5.8 million, including grants from the SFOE, the VSG research fund and the canton of Vaud.



Innovation Lab based on the Gaznat dispatching center in Aigle

GreenGas was built to meet the electrical and thermal energy needs of the Aigle site by integrating a power-to-gas plant consisting in particular of the methanisation reactor to produce CO<sub>2</sub>-neutral synthesis gas from the electricity generated by the photovoltaic modules. These solar modules were installed on all the Dispatching buildings between June 2022 and February 2023.

The commissioning of new nanoporous graphene membranes took place in August 2023 with the aim of capturing the CO<sub>2</sub> produced by the combustion gases emitted by the two combined heat and power (CHP) plants.

In the medium term, Gaznat intends to use the equipment and innovations tested at the Aigle site to cover its entire energy needs for electricity and heat, while producing CO<sub>2</sub>-neutral synthesis gas from renewable sources that will be fed into the gas grid in western Switzerland.

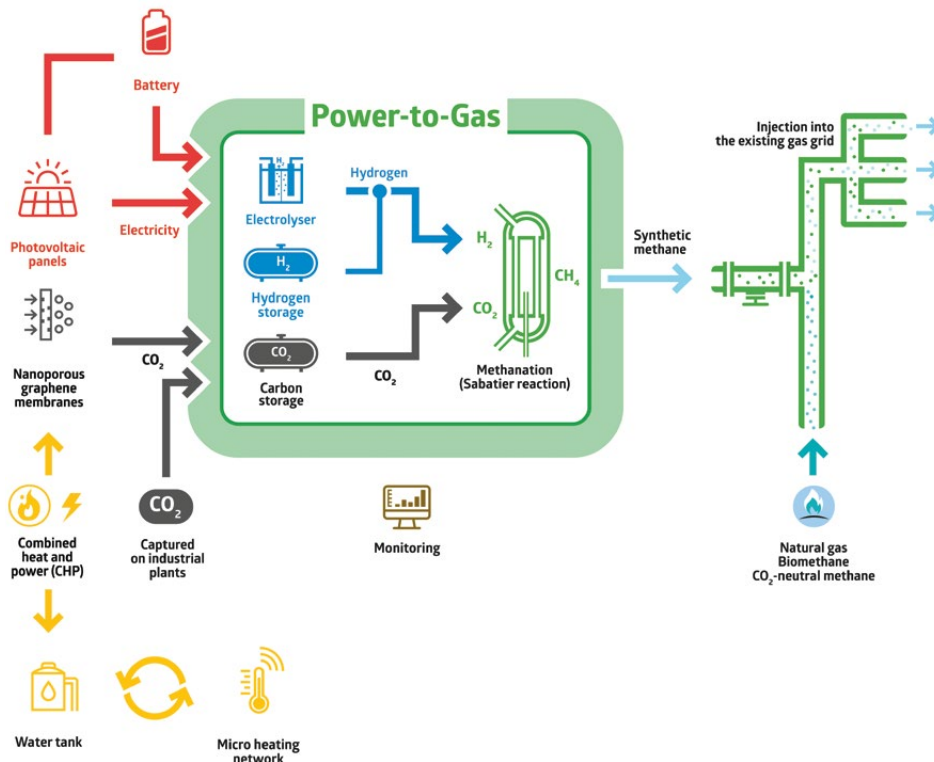
## FROM THE LAB TO INDUSTRY

The Innovation Lab's mission is to become Western Switzerland's test platform for energy innovation for projects funded at EPFL, but also for universities and start-ups wishing to test

their research results in an industrial environment. The Innovation Lab consists of twelve containers, each of which can accommodate one system. Currently, six containers are used for the electrolyzer, the methanation reactor, the hydrogen storage, the CHP system, the membranes for CO<sub>2</sub> capture and the monitoring system that ensures all the equipment is monitored. The projects financed by Gaznat, which are being tested in the Innovation Lab under industrial conditions, all have the goal of being brought to market.

## Securing energy supply with seasonal storage using power-to-gas

The GreenGas project is promising for the production of CO<sub>2</sub>-neutral synthesis gas and takes on an even greater dimension when coupled with seasonal gas storage. To achieve this goal, the power-to-gas plant being tested in the Innovation Lab is key, as it produces synthesis gas by utilising the surplus renewable energy generated in the summer. With this plant, surplus electricity generated by renewable energy sources such as solar, wind or hydroelectric power plants can be stored in the form of methane (synthetic natural gas) or hydrogen. This is a particularly promising technology that can help ensure Switzerland's sustainable energy supply.



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# Hydrogen and its derivatives

In both science and politics, discussions about hydrogen are increasingly including hydrogen derivatives, i.e. methane, methanol, ammonia and higher hydrocarbons together with bio based energy sources like biogas and wood (e.g. [1], section 5). These chemicals are mostly discussed in their role as sustainable energy carriers and only rarely as raw material for industrial products. Also, hydrogen as a reducing agent for metal oxides in steel production and for surface treatments is usually not considered important. There is one more role hydrogen and its derivatives play: The associated technologies and services for production, storage, transport and use are important export goods for our economy. Stadler Rail is an example: They are producing hydrogen trains, which do not make sense for Switzerland due to the high electrification of the Swiss railway system. But there is an international demand for these trains. These different roles of hydrogen and its derivatives are addressed at the Power-to-X Research Platform (FOEEN-X) operated at IET Institute for Energy Technology at the OST Eastern Switzerland University of Applied Sciences in Rapperswil.

The platform was initially built as part of the EU-project "Pentagon", the industry project "High efficiency power-to-gas pilot" (HEPP) and the research project "Integrated steam genera-

tion for solid oxide electrolysis via downstream catalytic fuel synthesis" (HotCat4Steam). The main goal of this first generation of projects was to experimentally demonstrate the increased efficiency of power-to-X processes, in thermally integrating high-temperature electrolyzers (HTE) and downstream fuel synthesis. A HTE electrolyses steam instead of liquid water. The downstream synthesis processes are all exothermic. Figure 1 compares the energy flows of two large-scale power-to-X processes in using methanation of H<sub>2</sub> and CO<sub>2</sub> as an example for a fuel synthesis process. IET and the Group of Energy Materials (GEM) from EPFL could demonstrate for the first time stable operation of a power-to-methane process with HTE using waste heat from the methanation for steam generation in the scale of 10 kW. It was shown that the efficiency can be up to 20 % points higher than when using a conventional electrolyser for liquid water, where the waste heat from the methanation leaves the process [4]. The projects also included further innovations: improved low-cost sensors to measure gas composition, advanced membrane technology for gas purification and innovative methanation technologies.

Since the completion of these projects, the platform was further developed and enlarged to accommodate more projects. It provides a

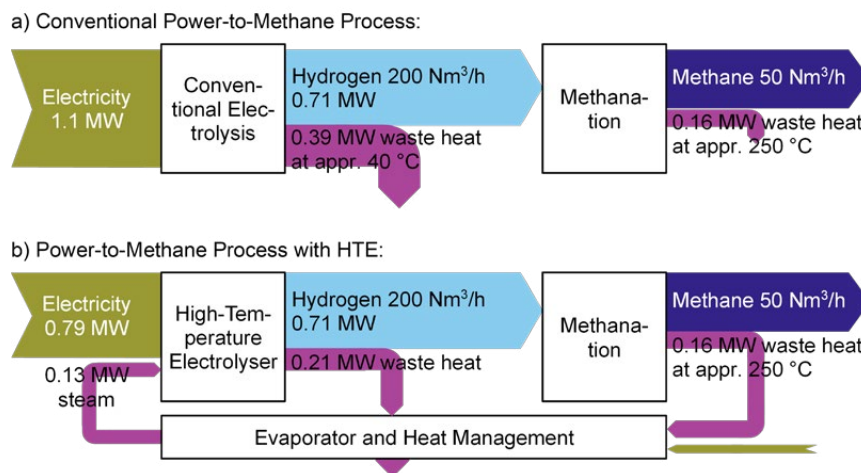


Figure 1 | Comparison of the power-to-methane process with (a) conventional electrolysis and (b) high temperature electrolysis (HTE) in the MW range, showing an increase in efficiency from 50 % in a) to 70 % in b). Chemical energy flows based on higher heating value (HHV). Efficiency is defined as  $(\dot{m}_{CH_4} \cdot HHV) / (electric\ power)$ . [2] translated.

"relevant environment" in the scale of 10 kW for the development of power-to-X technologies with a technology readiness level (TRL) 6. Developments currently conducted on the platform together with our industry partners, international research consortiums and our sisters SPF Institute for Solar Technology and UMTEC Institute for Environmental and Process Engineering are:

- Innosuisse project "Low-cost hydrogen refueling station" (LC-HRS).
- EU-project "Reversible SOEC/SOEFEC system for a zero-emissions network energy system" (24/7 ZEN), where the coupling of HTE and methanation developed in Rapperswil is upscaled.
- Innosuisse project "SynMeth efficient Syngas methanation reactor", with the perspective of using syngas from a Co-electrolysis of H<sub>2</sub>O and CO<sub>2</sub> in a HTE in a future project.
- EU-project "Revolutionary energy storage cycle with carbon free aluminium" (Reveal), where SPF and Umtec work in a consortium to develop a technology using the conversion of aluminium oxide into aluminium metal (Power-to-Al) to store renewable energy and produce a "renewable metal fuel" in the form of aluminium.
- The pilot and demonstration project ENSURE looks at the power side of power-to-X processes. A small-scale physical model of a power grid is built that can emulate challenges for the power grid (such as sudden frequency drops or complete blackouts). Experiments show, how power-to-X and X-to-power technologies can stabilize the electricity grid.

In the Innosuisse Flagship GreenHub lead by IET, the coupling of HTE and a downstream fuel synthesis process (in this case methanol synthesis) is upscaled and pushed up the ladder of TRLs in building a 25 kW plant at the waste incineration plant in Horgen to demonstrate seasonal storage. This activity is accompanied by research on system analysis and modelling, regulatory and sociopolitical aspects as well as business case developments.

The practical know-how and findings gained from projects conducted on the power-to-X research platform are also used for theoretical analysis (e.g. simulation tool PowerCheck) and

for techno-economic studies on behalf of different players in the energy domain. IET is one of the initiators of the Innosuisse Flagship "Decarbonisation of cities and regions with renewable gases" (DeCIRRA), where an interdisciplinary consortium of research organisations and implementation partners work on many of the numerous aspects of the future energy system with net zero emissions of greenhouse gases: Hydrogen, synthetic methane, biogas, carbon capture, transport and utilisation and/or storage, negative emission technologies, regulatory aspects, grid infrastructures. The results are condensed in a white paper and have been published in a short form [3].

IET Institute for Energy Technology thanks its funding partners, our industry partners and our academic partners for their long-standing support, co-operation and partnerships: European Commission, Forschungs-, Entwicklungs- und Förderungsfonds der Schweizerischen Gasindustrie (FOGA), Swiss Federal Office of Energy (SFOE), Federal Office for the Environment (FOEN), Staatssekretariat für Bildung, Forschung und Innovation (SBFI), Innosuisse, Interessengemeinschaft Power-to-X (IG-PtX), OST – Eastern Switzerland University of Applied Sciences, AlphaSYNT GmbH, Apex, Burckhardt Compression AG, Casale SA, Energie Zürichsee Linth AG, EnergiNova AG, Kanadevia Inova AG, Mems AG, Solydera SA, Arbor Fluidtec AG, Swagelok Switzerland, École polytechnique fédérale de Lausanne (EPFL) Group of Energy Materials (GEM), Paul Scherrer Institut (PSI) Thermochemical Processes (TCP) group, Haute École d'ingénierie et de gestion du canton de Vaud (HEIG-VD) Institut des énergies (IE).

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# POWERING THE FUTURE OF HYDROGEN SOLUTIONS

## VISION

A world fuelled by renewable energy – day and night, summer and winter.

## EXPERTISE

Hydrogen storage  
Hydrogen compression  
Hydrogenation of CO<sub>2</sub> (Synfuels)



## DEFINING ADVANTAGES



### TECHNICAL MASTERY

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### MATERIALS SCIENCE

Continuous innovation fueled by our in-house materials laboratory and dedicated team of scientists.



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### LOW EMISSIONS

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### COST-EFFECTIVE

Optimize energy use and reduce operational expenses across diverse applications.



### 1-STEP INTEGRATION

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Founded in 2017 as a spin-off of the Swiss Federal Institute of Technology in Lausanne (EPFL), GRZ is comprised of 30 team members, operating from our headquarters in Avenches, Switzerland. Fueled by a passion for a sustainable energy future, GRZ is not just innovating; we are revolutionizing the storage, compression, and utilization of hydrogen, setting new benchmarks for excellence in the industry.





Dr Noris Gallandat  
GRZ Technologies SA

# Industrialization of solid-state hydrogen storage

There have been advancements towards the scale-up and industrialization of solid-state hydrogen storage through the commercial launch of DASH Storage and DASH Power systems by GRZ Technologies SA. These systems include modular stacks containing a porous metal alloy which exothermically reacts to hydrogen forming a stable metal hydride. This process is reversible, and hydrogen can be recovered by heating the stack.

The **DASH Storage** solution is offered in two variants: the M-series and the C-series. DASH M-series offers modular stacks for metal hydride-based hydrogen storage at five standard sizes ranging from 1 to 45 kg hydrogen storage per module. On the other hand, the DASH C-series offers containerized hydrogen storage solutions with up to 675 kg of hydrogen storage in a 20-foot ISO container. A recent example of this product is the 225 kg containerised DASH Storage solution commissioned in 2024 located at Gruyère Hydrogen Power SA, in Bulle, Switzerland (figure 1). The entire assembly including the metal hydride stacks and the auxiliary thermal management system is housed in a 20-foot ISO container. This project serves as a testament to the viability of metal-hydride hydrogen storage systems achieving a high hydrogen storage density under extremely safe conditions (less than 30 bar and storage of hydrogen in the solid form).

The **DASH Power** systems have the added functionality of electrical power generation through the inclusion of fuel cell systems. The system includes fuel cell waste

heat recovery which is partially used to recover hydrogen from its metal hydride state, improving the overall system efficiency. The product is offered in five standard variants offering up to 225 kg of hydrogen storage capacity and up to 500 kWe / 4.5 MWhe of electrical power output/energy storage capacity with the entire system housed in a 20-foot ISO container. A DASH Power system with a peak electrical output of 500 kWe and energy storage capacity of 3.5 MWhe was commissioned in 2024 at the Fischer Group located in Achern, Germany (figure 2). The system delivers power during the peak demand periods, thereby reducing grid dependency and enabling peak shaving. This project demonstrates the viability of an inherently safe and robust hydrogen-based electricity storage system.



Figure 1 | DASH C-Series system commissioned at Gruyère Hydrogen Power SA, Bulle, Switzerland.



Figure 2 | DASH Power system commissioned at the Fischer Group, Achern, Germany.

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# Innovative hydrogen fuel station



Dr Hans Michael Kellner  
Messer Schweiz AG

## Description of the innovative concept

The new type of a hydrogen fuel station works with a thermal compressor and fulfills its compression task by using heat instead of electricity. The core element is the use of special metal hydrides. Here, the property of adsorption and desorption of the hydrogen atoms from a metal structure is utilized. Adsorption, or more precisely chemisorption, takes place at low pressure (e.g. the discharge pressure of an electrolysis process) when a vessel containing a special metal alloy is filled. After the complete adsorption (maximum hydrogen absorption by the metallic structure), the system is heated using any available heat source (e.g. waste heat) until the desired pressure is reached. The reachable pressure depends on the temperature level of the heat used. Hydrogen is desorbed and can be discharged at increased pressure. For the next adsorption step, the container is cooled down to starting conditions.

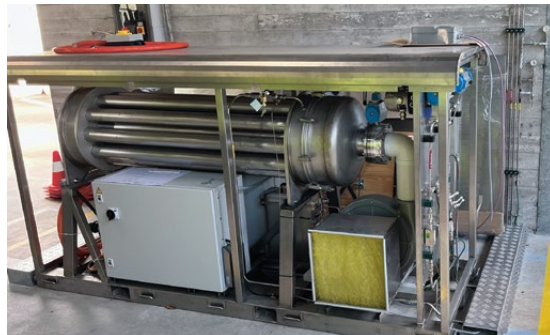
In case of a need of a continuous volume flow, more vessels with metal hydride are operated in parallel, staggered in Time. The entire compression unit, including the control system, heat and cooling system, is in one container.

Depending on the available temperature level, the required heat and the desired discharge pressure, the compressor can also be designed in two stages to meet the requirements. Messer offers standardized industrial compressors with pressures of up to 380 bar for the industrial market, but also up to 700 bar for the mobility sektor.

Metal hydrides can be used to build both very compact hydrogen storage tanks and hydrogen compressors that compress the hydrogen without moving parts due to thermodynamics and material properties.

The combination of metal hydride storage and compressor allows the hydrogen to be adsorbed directly from an electrolysis process (storage function) and then fed directly to the application in compressed form as required. The main advantage is that no hydrogen must be stored separately, which represents a major safety gain. Storage takes place at only 10 to 35 bar, depending on the hydrogen source.

Hydrogen released from metal hydrides is of high purity, in most cases more than 99.999%, which is greater than the purity required for PEM fuel cell cars of 99.97% (ISO 14687:2025). Its purity depends on the purity of the hydrogen fed into the tank and the reactivity of the impurities with the metal.



First approved hydrogen fuel station with thermal compression in Switzerland put into operation on 26 July 2024.

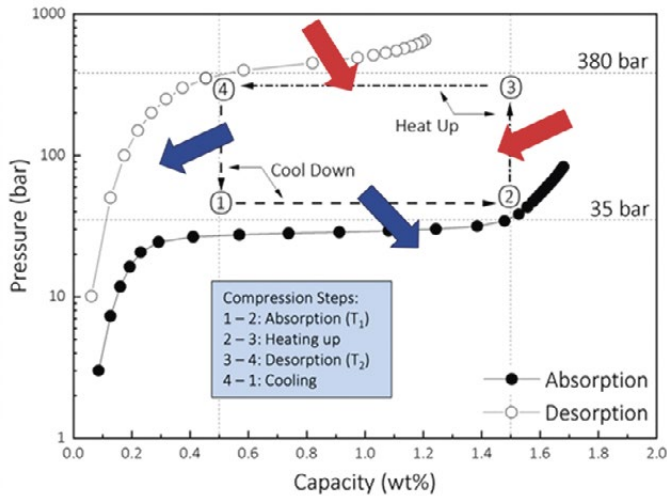
## Functional principle

The hydrogen compressor is based on a resource-saving and sustainable, innovative technology: metal hydride hydrogen compression. The hydrogen supplied is chemically adsorbed atomically on the structure of a special powdered metal alloy. A metal hydride is formed from the alloy. A pressure equilibrium is established between the solid and gaseous phases. When the metal is fully loaded, flow is stopped. In the next step, heat supply increases the pressure, which is determined by the temperature level, and releases the bounded hydrogen from the metal hydride. Once the desired pressure has been reached, the outlet is opened, and hydrogen flows out. Further heat is added to maintain pressure equilibrium and continue the desorption process. At the end of the cycle, the original metal alloy remains in the vessel.

The property of hydrogen absorption and desorption on a special metal alloy can thus be used to compress the useful gas hydrogen.

Thermochemical process cycle:

1. Hydrogen is absorbed at low temperature.
2. System is heated up until equilibrium at the final pressure.
3. Hydrogen is desorbed at elevated temperature.
4. System is cooled to the original temperature.



Typical compaction cycle for metal hydride technology

Compression takes place in batches. Several metal hydride containers are therefore used in parallel to ensure a continuous supply. The use of additional geometric hydrogen storage tanks may also be necessary in individual cases, depending on the task at hand.

### Individually customizable

The compression unit can be scaled as required. The function is not dependent on the geometric shape of the metal hydride container. This means that any supplied hydrogen flow can be processed. It does not matter at what pressure and temperature it is supplied or at what pressure it is to be compressed. Like the conventional compressor, the thermal compressor works with a compression ratio (inlet to outlet pressure). This allows individual tasks to be solved.

### The technology

As an alternative to an electrolysis, hydrogen can also be supplied by a gas supply company such as Messer. This can make economic sense for smaller quantities or as an interim solution until an electrolysis system is installed, possibly with its own renewable electricity generation.

### The metal hydride

The core component of the hydrogen compressor is the metal hydride. Metal hydrides are metals that can store hydrogen in the interstitial spaces, thereby increasing the hydrogen density up to twice the density of liquid hydrogen and approx. four times the density of hydrogen at 700 bar. This process can be compared to a dry sponge. If the temperature is then increased, the pressure in the metal hydride rises and the hydrogen is released again. Metal hydrides can be used to build hydrogen compressors that compress hydrogen without moving parts due to thermodynamics and material properties. All available types of heat and waste heat with a temperature level between 50 and 200 °C, depending on the desired pressure application, serve as heat sources. Pressures of up to 1,000 bar can be realized with this principle.

The lattice structure of metal hydrides is based on dense spherical packings of metal atoms. The spaces in between are filled with hydrogen atoms and embedded in them. This creates a solid solution in which the metal structure remains unchanged.

During hydrogen intercalation, hydrogen molecules adsorbed on the metal surface are first split into hydrogen atoms, which are then incorporated into the lattice.



Latest design of the hydrogen fuel station H24U

### Advantages

- The fuel station has no moving parts. It has no wearing parts and therefore no spare parts are required. In the consequence no service intervals are needed. This saves costs. Even the maintenance is very low.
- An important advantage is its noiseless compression. This allows to install it anywhere, even in residential areas. There is no building with sound insulation required and as it does not vibrate, no damping is required.
- The utilization of waste heat as energy drive leads to higher energy efficiency compared to conventional compression and to lower operating costs.
- The modular construction allows an easy expansion with additional units controlled by the master unit.
- It is environmentally friendly due to the lack of electricity and the use of waste heat. Twice reduces the burden on the environment.
- Higher economic efficiency in the overall view. The total investment (system, protective measures, construction measures) is lower than conventional compression. And even the operating costs are significantly lower.
- Hydrogen released is of high purity >99.999 Vol.-%. The metal hydride has a purification effect. This means, that the fed hydrogen is upgraded regarding quality.

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GRZ Technologies SA

# Hydrogen metal hydrides thermal compressor with low operational cost

30

Hydropole

The transition to renewable energy is accelerating, but the intermittent nature of sources such as wind and solar necessitates reliable and efficient energy storage solutions. Hydrogen (H<sub>2</sub>) is a promising energy carrier thanks to its versatility and near-zero greenhouse gas emissions. However, its low volumetric energy density requires compression to high pressures for practical storage and transport — typically around 200 bar for industrial use, 350 bar for heavy-duty vehicles, and up to 700 bar for passenger cars.

Conventional mechanical compressors, while widely used, face significant challenges. They suffer from reduced reliability due to the presence of moving parts, wear and tear, and frequent maintenance requirements. Additionally, they demand substantial electrical energy input, which can undermine overall system efficiency. Finally, the noise and vibration associated with the operation of mechanical compressors pose a challenge in certain contexts.

Metal hydride compressors offer a compelling alternative. By eliminating moving parts, they enhance system durability and reliability. Moreover, their ability to leverage low-grade or waste heat for thermal compression significantly reduces electrical energy consumption, aligning well with the goals of sustainable energy infrastructure.

GRZ developed one of the largest metal hydrides hydrogen compressors in the world. The compressor is operated by Messer Schweiz AG, a leading company in the gas sector, and installed on the chemical site of Lonza/Arxada in Visp, Switzerland. The compressor was designed to meet the specifications set forth in the table below.

Target	Value
Inlet pressure	10 bar
Outlet pressure	200 bar
H <sub>2</sub> flow rate	30 kgH <sub>2</sub> /h
Cooling medium	River water
Heating medium	Low-pressure steam

Two key areas for research and engineering efforts were the material development and the thermal management of metal hydride systems. The main challenge in development of key materials is maintaining the hydrogen storage capacity across the large number of cycles and minimizing non-ideal effects such as slope and hysteresis. Moreover, the materials used in the alloy should have stable and low market prices, which is directly linked to the avoidance of critical raw materials such as cobalt or nickel. The second main challenge is the thermal management of the system. Metal hydrides compression is thermally driven, and thermal management of the system directly affects efficiency and cost of the whole system. The importance of thermal management comes from the sensitivity of metal hydrides pressure to temperature and low thermal conductivity due to the powdered nature of activated metal hydrides alloys.

Metals with very high purity (> 99.5%) were used as raw materials to develop alloys prior to testing them for suitability. The alloys were prepared by induction melting in the form of flakes and are successively crushed into fine particles of 1 mm average diameter. The prepared alloys were then tested to determine the pressure-composition-isotherms (PCI) characteristics, the thermal conductivity, and the bulk density of the materials. Two candidate alloys developed by GRZ with dedicated specification to the presented application.

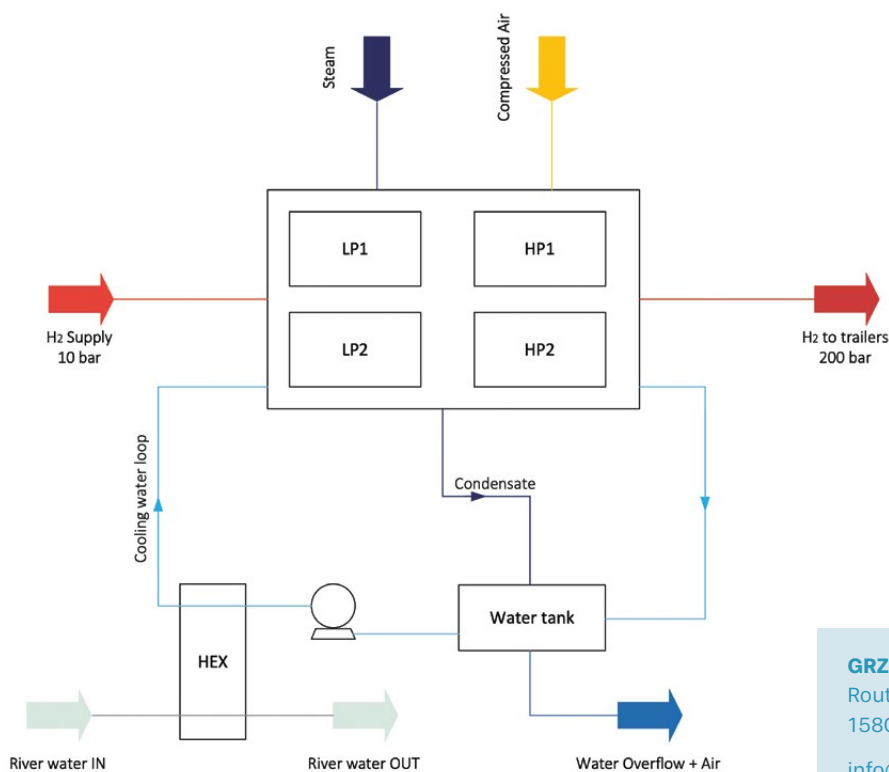
The thermal design of the compressor is based on the common shell and tube heat exchanger design with heat transfer fluid on shell side and MH alloys packed in tubes (called cells henceforth). The main parameters that are necessary to be optimized are cell diameter and heat transfer fluid flow profile. Mathematical models are developed to quantify the influence of heat transfer on cell walls on the MH sorption and compression within the cells. Tradeoffs are obtained and optimal configuration of cell diameter and shell side flow profile are selected. A block diagram of the system is shown on the opposite page.



HyCo compressor installed at operational site

The whole system is housed in two 20' ISO containers along with relevant process components as shown in figure 2. The system is fully compliant with all relevant safety guidelines and had obtained the CE mark. The fuelling process of empty trailer tanks is tested as a part of operational analysis of the system. Over multiple days of testing in both manual and automatic mode, the system has been in operation for over ten months, successfully compressing hydrogen from a 10 bar to up to 200 wbar in trailers. The successful operation of the required compression in automatic mode also proves the acceptability of the process logic and design methods. Based on the initial testing, performance was observed to be limited on the absorption side while achieving target pressure ratios and very high desorption rates.

In the ongoing work, the thermal and material design work undertaken are extended to development of 875 bar compression and hydrogen refuelling stations with fast refuelling. The successful demonstration of the technology at the industrial scale also sets the basis for commercialization and adoption in larger market.



Block diagram of the two-stage metal hydrides hydrogen compressor demonstrated at industrial scale

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# A model for planning a hydrogen refueling station



**Dr Panayotis**  
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Empa



**Arthur Couteau**  
Empa

Hydrogen refueling stations are generally set up in cascade systems. H<sub>2</sub> is stored in different pressure levels, depending on the installation and its purpose. Current passenger cars have a maximal pressure of 700 bar when fully refueled, so that the preferred storage pressure on the station side is at 900 bar. Tank sizes and numbers as well as pressure levels are the most important parameters for the layout of the station configuration.

Between the station tanks and the vehicle tanks there is a controlled pressure reduction unit and a heat exchanger. During the refueling process, pressure on the station tank reduces while in the vehicle tank increases. Once the pressure in the vehicle has equalized with the pressure in the station tank, a second station tank, at higher pressure, is connected. This continues until the desired pressure is reached within the vehicle tank.

The tank of a typical vehicle is made of two layers, an inside thermoplastic layer and an outside made of composite wrapping. The pressure tanks commonly used in vehicles can tolerate a maximum temperature of around 353 K. This is because the composite wrapping of the tank begins to degrade at that temperature. In order to prevent this, the heat exchanger cools the hydrogen after it is expanded through the reduction valve. A further complication is because of the real gas behavior of H<sub>2</sub>. Due to the Joule–Thomson effect, hydrogen heats up when expanded at a temperature above 193 K. As such the cooler requires more energy for larger pressure differences between the storage and vehicle tanks.

### The Empa Digital Twin

The Empa Digital Twin of an H<sub>2</sub> refueling station is taking into account these aspects on the station side. In addition, it accounts for the compression, the fluid dynamics and heat transfer from the H<sub>2</sub> to the tank walls as well as from there to the ambient, computing all relevant temperatures in the vehicle tank. It can be used for the layout of a station at different pressure levels and with different storage tank configurations. In parallel, the modeling of the refueling process allows the study of the influence of a series of station, vehicle and ambient specific parameters.

Figure 1 shows the pressure time histories during the refueling of an almost empty light duty vehicle. The pressure in the vehicle tank increases while the pressure in the station storage decreases. The decrease lasts until the station side overpressure is small. Thereafter a new station bottle has to be used. In total four station bottles are used for accomplishing the refueling for the examined configuration (this varies according to the volume of the station and of the vehicle tanks). In parallel, the Digital Twin is computing the temperatures in the storage tanks, after the pressure reducing station and in the vehicle tank (figure 2). The temperature in the storage tanks decreases as the pressure decreases. In contrast, in the pressure reduction unit the temperature increases given the real gas behavior of the hydrogen. Finally, in the vehicle tank the heat released by the compression leads to increasing temperatures. In the case shown in figure 2, H<sub>2</sub> is precooled to -30°C after the pressure reduction unit and before entering the dispenser and the vehicle tank.

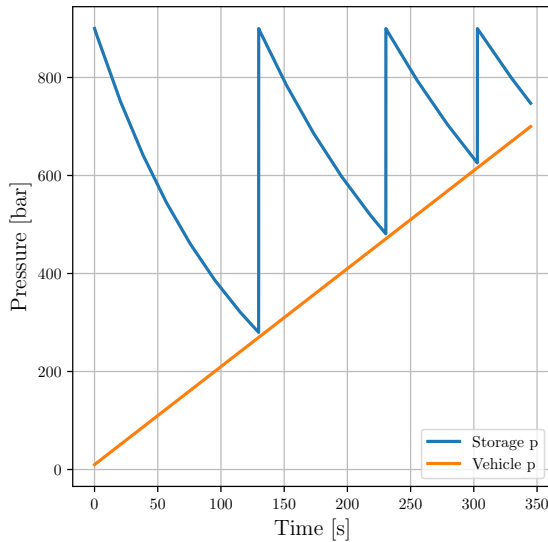


Figure 1 | Pressure time histories during H<sub>2</sub> refueling of a light duty vehicle in the storage tank (blue line) and in the vehicle tank (orange line).

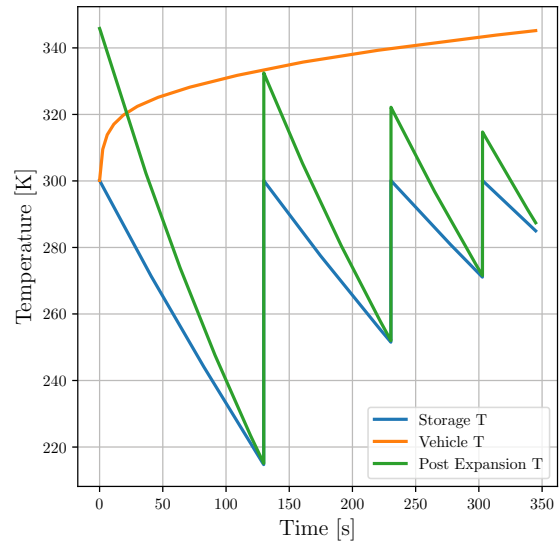


Figure 2 | Temperature time histories during H<sub>2</sub> refueling of a light duty vehicle in the storage tank (blue line), after the pres-sure reduction unit (green line) and in the vehicle tank (orange line).

### Model of the heat transfer in the vehicle tank

Single zone thermodynamic models have been developed over the recent years, successfully combining a single thermodynamic block for the gas with a one-dimensional diffusion equation for the heat transport through the tank shell. However, considering the whole tank to be isothermal has limitations, especially when considering large aspect ratio ( $AR = L/D$ ) tanks. Based on our measurements and simulations we have shown that when the vehicle tank aspect ratio becomes larger than three, the turbulent jet of inflowing H<sub>2</sub> does not reach the end of the tank. The tank should therefore be separated in two zones. The front zone is the region containing the inflow jet and is characterized by high velocities and thus high heat transfer coefficient. The rear zone consists of the rest of the tank, where the velocities are much lower and the influence of buoyancy on heat transfer is not negligible. The rear zone can, depending on the AR, be further separated in further zones. While all (of the rear zones) share the same heat transfer model (Nusselt correlation) as the flow is similar, we have observed that the temperature cannot be considered homogeneous. The three zone model in figure 3 leads to a better temperature prediction in the last part of the rear zone, where most critical values are reached.

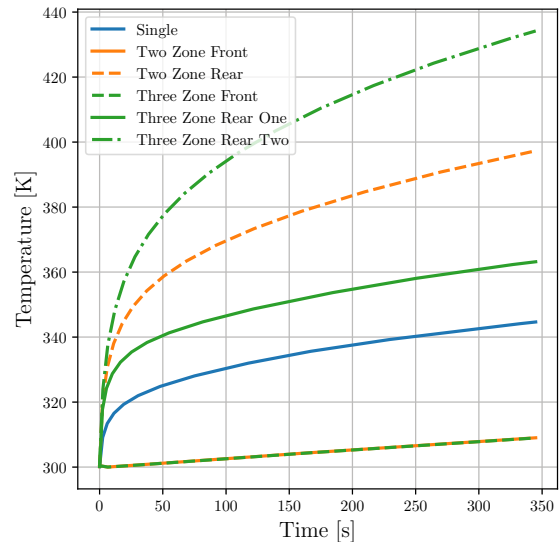


Figure 3 | Temperature time histories during H<sub>2</sub> refueling in a vehicle tank with high length to diameter ratio. The three-zone model leads to the most accurate prediction of the high temperatures in the rear part.

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# Status and outlook of the Swiss green hydrogen ecosystem



**Corey Houle**  
H2 Energy AG

Since 2020, over 9,000 tons of CO<sub>2</sub> have been saved by hydrogen fuel cell trucks in Switzerland. However, the European energy crisis has doubled the cost of producing renewable hydrogen, limiting fleet expansion in Switzerland. Despite this, international expansion and new hydrogen applications have advanced. With reliable infrastructure, Switzerland is set for continued growth in hydrogen mobility and other sectors, offering a cost-effective decarbonization pathway.

## The Swiss green hydrogen ecosystem today

H2 Energy and our partners have played a key role in the development of the Swiss green hydrogen ecosystem consisting of renewable hydrogen production, distribution/logistics, and public hydrogen refueling systems for trucks, buses and cars. Since the start of 2020, over 9,000 tons of CO<sub>2</sub> have been saved through the operation of 48 heavy duty fuel cell trucks on Swiss roads. Operated on the basis of a pay-per-use system by Hyundai Hydrogen Mobility (HHM), these trucks perform logistics for major Swiss companies like Coop, Migros and Spar and have driven over 11 million km to date. Over 1,200 tons of green hydrogen has been produced and distributed to a network of eighteen refueling stations by Hydrospider, a joint venture between H2 Energy, Alpiq and Linde. Refueling stations are owned and operated by Coop Pronto, Avia, Agrola, Schwab-Guillod, SOCAR and Oeltrans.



Swiss green hydrogen ecosystem key metrics (Q4, 2024).

The entire system has been built up without direct subsidies and operates at a very high level of reliability. Hydrogen is mainly produced in two plants, one in Niedergosgen (SO), owned and operated by Hydrospider and a second in Kubel (SG), owned by WPO, a joint venture between Avia Osterwalder and local energy producer SAK and SNEE. By using electricity

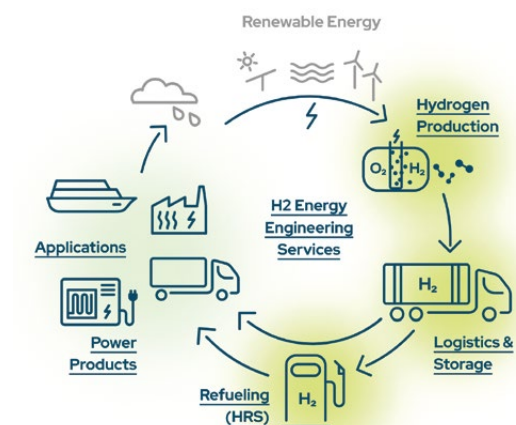
derived from hydropower, the green hydrogen used in the Swiss ecosystem has an extremely low carbon footprint.

## H2 Energy's role in the Swiss ecosystem

Founded in 2014, H2 Energy was responsible for the establishment of Switzerland's first public hydrogen refueling station in Hunzenschwil, a 35-ton fuel cell truck and a green hydrogen production at Eniwa's run of river hydrogen power plant in Aarau. This early-stage ecosystem was setup for Coop and allowed them to perform zero emissions logistics with 100% renewable hydrogen already in 2016, a world's first.

Building on this success, the current ecosystem has been developed and implemented together with key partners including Hyundai, Alpiq and Linde. H2 Energy has been responsible for the design and implementation of many aspects of the overall ecosystem including the hydrogen production sites at Niedergösigen (SO) and Kubel (SG), the refueling station architecture and planning and the containerized hydrogen logistics system as well as the safe, reliable and approved interface hard- and software used by Hydrospider.

The experience gained through the realization of these various projects and technologies is on



H2 Energy product and service offering, see [h2energy.ch](https://h2energy.ch) for more information.

offer from H2 Energy in the form of engineering services, as well as hydrogen storage and logistics solutions and fuel cell power products.

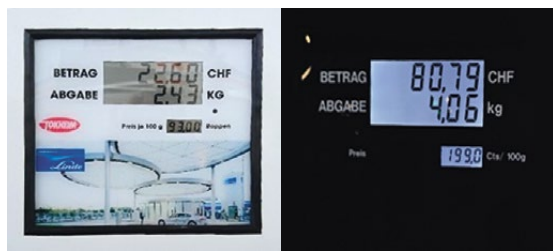
**Challenges to market expansion**

With the market price of renewable electricity representing the key cost driver in the production of green hydrogen, the Russian invasion of Ukraine in early 2022 and the subsequent European energy crisis has had a significant impact on the development of the green hydrogen ecosystem in Switzerland. Based on historical power prices in Switzerland and other factors such as the "heavy vehicle charge" (LSVA), the operation of hydrogen fuel cell trucks was in the beginning on a similar cost basis compared to diesel powered models. However, with the sharp increases in power prices during 2022 and the subsequently elevated prices since then, this is no longer the case.

Hydrogen prices at the pump have increased from approximately 10 CHF/kg in the period of 2016–2021 to around 20 CHF/kg from 2022 onwards. These additional fuel costs must be borne by the entire value chain which represents a significant challenge for all stakeholders and has limited the introduction of new vehicles.



Development of electricity prices in Switzerland (Source: [energiesdashboard.admin.ch/preise/strom](https://energiesdashboard.admin.ch/preise/strom)).



Hydrogen price development in Switzerland in 2016 (9.30 CHF/kg) vs 2024 (19.90 CHF/kg).

**Outlook for the Swiss green hydrogen ecosystem**

Despite these challenges which have limited the expected market expansion of hydrogen trucks in Switzerland there are successes that should be highlighted.

**International expansion of truck fleet**

Approx. 120 additional Hyundai Xcient Fuel Cell trucks have deployed within Europe through Hyundai Hydrogen Mobility (HHM). Most have

been purchased by German company Hylane and are being offered to logistics companies in Germany on a rental model. Additional trucks are now operating in France and Netherlands. The main driver for these purchases has been CAPEX subsidies which cover a large part of the additional investment cost between a hydrogen and a diesel truck. On an international level, the Hyundai truck fleet is expanding in the US, Canada and New Zealand.



Hyundai Xcient Fuel Cell trucks in Germany (top) and USA (bottom).

**Stationary fuel cell applications**

Initially launched in 2021, the Kvyreen fuel cell generator has been deployed in commercial operations in both Switzerland and Netherlands. Based on the 80 kW fuel cell power module from Toyota, the Kvyreen is available with both 80 and 160 kW power ratings as well as with AC or DC output. This multifunctional unit can be used for fast charging of battery electric vehicles and equipment as well as mobile or stationary power supply for events, construction sites or buildings. The technology platform can also be applied in other applications such as shipping and rail; more information is available on [h2energy.ch/kvyreen-hydrogen-generator](https://h2energy.ch/kvyreen-hydrogen-generator).



Kvyreen fuel cell charger (left) and Genset charger (right).

## Smart hydrogen logistics solutions

H2 Energy has launched a new range of smart hydrogen logistics solutions based on type III cylinders manufactured by Forvia. With an optimized design the 20-foot container version will have a capacity of 465 kg of compressed hydrogen at 380 bar. This large volume combined with a low weight will enable a significant reduction in the cost of hydrogen transport for high volume applications. More information is available on [h2energy.ch/hydrogen-storage-solutions](https://h2energy.ch/hydrogen-storage-solutions).



20 ft hydrogen storage container (top) and type III cylinder from Forvia (bottom).

Switzerland currently has 18 public hydrogen refueling stations in operation and a 19th in planning. With a daily fueling capacity for about 50 trucks each, this means that the existing refueling infrastructure could already support a fleet of 900 heavy duty trucks. With only 48 on the road there is significant room for expansion.

In contrast to other European countries, the entire Swiss green hydrogen ecosystem has been developed without any direct subsidies. However, with the phase out of the LSVA exemption for electric trucks (including fuel cell electric) planned from 2029 onwards the future of the ecosystem is far from secure.

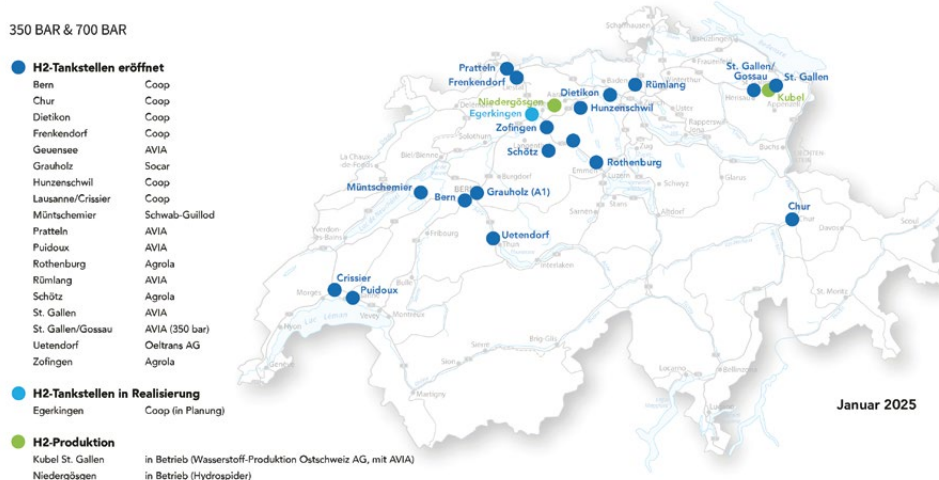
With the goal of becoming CO<sub>2</sub> neutral, the Swiss Confederation has established reduction targets for industry sectors as well as requirement for all companies to become net-zero by 2050 at the latest. The Swiss green hydrogen ecosystem, initially based on heavy duty trucks, has been proven to work on both a technical and commercial basis and has the potential to contribute significantly towards the decarbonization of the entire energy system. The key barrier that remains is that as long as the fossil-based energy sources — not only for the mobility sector — are not reflecting the costs caused by their emissions, a fair comparison with renewable energy-based systems remains imbalanced.

## Companies

Founded in 2014, H2 Energy aims to combat climate change by decarbonizing the energy system. We collaborate with like-minded individuals and organizations to make a difference. Active across the renewable hydrogen value chain, we offer expertise in hydrogen production plants, storage and logistics solutions, refueling stations, and fuel cell applications, drawing on years of experience.

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Hydrogen production and refueling stations in Switzerland (Source: [h2mobilitaet.ch/de/tankstellen](https://h2mobilitaet.ch/de/tankstellen)).



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# Hydrogen and fuel cells at OPmobility



Uwe Hannesen  
OPmobility

OPmobility, formerly known as Plastic Omnium, is a French automotive supplier with a presence in Fribourg, Switzerland. The company focuses on the development and production of automotive components, mainly exterior elements such as bumpers, front end modules including lighting, fuel tanks, SCR systems and, recently, battery systems and hydrogen solutions including high pressure vessels and fuel cell systems. In Fribourg, OPmobility has acquired Swiss Hydrogen SA in 2017, to enforce their competencies in fuel cell technologies. Swiss Hydrogen was a start up founded in Fribourg in 2014 as a successor of the hydrogen and fuel cell development activities at Belenos Clean Power Ltd, a subsidiary of the Swatch Group founded by Nicolas G. Hayek in 2007.

In the area of Belenos and Swiss Hydrogen the team has developed three demonstrator passenger vehicles with fuel cell systems offering 10 to 25 kW power.

Further systems with up to 100kW were developed and applied into maritime applications, a leisure boat, the Race for Water solar catamaran and a research vessel.

The 100 kW FC system was also applied in Switzerland's first 34 t truck in 2016. This project was carried out in Partnership with ESOR for H<sub>2</sub> Energy with Coop as end customer for the truck.

Since 2017, after being acquired by Plastic Omnium (now OPmobility), the team develops fuel cell systems for heavy duty automotive applications, notably the FCM 150, a fuel cell system with up to 177 kW power (nominal power 150 kW), which is now commercialized. The first customer is Stadler Rail. Four FCM150 will be used in each train, supplying a nominal power of 600kW per train. The narrow-gauge trains are delivered by Stadler to two South-Italian train operators. FCM150 is characterized by very high-power density and a system efficiency of almost 50% at nominal load.

Recently, the development of a next generation FC system with 360 kW power has been started for future long-haul trucks. The system efficiency will increase to 53% at 300kW and 60% at 100kW, providing a 25-40% fuel consumption advantage over Hydrogen combustion engine, depending on the hybridization strategy and the load cycle.



Figure 1 | Race for Water, the largest solar vessel was equipped with 2 x 30 kW FC system, electrolyser and on-board H<sub>2</sub> storage.



Figure 2 | 100 kW fuel cell system supplied to ESORO.



Figure 3 | OPmobility FCM150 Fuel cell system.

## OPmobility

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# A green hydrogen production plant in Bulle



Dr Patrick Sudan  
Gruyère Hydrogen  
Power SA (GHP)

For at least the last five years, green hydrogen has been a central topic in energy debates in Switzerland and Europe. It is seen as a key element in the transition to a low-carbon energy system, playing an essential role as a link between electrification and combustion systems. Its importance in the transition to cleaner, more sustainable energy systems is therefore undeniable.

The storage of surplus electricity using hydrogen is helping to make the country's energy supply more resilient. Power to X (PtX) technologies make it possible to absorb surpluses on the electricity grid, particularly during the period of high photovoltaic production, from March to October, when demand remains relatively low. This hydrogen can then be used in other sectors, in particular to produce high-temperature industrial heat, or stored for reuse in winter, thereby improving security of energy supply. However, this approach requires suitable seasonal storage infrastructures in Switzerland.

## A favourable context for a project in Bulle

Decarbonisation is the common thread running through the project in Bulle, which is the fruit of collaboration between Gruyère Energie SA (GESA), a regional energy supplier, and Liebherr Machines Bulle SA (LMB), which specialises in the manufacture of engines.

In 2020, the Liebherr Group announced its commitment to developing engines running on alternative fuels, with the aim of achieving carbon neutrality by 2050. With this in mind, two test benches have been installed at the Bulle site to develop a combustion engine powered by hydrogen.

Gruyère Energie, as the energy supplier for the Bulle (FR) region, has taken this specific demand into account by deciding to set up a green hydrogen production facility near LMB. This approach is also part of a drive to optimise the management of electricity surpluses, which are becoming increasingly frequent on the grid due to the growing number of photovoltaic installations connected.

In June 2021, this collaboration led to the creation of Gruyère Hydrogen Power SA (GHP), wholly owned by Gruyère Energie before Liebherr acquired 25% of the capital in May 2023, followed by Transports Publics Fribourgeois (3%).

When the project was launched in 2020, Gruyère Energie had already selected the site of the Planchy Sud heating plant in Bulle as the location for its green hydrogen production unit, financed by GHP. There were several strategic reasons for this choice:

1. **Proximity to LMB.** It is more efficient to transport electricity via power lines than to transport pressurised hydrogen by road.
2. **Infrastructure interconnection.** Gruyère Energie operates a drinking water network, a medium-voltage (MV) electricity network and a district heating network, all of which are directly accessible from the power station site.
3. **Use of an existing industrial site.** By locating on an already-developed site, we were able to avoid complex administrative procedures and often lengthy zoning processes.

The facility's strategic location also reduces the carbon footprint by avoiding the need to transport hydrogen by road. The green electricity supply is based on an energy mix combining



Figure 1 | Layout of the Gruyère Energie site with the Liebherr buildings just behind it.

photovoltaic solar production, waste wood cogeneration and supplements from the electricity grid.

The project stands out for its innovative, integrated approach, in which hydrogen production and consumption are concentrated in a limited area. It stands out in particular for:

- Direct distribution of hydrogen via a high-pressure pipeline, reducing dependence on road transport.
- The use of secure storage in the form of metal hydrides, optimising space and safety.

The GHP production facility is based on several essential stages:

1. **Electrolysis.** At the heart of the system, the PEM electrolyzers from Quest One (formerly H-Tec Systems) were chosen for their ability to absorb fluctuations in solar production while guaranteeing 99.995% purity of hydrogen. Two ME450 modules, with a rated power of 2 MW, can produce up to 38.5 kg of hydrogen per hour. AC/DC conversion and water treatment are integrated directly into these units, which keep pace with market trends.
2. **Storage.** GHP has opted for metal hydride storage, which offers a number of decisive advantages: (i) storage density four to five times greater than high-pressure gaseous storage; (ii) increased safety thanks to reduced storage pressure, minimising the risk of leaks; (iii) the possibility of using the heat present on the site to facilitate the desorption of hydrogen; (iv) greater energy efficiency, particularly for applications requiring hydrogen at low pressure (less than 30 bar).
3. **Compression.** A piston compressor supplied by Atlas-Copco compresses the hydrogen to 220 bar for an initial stage, then to 500 bar for the final output. This stage guarantees flexibility for industrial use and transport.
4. **Transport.** A 70-metre high-pressure transport pipeline links GHP to the Liebherr site, where there are two places for trailer-trailers. A *Transports publics fribourgeois* (TPF) railway separates the production site from the place of consumption.

The choice of transporting hydrogen through a pipeline makes it possible to respond to several market segments. The primary objective is to supply Liebherr with low-pressure hydrogen for its test benches. Secondly, GHP intends to develop a range of services for heavy mobility and industry, with the possibility of filling trailer-trailers for other custom-

ers. For this reason, the pipeline has been designed to transport hydrogen at both low and high pressure. The pipeline can transfer hydrogen at pressures of up to 450 bar, with a maximum flow rate of 350 kg/h.

### Future challenges and prospects

The facility has been operational since 1 October 2024 and GHP has begun a phase of fine-tuning its operation.

The main challenge is to eliminate all the imperfections associated with the system's regulation. The aim is to have a fully automated system, capable of operating without requiring the permanent presence of personnel on site. The complete management of the logistics chain, from the availability of the surplus green electron to the delivery of the hydrogen molecule at the right pressure and at the right time, is highly complex. Hence the importance of this test period, during which staff responsible for minor maintenance work must undergo specific training

Gruyère Hydrogen Power sees interesting prospects for 2026. If the plant is operating satisfactorily, the conditions set out in the federal government's hydrogen strategy should make it possible to improve the operation's economic performance. This mainly includes a favourable adjustment of electricity tariffs, through the implementation of the articles relating to support for PtX technologies in the Energy Ordinance, approved by the people in the vote on 9 June 2024.

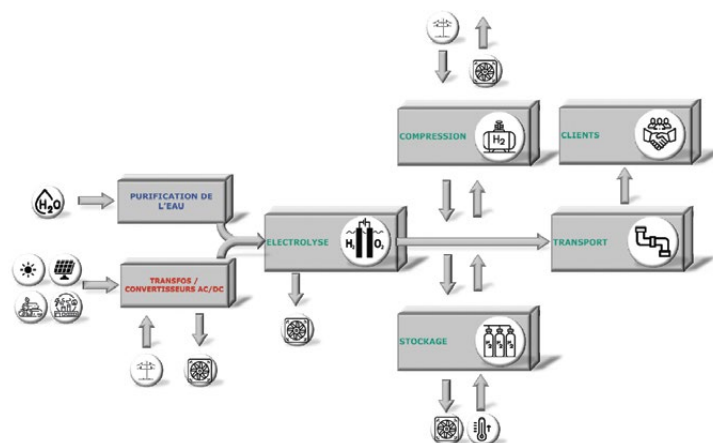


Figure 2 | Schematic diagram of the value chain set up by GHP.

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The background of the advertisement is a complex, blue-tinted industrial scene featuring various metal pipes, valves, and fittings. The SERTO logo, consisting of the word "SERTO" in a bold, white, sans-serif font followed by a stylized white arrow icon pointing to the right, is positioned at the top center. The arrow icon has a registered trademark symbol (®) to its upper right. The overall aesthetic is clean and technical, emphasizing precision and reliability.

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# Reversible hydrogen storage

## Formic acid hydrogen storage



Prof. em. Gábor Laurency  
EPFL

An alternative solution for the storage of hydrogen is to use a hydrogen carrier such as formic acid, which is the simplest combination of hydrogen and CO<sub>2</sub>. One liter of formic acid can carry 590 normal liters of hydrogen. Prof. Gábor Laurency's research group at EPFL, has developed a new, integrated formic acid-hydrogen fuel cell device.

Formic acid is liquid at normal conditions, easy to store, transport, and handle, and is produced from sustainable sources in hundreds of thousands of tons globally: it is already used widely in agriculture, and the leather, rubber, chemical, and pharmaceutical industries.

The device used to extract the hydrogen from formic acid consists of two main parts, a hydrogen reformer (HYFORM) and a proton-exchange membrane fuel cell (PEMFC). The reformer uses a ruthenium-based catalyst to extract hydrogen.

This unit can produce 7000 kWh yearly, and its nominal power is 800 Watts — roughly the equivalent of 200 smartphones being recharged simultaneously. Its electrical efficiency is currently up to 45%. As long as the formic acid used is produced sustainably, the fuel cell is completely environmentally friendly and allows long-term storage of renewable energy. It is quiet, emits clean gas, has zero carbon dioxide balance, and produces neither particles nor nitrogen oxides.

At the same time, the HYFORM-PEMFC is low-maintenance, needing no sulfur treatment, and features stable and long-term catalyst performance. Its technology is scalable, so it can be used in both households and industrial settings. Since it only needs to be fueled with formic acid, the system does not require connection to power grids, which makes it ideal for remote or inaccessible areas.

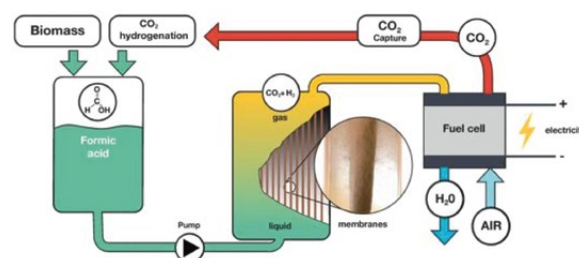


Figure 1 | Schematic process diagram for renewable energy storage as hydrogen converted into formic acid, an easy fuel to store and transport.



Figure 2 | The world's first integrated power supply unit that can produce electricity from formic acid, using a fuel cell in an energy-efficient, safe, cost-effective, and sustainable way.

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# Cracking ammonia for clean, resilient power



**Aris Maroonian**  
Neology Hydrogen SA

In a world where grid instability, diesel bans, and clean power shortages converge, Neology provides a scalable and emission-free alternative: ammonia-based energy.

## A critical challenge for the energy transition

Across construction, mining, and infrastructure sectors, diesel generators remain the default power source — yet they emit CO<sub>2</sub>, NO<sub>x</sub>, and particulates, are noisy, and rely on volatile fuel supply chains. Meanwhile, battery systems are impractical for high-load or long-duration use, and hydrogen faces prohibitive storage and transport costs.

Ammonia emerges as a superior hydrogen carrier: abundant, energy-dense, and compatible with existing infrastructure. But unlocking its potential depends on efficient and scalable ammonia cracking — precisely what Neology delivers.

## Our solution: the Ammonia Power Generator (APG)

Neology's containerized APG platform converts ammonia into high-purity hydrogen using a proprietary low-temperature cracking reactor operating at around 450°C — powered electrically, ensuring zero on-site emissions.

The system features:

- **Modular design**, scalable from 50 kW in 2026 to MW-scale deployments by 2030;
- **Integrated purification** delivering > 99.97% hydrogen purity for fuel cells;
- **Generator-agnostic output** compatible with fuel cells, hydrogen engines or future SOFCs;
- **Smart energy management**, onboard battery buffering, load smoothing and microgrid operation;
- **Compact and rugged container format**, deployable in remote or industrial settings.

At the heart of Neology's innovation lies a proprietary low-temperature catalyst, integrated with a pressure-tuned reactor and advanced purification system. Combined with zero-emission electric heating and model-based system engineering, the APG maximizes efficiency while reducing complexity and weight. This system design — fully containerized and engineered for

certification and safety compliance — enables real-world deployment without compromise.



Ammonia Power Generator (APG)

## From lab to road: demonstrated in the field

Neology has deployed a kilowatt-scale APG demonstrator, mounted on a fully electric vehicle to allow easy transport and operation at client sites. This mobile system enables flexible testing and outreach, while providing a live showcase of ammonia-to-power technology.



APG mounted on vehicle

The demonstrator has already attracted interest from sectors such as construction, maritime, and EV infrastructure, and was selected as a finalist in the Detroit Sustainable Cities Challenge, where it is being evaluated for clean backup power in municipal settings.

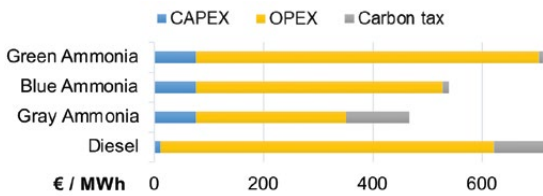
Beyond power generation, Neology's cracking platform is a stepping stone toward future hydrogen supply infrastructure, enabling local production for diverse applications — from airport equipment and ground logistics, to hydrogen-powered heavy-duty machinery on construction or mining sites.



Solution demonstrated in key use-cases: ports (maritime and air), construction sites, mining, and EV charging.

### Cost advantage and flexible business model

Neology adopts a rental-first model to eliminate upfront CAPEX and accelerate adoption, especially for municipalities, airports, and industrial operators. This allows early adopters to test and validate clean ammonia power without long-term investment constraints.



Cost comparison per MWh between diesel, and grey, blue and green ammonia supplies.

In terms of energy cost, Neology's APG already delivers competitive or superior levelized cost of electricity (LCOE) compared to diesel – with clear advantages in regulated or carbon-taxed markets:

- Using **blue ammonia**, the APG can deliver power at approx. 530 €/MWh;
- With **green ammonia**, the cost currently ranges around 710 €/MWh, but is projected to drop significantly with market scaling;
- In contrast, diesel often exceeds 720 €/MWh when accounting for carbon taxes, compliance costs and maintenance.

With no local emissions, near-silent operation, and reduced logistical constraints, the APG offers a uniquely sustainable, cost-efficient and policy-aligned alternative.

### Building a global green ammonia ecosystem

To ensure availability and scalability, Neology is establishing joint collaborations with green and blue ammonia producers and distributors, creating a reliable fuel ecosystem for deployment.

Our initial geographic focus includes:

- **Switzerland, Europe and Japan** — where regulatory readiness and infrastructure align with near-term deployment;
- Followed by **Latin America, Africa, MENA and the United States**, where energy access, diesel dependence, and clean fuel initiatives present strong mid-term opportunities.

### Field testing the future of clean power

In 2026, Neology will roll out the first field deployments of its 50 kW Ammonia Power Generator (APG) units as part of a pilot program across Switzerland and Europe. These early-stage trials aim to prove the APG's viability as a silent, zero-emission replacement for diesel in off-grid and backup scenarios.

The pilot units will be made available through a turnkey rental model, with Neology providing installation, regulatory compliance, and full ammonia fuel supply. Designed to be plug-and-play, the solution targets use cases such as temporary event power, construction sites in low-emission zones, EV charging in constrained-grid areas, and auxiliary power at ports or airports.



Model	APG - 50
Dimensions	3500 x 2200 x 2200 mm
Weight	4,000 kg
Power	62.5 kVA / 50 kW (PRP)
Battery storage	50 kWh
Voltage Output	400 VAC / 480 VAC
Frequency	50 Hz – 60 Hz

\* Specifications are subject to change.

Technical specifications of the pilot unit (50 kW APG, containerized, with PEM fuel cell).

By lowering the entry barrier through a fully inclusive service offer, Neology hopes to accelerate adoption and validate the operational benefits of ammonia as a scalable energy vector — particularly in applications where electrification and hydrogen have so far struggled to compete with diesel on flexibility and cost.

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# Hydrogen for seasonal energy storage



Prof. Christoph Ellert  
HES-SO Valais-Wallis

## The implication of applied education

The potential and the role of hydrogen for the energy turnaround is well known and discussed for several decades [1]. Several times since the 1980ies hydrogen has been expected to become a major energy vector, often with unrealistic promises and expectations fueled by the marketing departments or researchers themselves. Already in the last decade of the last millennium several major car manufacturers based their development on hydrogen propulsion, using either fuel cells or internal combustion engines fed with hydrogen [2]. However, the technology didn't enter the market for various reasons, availability of hydrogen, cost of hydrogen and the maturity of the technical components, compared to the classical fossil fuels. One major reason for the missing interest has been, that in terms of environmental impact, the availability of hydrogen was based only on steam reforming, thus releasing as much CO<sub>2</sub> into the atmosphere as with direct combustion of fossil fuel. The lack of renewable electricity for electrolytic hydrogen did therefore play a crucial role as well. This last reason has changed since the beginning of the rise of massive PV-installation worldwide and the way seems open now for hydrogen to really become

an important cornerstone of the energy transition, even though twenty years may still be ahead of us. PV-installations are strongly rising, however not even the electric energy supplied by nuclear power plants has been replaced nor the electricity is generated by solar or wind yet, required to feed all the heat pumps to be installed or to power the expected fleets of electric vehicles entering the roads.

To be ready in ten or twenty years, when there will be sufficient renewable electricity in Switzerland and Europe generated from solar or wind to produce hydrogen on a large-scale by electrolyzers, our hydrogen group at the university of applied science in Valais in Sion, has been active for the last ten years on installation and education of hydrogen technology and power to gas. As renewable hydrogen may generate benefits via several ways of commercialisation (see figure 1), the aim has been to distribute a broad knowledge on applications and to pursue a development of the technology in house, allowing to use solar energy directly from the roof of the building, intermediate storage via batteries, hydrogen generation, storage and reconversion for various applications.

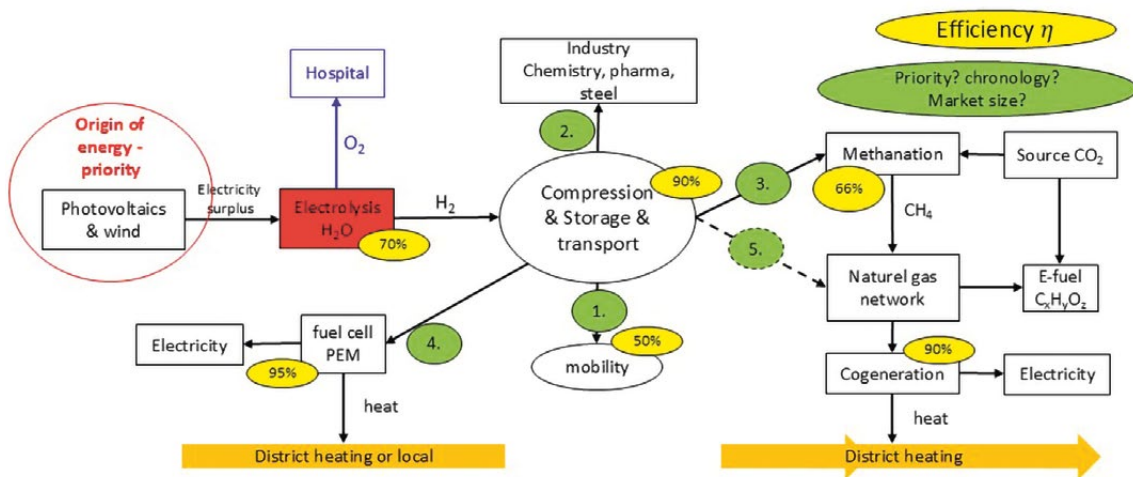


Figure 1 | Schematics of the different pathways how renewable hydrogen may generate benefits.

The result shown schematically in figure 2 is a (nearly) complete system representing all major aspects of an entire solar PV and power to gas installation, from the PV-generator on the roof, connected to a DC-microgrid, carrying the electric power to the batteries for short term storage and to the electrolyzer for hydrogen conversion. The generated hydrogen is fed after drying into metal hydrides, ready to be used for fuel cell conversion or feeding a methanation reactor. For the latter the required CO<sub>2</sub> is either generated by a biogas fermentation of food waste or taken from commercial CO<sub>2</sub> bottles. It is worthwhile to note, that nearly the entire power to gas system has been installed by more than thirty student projects either during their bachelor's or master's thesis or in applied semestrial projects. At present, the HESSO prepares to install an enlarged version of the shown system in a new satellite building, executed by professionals according to Swiss installation standards, assuring safety such that a operation may even be done by non-specialists and the system may serve for the education of potential future operators, e.g. on a training course on hydrogen and/or power to gas.

The described work on hydrogen acknowledges initial funding by EOS-Holding (2016–2018), the DC-microgrid received funding from Swiss Federal Office of Energy (2018–2019) and Innosuisse (2021–2023). The installation of the entire P2G demonstrator could only be realized thanks to the support of the Canton of Valais for laboratory and equipment and based on the education of the students in course of their bachelor and master studies at the HES-SO.

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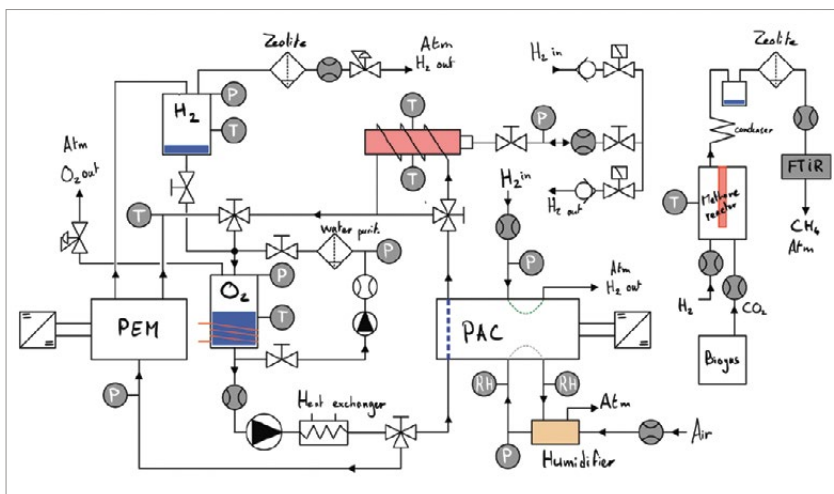
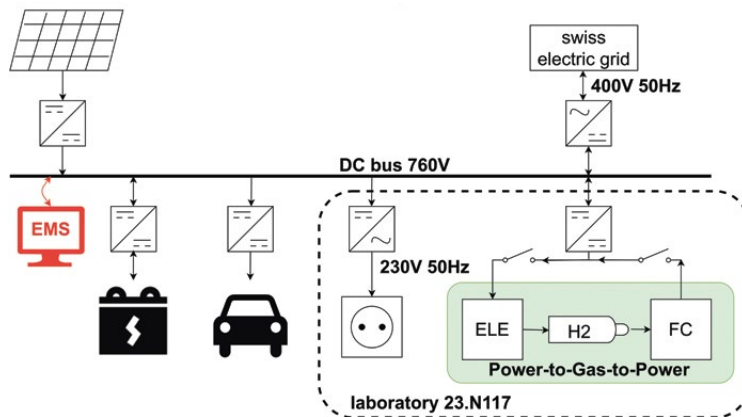


Figure 2 | Schematics of the installed P2G system [3], connected to the PV-powered DC-microgrid of the HES-SO Valais. The methanation reactor and bioreactor are shown only the more detailed drawing below [4].

# Tube fittings for the energy transition



Stephan Albrecht  
Serto AG

Hydrogen is a key element of the energy transition. Numerous countries have adopted strategies and measures to promote hydrogen technologies and accelerate the development of a hydrogen economy. The focus here is particularly on technologies for the production, storage and utilization of hydrogen. In addition to the central technology components, the corresponding devices and systems always include tubes that transport the hydrogen from one point to another. Tube fittings are used to connect the tubes and join them together. Such components must be suitable for use with hydrogen. A corresponding seal of approval facilitates the selection of suitable products.

48

Hydropole

For the long-term success of the energy transition and for climate protection, we need options to fossil fuels. As a versatile energy source, hydrogen plays a key role in this and has become the beacon of hope for global efforts to decarbonize the energy system. However, the production and transport of hydrogen is associated with challenges. For example, the operators of gas supply networks must make their infrastructure fit for the planned addition of hydrogen. But what exactly are the challenges? Two factors are crucial: the tightness of the components used and the hydrogen resistance of their materials. This topic may be uncharted territory for grid operators. However, other players in the hydrogen sector have not only been confronted with these questions since the energy transition. For example, suppliers of electrolyzers for the production of hydrogen (H<sub>2</sub>) from water. These devices and systems have become increasingly important in view of the immense demand for hydrogen, but they have been built for a long time. Hydrogen applications are also familiar territory for manufacturers of tube fittings, who supply connection components for tube lines in electrolyzers. The knowledge and means to fulfill the requirements for tightness and resistance are also well known.

Tightness is a relative term. There is no such thing as absolute tightness in technical systems. This is especially true for detachable connections of individual components, which is what pipe fittings are. A tightness requirement is specified by means of a maximum



Figure 1 | Detail of the tubing of a compact electrolyzer.

permissible leakage rate — if this is fulfilled, the connection is considered tight. The leak rate is usually specified in the unit "millibar times litres per second" or "mbar·l/s". This expresses the pressure loss due to a leak. For example, a bicycle tyre is considered leak-proof if the leak rate is less than  $1.0 \times 10^{-4}$  mbar·l/s. There are no binding specifications for tube fittings in hydrogen systems. In most applications, however, leakage rates of less than  $1.0 \times 10^{-8}$  mbar·l/s are required. This corresponds to a gas loss of less than 1 cm<sup>3</sup> in three years. But what is so challenging about hydrogen? It is the fact that H<sub>2</sub> is the smallest molecule in the world and as such can also pass through the interspaces that other gases cannot. The sealing technology of a tube fitting must take this fact into account and the hydrogen tightness must be proven. Helium leak test systems with a vacuum chamber and mass spectrometer are typically used for this purpose. Under defined conditions, a test specimen is pressurized in a vacuum and the spectrometer counts the helium atoms that make it out again. The leak rate can then be determined from this.

The term resistance of a material covers several effects that can occur during long-term contact with hydrogen. One of these is permeation or

diffusion, i.e. the process by which a substance passes through a solid. Hydrogen has this ability, that has to be considered particularly for plastics. This means that hydrogen can escape from a plastic tube without any mechanical leak. For use with hydrogen, plastics must therefore be diffusion-tight or have the lowest possible permeability. Another very significant effect is the so-called hydrogen embrittlement of steels. This complex process begins with the penetration of atomic hydrogen into the structure and continues with its diffusion into areas of higher tension, where it combines to form molecules. Over time, the localized hydrogen concentration increases, causing the tensions to rise. External forces such as high pressure — which is the case in many hydrogen applications — further increase these tensions. At some point, the critical point is reached and cracks form, which can lead to the complete failure of the component. Stainless steels with an austenitic structure (face-centered cubic) have proven to be particularly resistant to hydrogen embrittlement, which is why they are the first choice for manufacturers of tube fittings. Proving the suitability of the selected material is much more difficult than proving the tightness of a tube fitting. Complex metallurgical analyses are required to assess the risk of embrittlement of a structure.

Manufacturers of tube fittings are therefore familiar with hydrogen applications and can recommend the right products to their customers. But what has changed since the energy transition? It has changed the market, as numerous new suppliers are participating. These include many start-ups that are developing innovative products based on the latest findings from universities. Their focus is naturally on the actual technology, such as a new electrolysis process. However, they deal with the associated tubing as far as necessary, specify the requirements and evaluate the suitable components. The difficulty here is to assess suitability without the relevant experience. To simplify this, manufacturers of tube fittings have increasingly had their products certified in accordance with Regulation (EC) No.79/2009 on the type approval of hydrogen vehicles (commonly referred to as EC79) in recent years. The associated tests are very demanding and prove the required tightness and resistance. Products with the EC79 label can therefore be used without further evaluation in the pressure level authorized for them. Unfortunately, EC79 was withdrawn without replacement in summer 2022. Others, such as UNECE Regulation No.134, are not an alternative as they do not take tube fittings into account. It is therefore desirable that a general hydrogen test standard for tube fittings is created — not just for vehicles, but for industrial hydrogen applications in general. This is in the interests of both users and suppliers.

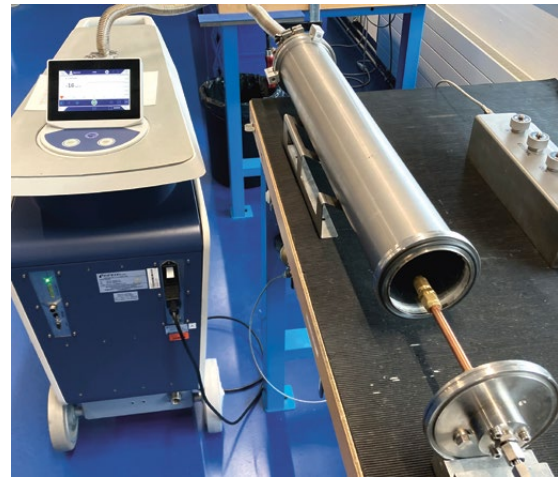


Figure 2 | Helium leak test system with vacuum chamber and mass spectrometer.



Figure 3 | Homogeneous austenitic microstructure of two bolted parts.

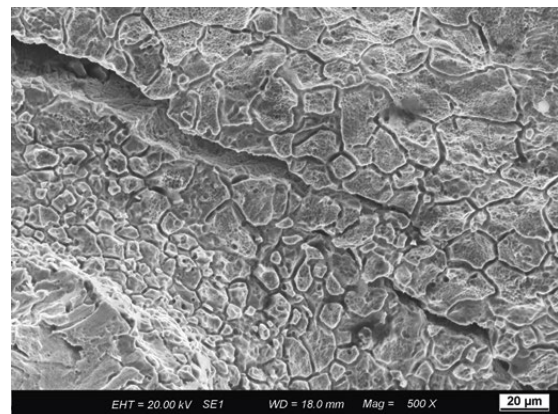


Figure 4 | Crack initiation at the corrosively attacked grain boundaries.

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## Hydrogen research and activities

The Institute of Energy (IE) at the School of Engineering and Management Vaud (HEIG-VD), which itself is part of the University of Applied Sciences and Arts Western Switzerland (HES-SO), brings together around seventy researchers and experts. They are engaged in a broad range of research activities spanning both electrical and thermal energy domains.

The Ra&D activities in the field of hydrogen are mainly driven by five faculty members and constitute one of our priority axes. These range from sustainable production and storage of hydrogen, to its integration into larger energy systems, as well as its usage in hard-to-abate sectors. Indeed, hydrogen is not only considered as a promising energy vector that can provide

seasonal storage solutions at different levels, but it is also a chemical compound that needs to be supplied without resorting to fossil energy sources. Possible cogeneration applications and hydrogen distribution in urban zones also constitute an active research topic.

HEIG-VD pursues regional, national as well as international projects and mandates. It actively participates in committees and other endeavours related to hydrogen and other renewable gases.

One of the faculty members of the HEIG-VD Institute for Energies was the main author of the recent report of AEE Suisse on hydrogen, [zenodo.org/records/10925738](https://zenodo.org/records/10925738).

50

Hydropole

### Production of hydrogen from plastic wastes



Prof. Gilles Courret

#### Project C3 — Closed carbon cycle for mixed plastic waste

Funding: HES-SO | Period: 2024–2028

The aim of this flagship four-year project, in collaboration with three other HES-SO institutes — HES-SO Valais-Wallis – HEI, HEPIA and HEIA-FR — is to replace fossil fuels as a carbon source with chemically recycled mixed plastic waste. Plasma depolymerization of plastic waste is used to produce a mixture of gases, including H<sub>2</sub>. At HEIG-VD we are responsible for the development of the microwave plasma reactor with optimization of energy efficiency,

chemical selectivity and throughput. We have extensive experience of plasma processes in areas such as gas reforming, plasma lighting and disinfection, as well as expertise in non-equilibrium modeling.

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## Ammonia and hydrogen in mobility application



Prof. Marc Pellerin



Dr Philippe Morey

Funding: Neology | Period: 2023–2024

In 2024, the start-up Neology called upon the expertise of the Institute of Energies (IE) of the School of Engineering and Management of the Canton of Vaud (HEIG-VD) to innovate in the field of hydrogen mobility. This collaboration aimed to develop sustainable mobility solutions using ammonia as an alternative storage medium for hydrogen. Ammonia offers the advantage of a high storage density compared to traditional methods, as it liquefies at low pressure and room temperature. The decomposition of ammonia ( $\text{NH}_3$ ) produces only hydrogen ( $\text{H}_2$ ) and nitrogen ( $\text{N}_2$ ).

The IE team worked with Neology's team to create a test bench to characterize the performance and operating constraints of the ammonia cracking reactor developed by Neology. Subsequently, a complete system was built in the form of a demonstrator, integrating the ammonia cracking reactor, its automated control system, and the consumption of the produced hydrogen in a fuel cell.

This demonstrator was integrated as a range extender on a small electric utility vehicle, illustrating an onboard solution for zero-emission electricity production



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## Sustainable production of hydrogen in run-of-the-river power plants



Prof. Massimiliano Capezzali

Funding: Innosuisse + Gaznat SA

Hydropower could play a crucial role in the mass production of decarbonized hydrogen and synthetic methane in the future. Switzerland is however in a situation of structural electricity shortage during winter. Thereby arises the problem of implementing hydrogen production and planning it in a feasible time and space distributed market, while improving energy system resilience.

The project is part of the Innosuisse flagship project DECIRRA ([decirra.ch](http://decirra.ch)) and aims at identifying an optimal use of run-of-the-river hydropower for  $\text{H}_2$  production in Switzerland with the basic idea of valorizing excessive or unprofitable power production. The approach takes into account the operational characteristics of hydropower plants, as well as the technical constraints and possible configurations of P-to-H plants, e.g. in terms of electrolyzers size. Local  $\text{H}_2$  storage is also included.

The project will provide a robust multi-decision framework based on industrial organization, econometrics and engineering that allows to develop and evaluate a series of criteria for harnessing hydropower for the production of another energy carrier, while maintaining the security of electricity supply at national level.

The potential markets for hydrogen and oxygen as basic chemical compounds for industry and other economic sectors will also be taken into account.

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# Decentralized H<sub>2</sub> hubs to valorise local excess photovoltaic production



**Mathieu Boccard**  
Planair SA

## INTRODUCTION

### Context

The energy transition requires the decarbonation of all sectors. Hydrogen production by electrolysis using renewable electricity can contribute to this in several ways: by serving as an intermediate for storing surplus summer electricity production, as a fuel for mobility, particularly for heavy-duty vehicles, or by being injected into the natural gas network. Under current market conditions, green hydrogen production requires renewable electricity not only in abundance, but also at a low price. So far, most production sites in Switzerland, whether operational or planned, rely on run-of-river hydropower. However, such sites are typically isolated compared to the hydrogen needs. Besides, the potential for developing new hydropower is limited, particularly in comparison with other renewable sources such as photovoltaics whose technical potential is estimated at above 50 TWh/year.

### Proposed solution

We evaluate here another strategy, namely decentralized, neighbourhood-scale green hydrogen production from excess photovoltaic electricity. Bringing hydrogen production closer to photovoltaic production avoids the need to transport the local production via the electricity grid, and therefore the necessary reinforcement costs. It also creates locally additional value on top of self-consumption. Finally, decentralized hydrogen availability could serve local needs, shortening transport routes.

The current preference for hydropower-based hydrogen production is mainly due to the continuous power supply, which maximizes the electrolyzer operating time. However, the recent trend of near-zero electricity price on the market during daytime due to photovoltaic surplus brings new prospects in terms of optimal operating time. Also, the recent massive fall of battery prices mitigates the issue of intermittent supply. Finally, the recent legislation changes further strengthens the potential of delocalized approaches through local electricity communi-

ties. The drop in feed-in tariff, and the exemption from grid taxes could facilitate the business case for such hydrogen production.

### Model description

To evaluate the H<sub>2</sub>-production potential around medium-to-low-voltage transformer substations, we analyzed the general data on nearly 3,100 substations. After filtering to rural and peri-urban areas, this data was supplemented with Planair assumptions to provide all the information required for the optimization model, sketched in figure 1. Details of the model and results will be provided in the final report of the study [1].

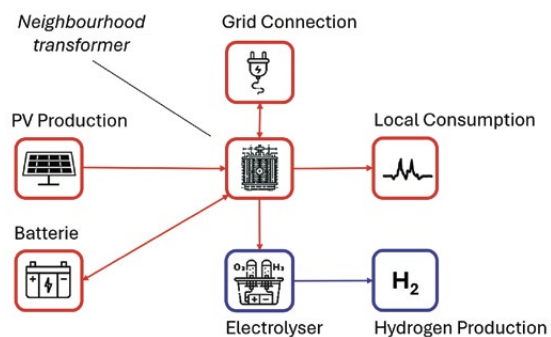


Figure 1 | Sketch of the model used in the optimizations.

Table 1 | Matrixes of the 54 situations evaluated in this study: nine situations for each of the two neighbourhoods, over three-time horizons 2025, 2035 and 2050.

Rural area Transformer size	PV potential		
	low	medium	high
Small (100 kW)	x	x	x
Medium (250 kW)	x	x	x
Large (400 kW)	x	x	x

Suburban area Transformer size	PV potential		
	low	medium	high
Small (250 kW)	x	x	x
Medium (400 kW)	x	x	x
Large (630 kW)	x	x	x

## RESULTS

### Data analysis on the availability of local surplus

In 2025, little surplus at neighborhood level is recorded, below 10 MWh per year. In 2035 and 2050 projections, significant surplus is however expected.

In 2035, rural neighborhoods with a high PV potential have a yearly electricity surplus amounting to about 200 MWh for a 250 kW transformer. For suburban neighborhoods, 200 MWh are also observed but for a 400 kW transformer). For neighborhoods with a median PV potential, the surplus is around half in both geographical zones, and virtually nil in cases of low PV potential. Thus, a PV surplus enabling the production of more than 5 t of H<sub>2</sub> is therefore only available for the largest transformer sizes and high PV potentials.

In 2050, PV surpluses are present in all situations, even in the case of low PV potential neighborhoods. The volume of expected surplus is multiplied by four compared with 2035. In both types of districts, up to 1.7 GWh per year are available for large transformers and a high PV potential in the neighborhood (1.0 GWh for median-sized transformers).

### Optimisation of hydrogen production

Using the local excess electricity, as well as electricity import at a preferential tariff in summer, the economic viability of the production of hydrogen was evaluated. Example results are given in the table 2. In this table, we see that the optimal electrolyzer size increases with time, especially between 2035 and 2050. This is accompanied by a reduced production cost, driven by the higher local electricity supply and decreased modeled electrolyzer price. The total hydrogen production also increases, although less than the electrolyzer size: The load factor of the electrolyzer is indeed reducing, from 47% in 2025 to 30% in 2050.

Table 2 | Extract of the model output for a rural district, 400 kW transformer, high PV potential

Horizon	electrolyzer size	H <sub>2</sub> production costs	annual H <sub>2</sub> production
2025	340 kW	7.40 CHF/kg	30 t
2035	450 kW	6.00 CHF/kg	35 t
2050	1,100 kW	4.60 CHF/kg	62 t

Note: an electricity price for electrolyzer supply from the grid during summer of 8 cts/kWh is used here. Self consumption of local energy is set to 7 cts/kWh for the share of injected energy at a power below the transformer power rating. For power exceeding the transformer rating, excess energy is considered free.

We made a preliminary extrapolation of the obtained results to Switzerland as a whole, by using the ratio of PV potential in the studied area compared to the nation-wide PV potential. An estimated total of around 280,000 t/year of hydrogen could thus be produced by 2035, and 480,000 t/year in 2050. This represents a considerable total of 9 TWh of chemical energy for 2035 (16 TWh for 2050), or more than twenty (resp. thirty) times Switzerland's current hydrogen consumption. Nevertheless, this volume corresponds well to the 11 TWh of necessary chemical energy generation from surplus electricity modeled in Roger Nordmann's recent book [2].

The total electrolyzer capacity to be installed would be 3.6 GW in 2035 and 8.1 GW in 2050, for a total investment of 6.1 billion francs in 2035, to be completed by 5.2 billion francs by 2050. This investment is lower than the estimation of grid costs necessary to sustain the energy transition of several tens of billions of francs [3]. By converting surplus electricity in a more polyvalent energy vector, it also brings additional value compared to grid reinforcement.

## CONCLUSION

The simulations discussed here indicate that local hydrogen production at the neighborhood scale is economically feasible in the medium-term, or even in the near-term provided cheap electricity from the grid is available during summertime. With a potential of around 10 TWh per year, decentralized H<sub>2</sub> production could constitute a pillar of Switzerland energy transition.

Challenges to tackle in the next steps of this work are evaluating the storage, eventual transportation and utilization of this decentralized hydrogen (not considered here), as well as a discussion of the required policies to make it happen (electricity tariffs, incentives).

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- [3] [www.news.admin.ch/fr/nsb?id=91974](http://www.news.admin.ch/fr/nsb?id=91974)

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# Innovative hydrogen solution for industrial applications

This paper presents EasyEnergy's advanced hydrogen production and storage technology implemented at a leading Swiss steel treatment facility. Combining safer electrolysis with innovative metal hydride storage, the system demonstrates significant advancements in industrial hydrogen application through enhanced safety, efficiency, and sustainability while addressing operational challenges in annealing processes.

## INTRODUCTION

Industrial hydrogen systems traditionally present challenges related to safety, efficiency, and spatial requirements. EasyEnergy has developed a comprehensive solution that addresses these challenges through innovations in both production and storage. This implementation at our customer's facility demonstrates how next-generation hydrogen technology can effectively serve industrial annealing processes.

## EASYENERGY'S HYDROGEN TECHNOLOGY

### Advanced electrolysis system

EasyEnergy's hydrogen production system offers significant advantages over conventional approaches:

- **Low-concentration electrolyte.** Utilizing only 2% potassium hydroxide (KOH) versus 20–40% in traditional systems, significantly improving safety profiles.
- **Modular architecture.** Multiple electrolyzers in series and parallel configurations enable maintenance without system shutdown and provide scalability for future needs.
- **Modular production,** perfectly suited to accommodate for changing renewable energy supply or fluctuating demand. Production can be ramped from 12–100% of nominal H<sub>2</sub> flow rate (3–25 Nm<sup>3</sup>/h).
- **Integrated balance of plant.** Comprehensive auxiliary components optimized for seamless operation simplify management and enhance safety.
- **Resource optimization.** Integration with existing water treatment infrastructure reduces implementation costs.

### Advanced hydrogen drying system

The solution includes dedicated drying technology ensuring ultra-pure hydrogen:

- **Molecular sieves.** Achieves hydrogen purity exceeding 99.999% by means of 4A molecular sieves (zeolites) that adsorb and retain the moisture contained in the gas.
- **Intelligent regeneration.** Automated protocols maintain optimal drying performance through microprocessor-controlled cycle adjustments.

### Metal hydride storage solution

The innovative solid-state hydrogen storage offers distinct advantages:

- **Resource optimization.** No need for a compressor to store H<sub>2</sub>, less CAPEX and less OPEX.
- **Compact design.** High volumetric density requires significantly less space than equivalent high-pressure storage systems.
- **Enhanced safety.** Low-pressure operation eliminates risks associated with high-pressure vessels. (40 bar instead of 300bar)
- **Advanced thermal management.** Enables precise control of hydrogen absorption and desorption processes.
- **Operational flexibility.** Rapidly modulates flow rates and pressure to accommodate changing requirements.



Figure 1 | Overview of EasyFlex installation on-site.

## IMPLEMENTATION AND INTEGRATION

### Critical integration aspects

The successful implementation highlighted several key considerations:

- **Process-specific analysis.** Comprehensive assessment of demand profiles, pressure requirements, and purity specifications ensured optimal system dimensioning.
- **Legacy system integration.** Adaptable interfaces enable seamless communication with existing SCADA and process control systems.
- **Infrastructure adaptation.** Modular design addresses site-specific constraints including limited footprint and facility layout restrictions.
- **Operational transition.** Carefully orchestrated migration from previous hydrogen system without production interruption.
- **Knowledge transfer.** Comprehensive training programs ensure facility personnel understand operation, maintenance, and safety protocols.

### Comprehensive safety implementation

Multiple layers of protection were integrated into the system:

- **Inherently safer design.** Low-concentration electrolyte and solid-state storage eliminate hazards rather than merely controlling them.
- **Multi-parameter monitoring.** Comprehensive sensing of critical parameters provides early detection of potential deviations.
- **Automated safety protocols.** Dedicated algorithms evaluate system status and initiate appropriate responses to abnormal conditions.
- **Physical separation.** Strategic segregation with appropriate barriers and explosion protection measures enhance safety.
- **Emergency response integration.** Safety features coordinate with facility-wide emergency procedures.

### Measurable benefits

The implementation has yielded significant operational improvements:

- **Enhanced safety.** Substantially reduced chemical risks through lower-concentration electrolytes and low-pressure storage.
- **Space optimization.** Compact design liberated valuable floor space within the production facility.
- **Operational continuity.** Maintenance on individual components without halting production reduces downtime.
- **Energy efficiency.** Improved energy-to-hydrogen ratio with reduced electricity consumption.
- **Renewable integration.** Configured to interface with on-site photovoltaic system installed in 2024.

### Technical collaboration

The development leveraged expertise from EasyEnergy's partnerships within the Hydropole network, including technical collaboration with technology leaders GRZ, Enapter and Bluenergy. This collaborative approach facilitated the incorporation of complementary innovations, demonstrating how industry partnerships can accelerate technological advancement.

## FUTURE APPLICATIONS

The system's adaptability makes it suitable for various industrial applications beyond metal annealing, including:

- heat treatment operations in metallurgical processes;
- glass manufacturing requiring controlled atmosphere;
- electronics manufacturing with precise atmospheric requirements;
- food processing applications requiring hydrogen;
- chemical synthesis utilizing hydrogen as a reactant;
- energy storage from medium to long term storage;
- energy storage for black start systems and backup power;
- integration in datacenter energy supply.

## CONCLUSION

EasyEnergy's EasyFlex hydrogen solution demonstrates how advanced technology can transform industrial processes while addressing multiple operational challenges. The implementation at the steel processing facility illustrates comprehensive benefits achievable through thoughtful systems integration and material innovation. The key advantages — enhanced safety, spatial efficiency, increased storage capacity, operational flexibility, and renewable energy integration — represent significant advances in industrial hydrogen applications.

56

Hydropole

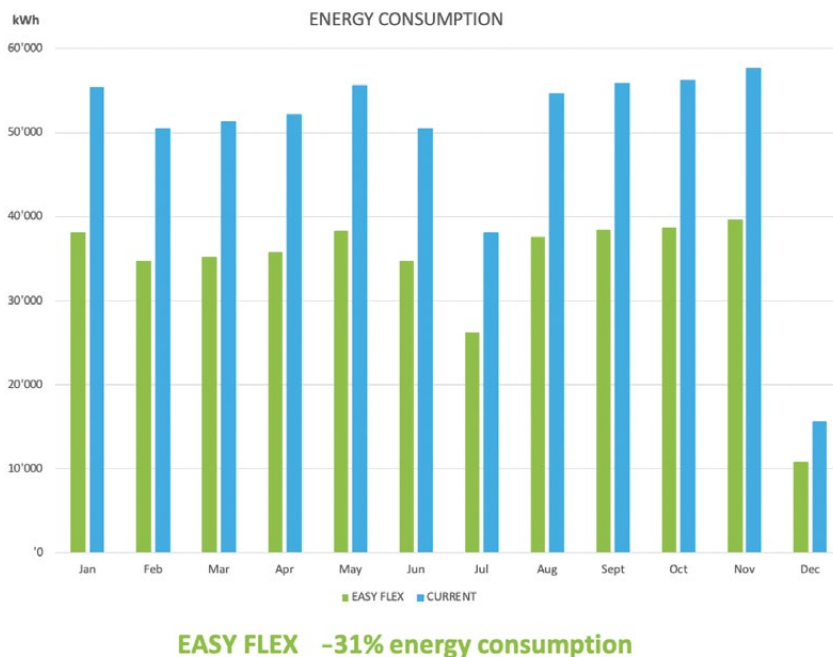


Figure 2 | EasyFlex vs previous system: energy consumption.

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# Advancing Swiss innovation in fuel cell technology

Established in 2017 and headquartered in Nyon, EH Group is proud to be a key contributor to the country's growing hydrogen ecosystem. Specializing in high-performance fuel cell systems, our mission is to accelerate the deployment of hydrogen-based energy solutions across critical sectors—supporting Switzerland's goals for carbon neutrality, energy resilience, and technological leadership.

At the core of our offering is the EH-TRACE 250 kW fuel cell system, designed for modular deployment in high-power applications. In 2024, this system received Approval in Principle (AiP) from leading maritime classification body DNV, marking a major milestone for its use in marine environments. With inland waterways playing a vital role in

Switzerland's clean mobility strategy, EH-TRACE is ideally suited for integration into lake vessels and ferries — offering zero-emission propulsion with high reliability and efficiency.

EH Group's proprietary stack design is built for scalability and manufacturability, combining ultra-high power density with a highly automated assembly process. This approach enables cost-effective production while maintaining performance and durability — key factors for successful integration into commercial systems.

We are currently focused on three strategic application areas within Switzerland and beyond:

- **Large stationary power.** Our fuel cells are ideally suited for deployments in data centers and resilient microgrids, providing clean backup and off-grid power with seamless integration into existing infrastructure.
- **Marine.** As lakes and inland waterways take on a greater role in sustainable transport, our DNV-approved systems are powering a new class of zero-emission vessels.
- **Aviation.** We are collaborating with aerospace partners to support low-weight, high-efficiency solutions for electric aviation — aligning with Switzerland's commitment to innovation in clean mobility.

EH Group's technology is already in use across multiple regions, with deployments in Switzerland, across Europe, UK, India, and Australia, demonstrating the versatility and global competitiveness of Swiss-made hydrogen technologies.

Looking toward 2026 and beyond, we remain dedicated to supporting the rollout of hydrogen infrastructure in Switzerland, advancing fuel cell adoption across key sectors, and fostering international collaboration. As a member of Hydropole, EH Group is committed to turning innovation into impact—ensuring hydrogen plays a foundational role in the country's sustainable energy future.



EH 250kW FC system.

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**Vincent Boucand**  
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Bulle

# Developing hydrogen internal combustion engine

58

Hydropole

In a world where the reduction of global greenhouse gases is one of the most pressing challenges, we at Liebherr stand at the forefront of innovation, working tirelessly to develop alternative and climate-friendly powertrain concepts. With a wide array of products that serve industries around the globe, the company knows that there is no one-size-fits-all solution when it comes to achieving net-zero emissions. That is why we are committed to an open approach to powertrain technology, exploring a diverse range of fuels that can meet varying demands and operational environments.

For machines with high-energy requirements, hydrogen-based powertrains are a promising option for nearly greenhouse gas-neutral performance. We at Liebherr-Components have made a significant investment in the development of our hydrogen engine and the respective test facilities since 2021, at our Liebherr engine competence centre in Bulle (Switzerland). The Liebherr Machines Bulle SA team is engaged into the development of hydrogen internal combustion engine technology for a more environmentally friendly future of construction equipment machines.

Since 2022, our engineering team in Canton Fribourg has been rigorously testing hydrogen engines. The groundwork was laid in 2021 with the conversion of two engine test benches, incorporating advanced safety features for handling hydrogen. In autumn 2022, Liebherr showcased its first hydrogen-powered crawler excavator, – R 9XX H2, at the world's leading trade fair for construction machinery, Bauma, held in Munich once every three years, where it received an innovation award.

We at Liebherr-Components are convinced that a hydrogen engine brings intrinsic advantages with its compact size, reduced weight, cost efficiency, easy retrofit, ability to cope with vibrations, dust, low fuel quality and the possibility to utilise the existing service and remanufacturing infrastructure. These are clear benefits that set a hydrogen engine apart from batteries and fuel cell technologies. Compared to traditional diesel engines, a hydrogen engine runs on pure

hydrogen and therefore causes near zero CO<sub>2</sub> and particulate matter emissions. Even nitrogen oxide emissions are drastically reduced in the engine outlet before catalysts are used, so that a hydrogen engine can compete with other zero-emission technologies on the account of the newly engineered after-treatment system.

The first application of the 300kW six-cylinder hydrogen engine is intended to be a Liebherr wheel loader, a machine that requires high power and demands excellent transient performance in comparison to other construction machines. To meet these challenges, our engineers concentrate on several key areas, such as an advanced boosting system, improved crankcase ventilation system, advanced fuel injection and ignition technologies, an exhaust after-treatment system to reduce emissions, new software and optimized combustion technology. For example, the refinement of the lube oil formulation related to combustion challenges is another key focus. Hydrogen combustion produces a significant amount of water vapour, which can accumulate in the engine lube oil, leading to viscosity changes and potential corrosion. Our engineers are collaborating with lubricant experts to develop a specific lube oil to address issues such as pre-ignition, for example, that can be influenced by oil droplets in the combustion chamber.

On our site in Bulle, we have already accumulated thousands of hours on our test benches. A key strength of the approach by our engineering team is a vertical integration. This means that we develop crucial components, like a fuel injection system and an electronic control unit, in-house. Even the software that makes the machine operate efficiently is being developed at Liebherr Machines Bulle SA in Switzerland. By tackling technical complexities and leveraging our internal expertise, we are driving innovation towards powerful, efficient and clean machines for tomorrow.

Addressing the unique challenges of hydrogen combustion is a core part of our R&D efforts. For instance, ensuring engine startability under low

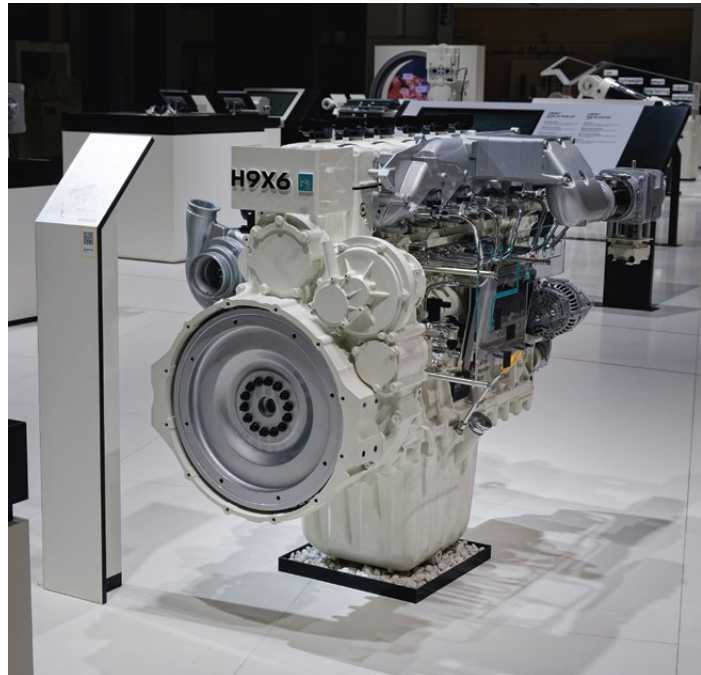
temperatures is a crucial technical hurdle for machines that must operate all-year round in diverse climates. The high diffusivity and wide flammability range of hydrogen, though being beneficial for lean-burn operation, also present challenges that require advanced control strategies to ensure reliable ignition and stable combustion, even under negative ambient temperatures.

Furthermore, we are optimising engine components to maximise efficiency. Cylinder head optimisation for air flow management is critical to ensuring the precise delivery of the hydrogen-air mixture into the combustion chamber. Our engineers are using advanced computational fluid dynamics (CFD) to refine the design of intake ports and combustion chamber shape with the goal of achieving homogeneous mixture formation and knock-free combustion.

To protect our technological advancements and competitive advantage, we are actively engaged in the patenting technical solutions that enhance machine drivability and performance.

Beyond the work on the engine test benches, a major focus for our team is the long-term viability and real-world performance of hydrogen engines for off-road machines. To this end, Liebherr has delivered several hydrogen engines for installation in Liebherr machines, which will undergo extensive testing for a period of several years. This programme is designed to gather feedback on the hydrogen engine technology, including the reliability of the energy storage system under real operational conditions.

Fuelling the engines is key to acceptance in the market. Fuelling them in a "green" way, even more so. Therefore, our engine test benches in Bulle are connected to the Gruyere Hydrogen Power (GHP) facility located a few metres away, for green hydrogen to be directly provided through a specially laid pipeline. This ensures a continuous and sustainable source of energy for the engine development.



Liebherr hydrogen internal combustion engine.



The six-cylinder hydrogen engine.

# Shaping the future with high pressure

### Technological expertise for products for the hydrogen market

Nova Werke AG, headquartered in Effretikon (Switzerland) and with subsidiaries in France, Germany, Italy and Hong Kong, is an internationally active technology company. Under the Nova Swiss quality brand, the company develops and manufactures innovative solutions in three areas: high-pressure technology, engine components, and surface technology.

Particular focus is given to the development and production of high-pressure components for the hydrogen market, which is a key segment of the energy future. The safe handling of hydrogen requires products of the highest precision and quality, as well as comprehensive expertise. As an experienced manufacturer, Nova Swiss offers a comprehensive range of certified high-pressure components for storage, transport and refueling applications, with pressure ratings from 350 to 1,380 bar (35 to 138 MPa). These components are suitable for use in hydrogen refueling stations, vehicles and storage systems.

### Technology for maximum safety and economy

Nova Swiss relies on tried-and-tested materials, advanced surface coatings and precise manufacturing processes to ensure maximum safety, reliability and durability. The products are 'plug and play', meaning they are cleaned, tested and ready for immediate use without any additional work or testing. Thanks to their high number of opening and closing cycles, they are particularly durable and require little maintenance, resulting in low operating costs and high sustainability.

The portfolio in the H<sub>2</sub> sector includes, among other things:

- **Manual and pneumatically actuated needle valves** (for pipes ¼' to 1', up to 1,380 bar).
- **Solenoid valves** with minimal space requirements (up to 1,000 bar).
- **Check valves** with hard and soft seats for high tightness in all pressure ranges.
- **Safety valves** (CE-certified, up to 4,500 bar).
- **Diaphragm compressors** for clean compression (up to 3,000 bar).
- **Fittings**, adapters and high-pressure pipes (for pipes ¼' to 1', up to 1,380 bar).
- **Ball valves** (for pipes ¼' to 1', for 1,380 bar).



Headquarter Nova Werke AG, Effretikon.

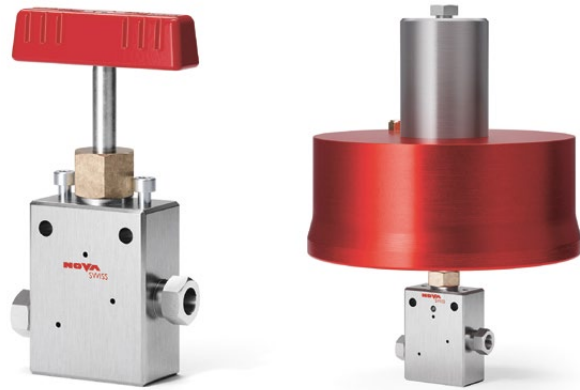
### Experience, values and innovation

With decades of experience in high-pressure technology and a culture of ongoing innovation, Nova Swiss is a company with a strong heritage. Our core values of appreciation, trust and sustainability not only characterize the way we work together, but also our customer relationships and product development.

As well as focusing on hydrogen, Nova Swiss offers technologically advanced solutions in engine components and surface technology. Customers from a wide range of industries benefit from our high level of technological expertise, short development cycles and Swiss-quality production.

### We are a strong partner for a sustainable energy future

With its clear commitment to renewable energies, state-of-the-art manufacturing expertise and high reliability, Nova Swiss is a leading partner in the hydrogen sector. The company is not just shaping the energy transition; it's driving it forward at full pressure.



Manually (left) and pneumatically (right) actuated needle valve



Diaphragm compressor



Fitting

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# Hydrogen history



Prof. Andreas Züttel  
LMER, EPFL

**1520** First recorded observation of hydrogen by Paracelsus through dissolution of metals (iron, zinc, and tin) in sulfuric acid.

**1625** First description of hydrogen by Johann Baptista van Helmont. First to use the word "gas".

**1662** **Robert Boyle's** law: gas law relating pressure and volume.



**1766** Henry Cavendish publishes in "On Factitious Airs" a description of "dephlogisticated air" by reacting zinc metal with hydrochloric acid and isolates a gas seven to eleven times lighter than air.

**1783** **Jacques Charles** makes the first flight with his hydrogen-filled gas balloon or Charlière.



Fig. 187. Descente d'un ballon à gaz hydrogène de Jacques Charles.

**1783** **Antoine Lavoisier** and Pierre Laplace measure the heat of combustion of hydrogen using an ice calorimeter.



**1784** Jean-Pierre Blanchard attempts a dirigible hydrogen balloon, but it was unable to steer.

**1787** Louis-Bernard Guyton de Morveau and others give hydrogen its name (Gk: hydro = water, -genes = born of).

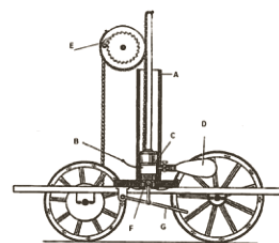
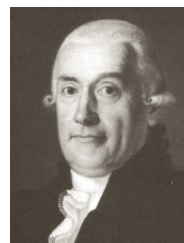
**1787** Charles's law (gas law, relating volume and temperature).

**1789** Jan Rudolph Deiman and Adriaan Paets van Troostwijk use an electrostatic machine and a Leyden jar for the first electrolysis of water.

**1800** William Nicholson and Anthony Carlisle break down water into hydrogen and oxygen by electrolysis with a voltaic pile.

**1801** Humphry Davy discovers the concept of the fuel cell.

**1806** **François Isaac de Rivaz** builds the **de Rivaz engine**, the first internal combustion engine powered by a mixture of hydrogen and oxygen.



**1809** Thomas Forster observes with a theodolite the drift of small free pilot balloons filled with "inflammable gas"

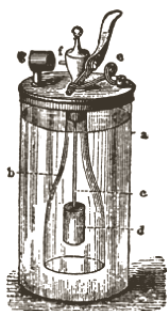
**1809** Gay-Lussac's law, a gas law relating temperature and pressure.

**1811** Avogadro's law, a gas law relating volume and amount of substance.

**1819** **Edward Daniel Clarke** invents the hydrogen gas blowpipe.



**1823** **Döbereiner's Lamp**, a lighter invented by Johann Wolfgang Döbereiner.

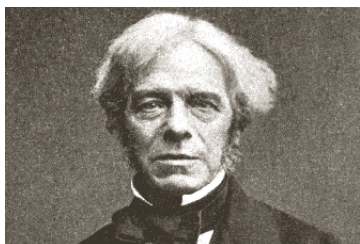


**1824** Michael Faraday invents the rubber balloon.

**1826** Thomas Drummond builds the Drummond Light.

**1826** Samuel Brown tests his internal combustion engine by using it to propel a vehicle up Shooter's Hill.

**1834** **Michael Faraday** publishes Faraday's laws of electrolysis.



**1834** Benoît Paul Émile Clapeyron – Ideal gas law.

**1836** John Frederic Daniell invents a primary cell in which hydrogen is eliminated in the generation of the electricity.

**1839** **Christian Friedrich Schönbein** publishes the principle of the fuel cell in the *Philosophical Magazine*.



**1839** William Robert Grove develops the Grove cell.

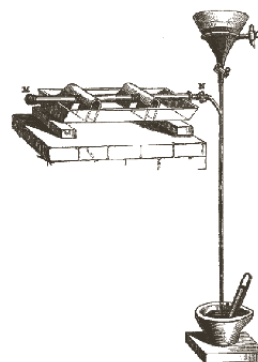
**1842** William Robert Grove develops the first fuel cell (which he calls the gas voltaic battery).

**1849** Eugène Bourdon Bourdon gauge (manometer).

**1863** Etienne Lenoir makes a test drive from Paris to Joinville-le-Pont with the 1-cylinder, 2-stroke Hippomobile running on coal gas.

**1866** August Wilhelm von Hofmann invents the Hofmann voltameter for the electrolysis of water.

**1868** **Thomas Graham** discover the metal-hydrides by absorbing hydrogen in Palladium.



**1873** Thaddeus S. C. Lowe – water gas; the process uses the water gas shift reaction.

**1874** Jules Verne – *The Mysterious Island*: "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."

**1884** Charles Renard and Arthur Constantin Krebs launch the airship La France.

**1885** **Zygmunt Florenty Wróblewski** publishes hydrogen's critical temperature as 33 K; critical pressure, 13.3 atmospheres; and boiling point, 23 K.

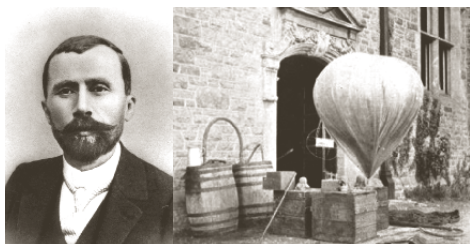


**1889** Ludwig Mond and Carl Langer coin the name fuel cell and try to build one running on air and Mond gas.

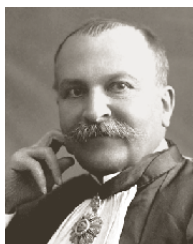
**1895** Hydrolysis.

**1896** D.D. Jackson and J.W. Ellms, hydrogen production by microalgae (*Anabaena*).

**1896** **Leon Teisserenc de Bort** carries out experiments with high flying instrumental **weather balloons**.



**1897** **Paul Sabatier** facilitates the use of hydrogenation with the discovery of the Sabatier reaction.

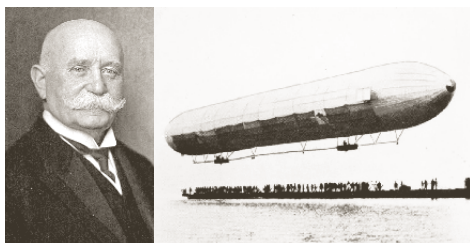


**1898** **James Dewar** liquefies hydrogen by using regenerative cooling and his invention, the vacuum flask at the Royal Institution of Great Britain in London.



**1899** James Dewar collects solid hydrogen for the first time.

**1900** **Count Ferdinand von Zeppelin** launches the first hydrogen-filled **Zeppelin LZ1** airship.



**1901** Wilhelm Normann introduces the hydrogenation of fats.

**1903** Konstantin Eduardovich Tsiolkovsky publishes "The Exploration of Cosmic Space by Means of Reaction Devices".

**1907** Lane hydrogen producer.

**1909** Count Ferdinand Adolf August von Zeppelin make the first long distance flight with the Zeppelin LZ5.

**1909** Linde–Frank–Caro process.

**1910** The first Zeppelin passenger flight with the Zeppelin LZ7.

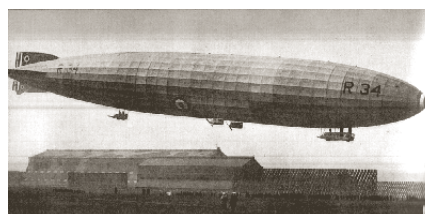
**1910** **Fritz Haber** patents the Haber process.



**1912** The first scheduled international Zeppelin passenger flights with the Zeppelin LZ13.

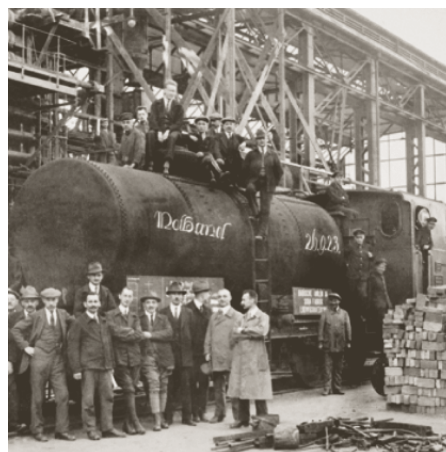
**1913** Niels Bohr explains the Rydberg formula for the spectrum of hydrogen by imposing a quantization condition on classical orbits of the electron in hydrogen.

**1919** The first Atlantic crossing by airship with the **Beardmore HMA R34**.



**1920** Hydrocracking, a plant for the commercial hydrogenation of brown coal is commissioned at Leuna in Germany.

**1923** **Steam reforming**, the first synthetic methanol is produced by BASF in Leuna.



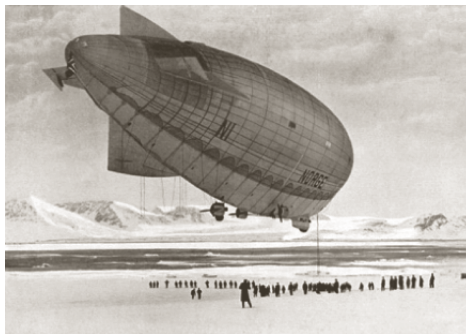
**1923** J. B. S. Haldane envisions in *Daedalus; or, Science and the Future* "great power stations where during windy weather the surplus power will be used for the electrolytic decomposition of water into oxygen and hydrogen".

**1926** Wolfgang Pauli and Erwin Schrödinger show that the Rydberg formula for the spectrum of hydrogen follows from the new quantum mechanics.

**1926** Partial oxidation, Vanderveer and Parr at the University of Illinois use oxygen in the place of air for the production of syngas.

**1926** Cyril Norman Hinshelwood describes the phenomenon of chain reaction.

**1926** Umberto Nobile makes the first flight over the North Pole with the **hydrogen airship Norge**.



**1929** Paul Harteck and Karl Friedrich Bonhoeffer achieve the first synthesis of pure parahydrogen.

**1929** The **hydrogen-filled LZ 127 Graf Zeppelin** makes a 33,234 km (20,651 mi; 17,945 nmi) circumnavigation of the world. It is the first and only airship to do so, and the second circumnavigation of the globe by air. The voyage took a total of 21 days, 5 hours and 31 minutes.



**1930** Rudolf Erren – Erren engine – patent CH148238A – Improvements in and relating to internal combustion engines using a mixture of hydrogen and oxygen as fuel.

**1935** Eugene Wigner and H.B. Huntington predict metallic hydrogen.

**1937** The **Zeppelin LZ 129 Hindenburg** is destroyed by fire.



**1937** The Heinkel HeS 1 experimental gaseous hydrogen-fueled centrifugal jet engine is tested at Hirth in March the first working jet engine.

**1937** The first hydrogen-cooled turbogenerator goes into service at Dayton, Ohio.

**1938** The first 240 km hydrogen pipeline Rhine-Ruhr.

**1938** Igor Sikorsky from Sikorsky Aircraft proposes liquid hydrogen as a fuel.

**1939** Rudolf Erren – Erren engine – US patent 2,183,674 – Internal combustion engine using hydrogen as fuel.

**1939** Hans Gaffron discovers that algae can switch between producing oxygen and hydrogen.

**1941** The first mass application of hydrogen in internal combustion engines: **Russian lieutenant Boris Shelishch** in the besieged Leningrad converts some hundreds **cars "GAZ-AA"** which serve posts of barrage balloons of air defense.



**1943** Liquid hydrogen is tested as rocket fuel at Ohio State University.

**1943** Arne Zetterström describes hydrox.

**1947** Willis Lamb and Robert Retherford measure the small energy shift (the Lamb shift) between the  $2S_{1/2}$  and  $2P_{1/2}$  orbitals of hydrogen, providing a great stimulus to the development of quantum electrodynamics.

**1949** Hydrodesulfurization (catalytic reforming) is commercialized under the name "platforming process".

**1951** Underground hydrogen storage.

**1952** **Ivy Mike**, the first successful test of a nuclear explosive based on hydrogen (actually, deuterium) fusion.



**1952** Non-refrigerated transport Dewar.

**1955** W. Thomas Grubb modifies the fuel cell design by using a sulphonated polystyrene ion-exchange membrane as the electrolyte.

**1956** **First 4 MW electrolyzer** producing hydrogen from renewable energy (hydroelectric power plant in Switzerland).



**1957** The specifications for the U-2 a double axle liquid hydrogen semi-trailer are issued.

**1957** **Pratt & Whitney's model 304 jet engine** using liquid hydrogen as fuel tested for the first time as part of the Lockheed CL-400 Suntan project.



**1958** Leonard Niedrach devises a way of depositing platinum onto the membrane, known as the Grubb-Niedrach fuel cell.

**1958** Allis-Chalmers demonstrates the **D12**, the first 15 kW fuel cell tractor.



**1959** Francis Thomas Bacon builds the Bacon Cell, the first practical 5 kW hydrogen-air fuel cell to power a welding machine.

**1960** Allis-Chalmers builds the first fuel cell forklift.

**1961** **RL-10** liquid hydrogen-fuelled rocket engine first flight.



**1964** Allis-Chalmers builds a 750-watt fuel cell to power a one-man underwater research vessel.

**1965** The first commercial use of a fuel cell in Project Gemini.

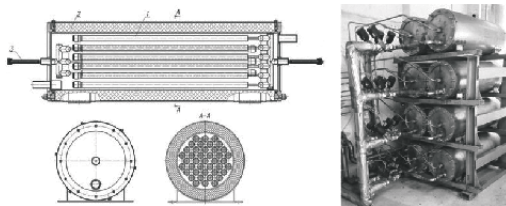
**1966** J-2 (rocket engine) liquid hydrogen rocket engine flies.

**1966** Karl Kordesch **Fuel cell car** with pressurized hydrogen.

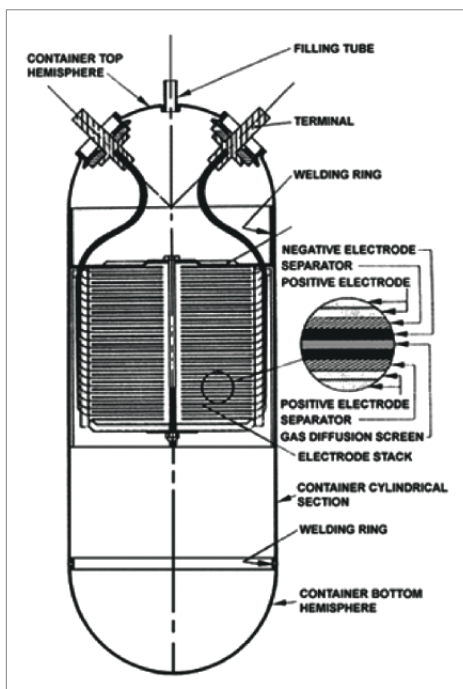


**1967** Akira Fujishima discovers the Honda-Fujishima effect, used for photocatalysis in the photoelectrochemical cell.

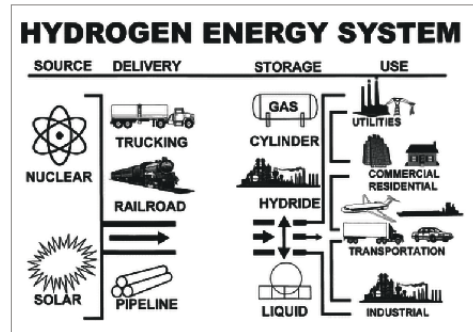
**1967** Metal hydride compressor.



**1970** Nickel hydrogen battery.



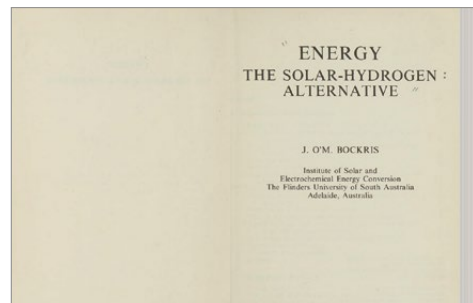
**1970** John Bockris or Lawrence W. Jones coins the term "**hydrogen economy**".



**1973** The 30 km hydrogen pipeline in Isbergues.

**1973** Linear compressor.

**1975** John Bockris, *Energy: The Solar-Hydrogen Alternative*, ISBN 0-470-08429-4.



**1979** HM7B rocket engine.

**1981** Space Shuttle Main Engine first flight.



**1988** First flight of **Tupolev Tu-155**, a variant of the Tu-154 airliner designed to run on hydrogen.



**1989** BMW unveiled the world's first hydrogen 12-cylinder engine at the International Motor Show in Frankfurt.



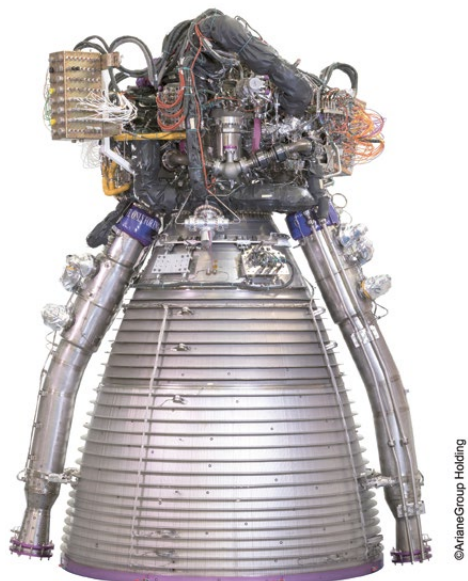
**1990** The first solar-powered hydrogen production plant Solar-Wasserstoff-Bayern becomes operational.



**1994** Daimler-Benz AG presents NECAR I hydrogen car with a fuel cell and a hydrogen tank.

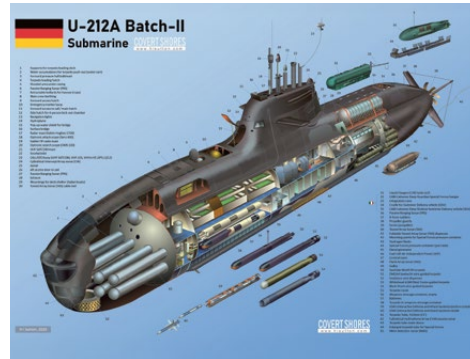


**1996** Vulcain rocket engine.



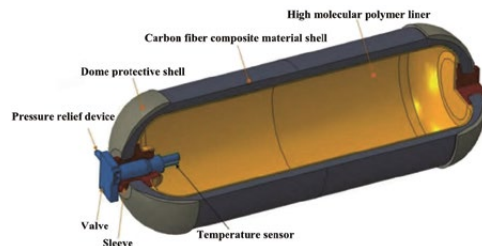
**1997** Anastasios Melis discovers that the deprivation of sulfur will cause algae to switch from producing oxygen to producing hydrogen.

**1998** Type 212 submarine.



**2000** Peter Toennies demonstrates superfluidity of hydrogen at 0.15 K.

**2001** The first type IV hydrogen tanks for compressed hydrogen at 700 bar (10000 PSI) are demonstrated.



**2002** Type 214 hydrogen submarine from Thyssen-Krupp.



**2002** The first hydrail locomotive is demonstrated in Val-d'Or, Quebec.

**2002** Daimler-Benz AG presents the Nekar 4 with liquid hydrogen and a fuel cell.

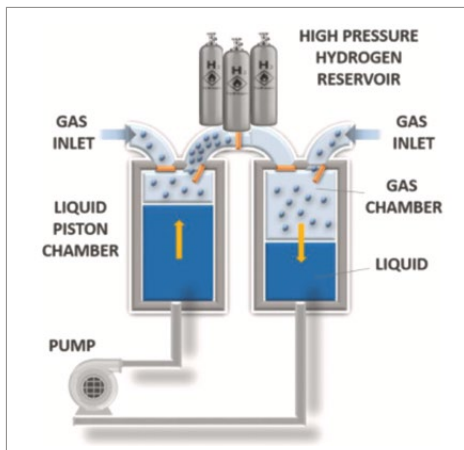


**2004** DeepC, an autonomous underwater vehicle propelled by an electric motor powered by a hydrogen fuel cell.

**2004** Snow groomer with ICE and metal hydride demonstrated in Switzerland.



**2005** Ionic liquid piston compressor by Linde.



**2014** Toyota releases its first hydrogen fuel cell car, the **Mirai**.



**2014** Hyundai Nexo hydrogen car FCEV.



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# Hydrogen facts



Prof. Andreas Züttel  
LMER, EPFL

## HYDROGEN TODAY AND IN FUTURE

### Hydrogen from fossil fuels

The global hydrogen production in 2023 amounts to 120 Mt of hydrogen containing to 4760 TWh of energy. Today 98% of the hydrogen is of fossil origin and used as a chemical reactant, mainly in oil refineries and for ammonia synthesis.

Hydrogen is primarily produced through the following methods today:

- **Steam methane reforming (SMR).** The most common method, accounting for nearly 50% of global hydrogen production. It involves reacting methane with steam at high temperatures to produce hydrogen and carbon dioxide. If CO<sub>2</sub> is captured, it is termed "blue hydrogen".
- **Coal gasification.** Used in some regions, this process converts coal into synthesis gas (hydrogen and carbon monoxide) by reacting it with steam and oxygen.
- **Electrolysis.** Splits water into hydrogen and oxygen using electricity. When powered by renewables, it produces "green hydrogen," though it currently represents only about 5% of global production.
- **Other methods.** Experimental processes like methane pyrolysis (producing solid carbon instead of CO<sub>2</sub>), biological methods using microbes, and photolytic water splitting are being explored for cleaner production.

The hydrogen is transported in pipelines and compressed (200–350 bar) in trailers. For storage the hydrogen is liquified and stored in cryotanks or compressed to 30–200 bar in steel cylinders. Alternatively, hydrogen can be stored in metal hydrides.

### Hydrogen applications

#### HYDROCRACKING

Hydrocracking is a catalytic refining process used to break down heavy hydrocarbon molecules into lighter, more valuable products like diesel, jet fuel, kerosene, and gasoline.

The process is divided into following steps:

1. **Feedstock preparation.** Heavy fractions like vacuum gas oil (VGO) or other distillates are preheated and mixed with hydrogen gas.
2. **First-stage reactor.** The mixture enters a reactor under high pressure (70–140 bar) and high temperature (400–850°C), where it passes over a catalyst. Hydrogen reacts with sulfur and nitrogen impurities, converting them into hydrogen sulfide (H<sub>2</sub>S) and ammonia (NH<sub>3</sub>), while initial cracking of hydrocarbons begins.
3. **Separation.** Hydrocarbon vapors are cooled, and liquid products are separated from gases in a hydrocarbon separator. Hydrogen is recycled.
4. **Second-stage reactor.** Remaining feedstock undergoes further cracking at even higher temperatures and pressures in a second reactor to maximize conversion into lighter products.
5. **Fractionation.** The resulting products are sent to a fractionator, where they are separated into desired outputs like diesel, kerosene, naphtha and LPG.

Hydrocracking is highly flexible and efficient for producing clean fuels with low sulfur content, meeting modern environmental standards.

#### AMMONIA SYNTHESIS

Ammonia is synthesized today primarily through the Haber-Bosch process, which combines nitrogen from the air with hydrogen under high pressure (100–350 bar) and high temperature (400–550°C) using iron-based or ruthenium catalysts. This exothermic reaction produces ammonia (NH<sub>3</sub>) while continuously removing ammonia to maintain equilibrium.

Recent advancements include transition metal-free catalysts. Ba-Si oxynitride-hydride catalysts, which operate under milder conditions, reducing energy requirements and emissions were developed. Enhanced performance is achieved by adding ruthenium nanoparticles.

## METHANOL SYNTHESIS

Methanol is synthesized today primarily through industrial production using synthesis gas (Syngas).

### Process overview

1. Syngas, a mixture of carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), and hydrogen (H<sub>2</sub>), is produced via steam reforming or autothermal reforming of natural gas, or by gasifying coal or biomass.
2. CO and H<sub>2</sub> react over a copper-zinc-alumina catalyst at high pressure (50–100 atm) and temperatures around 250°C to form methanol (CH<sub>3</sub>OH).
3. Excess H<sub>2</sub> can be balanced by injecting CO<sub>2</sub>, which also reacts to form methanol.

## FAT HARDENING

Fat hardening, also known as hydrogenation, is a chemical process that converts unsaturated fats into saturated fats by adding hydrogen atoms to their double bonds. This process alters the physical and chemical properties of fats, making them more solid and stable at room temperature.

### Process overview and implications

Unsaturated fats (e.g., vegetable oils) are combined with hydrogen gas in the presence of a metal catalyst, typically nickel, under high temperature and pressure.

Hydrogen atoms attach to the carbon atoms of double bonds, converting them into single bonds, thus saturating the fat molecules:

- **Partial hydrogenation.** Only some double bonds are saturated, resulting in semi-solid fats like margarine. This process is widely used in food production but has faced scrutiny due to its health implications due to trans fats as a side effect, which is associated with increased health risks like heart disease.
- **Full hydrogenation.** All double bonds are saturated, creating fully solid fats for baking (e.g., shortening) and spreads like margarine, with no trans fats.

## Hydrogen from renewable energy

The global CO<sub>2</sub> free hydrogen production in 2023 was 2.5 Mt of blue hydrogen and 0.15 Mt of green hydrogen. The color of the hydrogen is used to distinguish between the hydrogen production pathways with different CO<sub>2</sub> emissions.

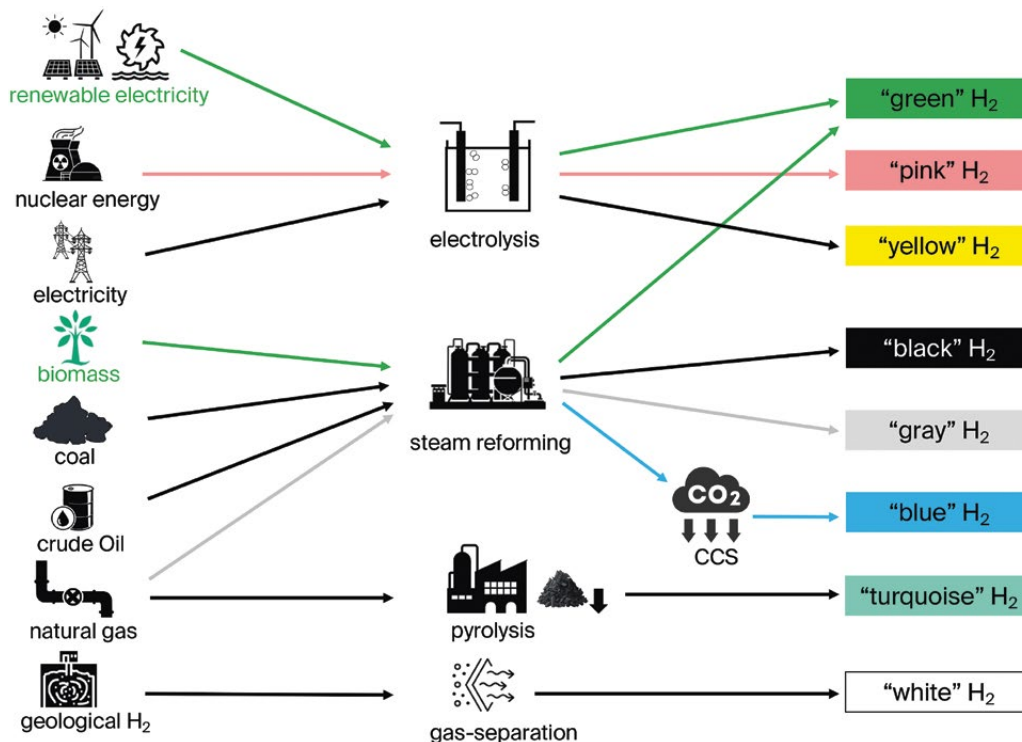


Figure 1 | Origin of the hydrogen with the production pathway and the resulting color.

The colors of hydrogen refer to the methods used for its production and their environmental impact:

- **Green hydrogen.** Produced via electrolysis using renewable energy like wind or solar. It is emission-free and considered the most sustainable option.
- **Blue hydrogen.** Made from natural gas through steam methane reforming, with carbon emissions captured and stored (CCS), making it low-carbon but reliant on fossil fuels.
- **Black hydrogen.** Steam reforming of coal.
- **Gray hydrogen.** Derived from natural gas without CCS, emitting significant CO<sub>2</sub>. It is the most common production method today.
- **Black/brown hydrogen.** Produced from coal or lignite, releasing high amounts of CO<sub>2</sub> and carbon monoxide.
- **Yellow hydrogen.** Created via electrolysis powered by solar energy.
- **Pink hydrogen.** Generated using nuclear-powered electrolysis, offering carbon-free production but raising concerns about nuclear waste.
- **Turquoise hydrogen.** Produced through methane pyrolysis, yielding solid carbon instead of CO<sub>2</sub>, offering a lower-carbon alternative.
- **White hydrogen.** From geological sources, e.g. as byproduct of natural gas or steam from geothermal extraction.

### Energy storage with hydrogen

Renewable energy storage using hydrogen has both advantages and challenges in terms of efficiency and cost:

- The round-trip efficiency of hydrogen storage is typically low, ranging from 30% to 50%, compared to 70–90% for batteries.
- Conversion losses occur during electrolysis (65–70% efficiency for current systems) and re-electrification (up to 60% efficiency in fuel cells or 60% in combined cycle plants).
- Hydrogen storage systems have high capital costs due to expensive components like electrolyzers, fuel cells, and storage tanks.
- Storage costs are also influenced by the form of hydrogen (compressed gas, liquid, in solid form, or stored in salt caverns), with underground salt caverns offering lower costs for large-scale applications.

### New applications for hydrogen

Hydrogen's low efficiency makes it less suitable for short-term energy storage but ideal for long-term, large-scale seasonal energy storage, where its high energy density and indefinite storage capability outweigh efficiency concerns.

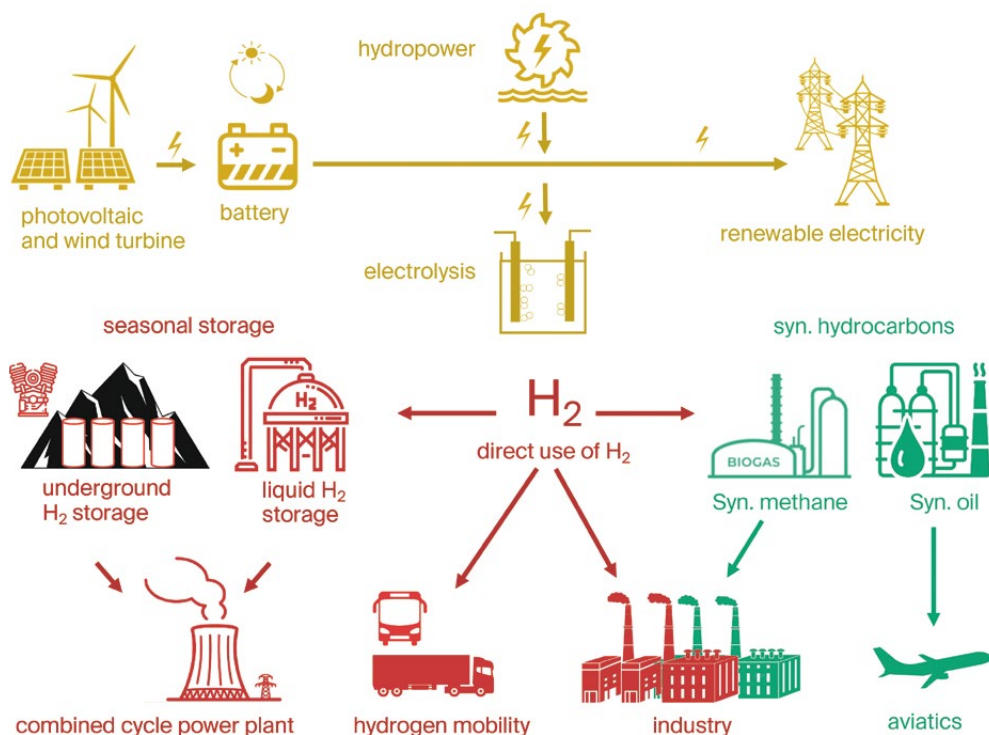
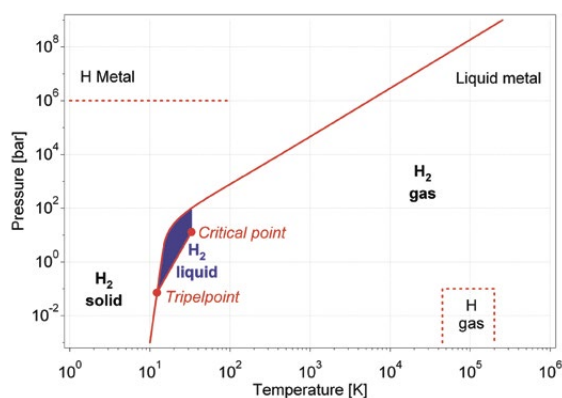


Figure 2 | Hydrogen from renewable energy and the potential future applications.

## PROPERTIES OF HYDROGEN

Hydrogen — (Gr. *hydro*, water, and *genes*, forming). Hydrogen was prepared many years before it was recognised as a distinct substance by Cavendish in 1766. It was named by Lavoisier. Hydrogen is the most abundant of all elements in the universe, and it is thought that the heavier elements were, and still are, being built from hydrogen and helium. It has been estimated that hydrogen makes up more than 90% of all the atoms or three quarters of the mass of the universe. Hydrogen is found in the sun and most stars, and plays an important part in the proton-proton reaction and carbon-nitrogen cycle, which accounts for the energy of the sun and stars. It is thought that hydrogen is a major component of the planet Jupiter and that at some depth in the planet's interior the pressure is so great that solid molecular hydrogen is converted into solid metallic hydrogen. In 1973, it was reported that a group of Russian experimenters may have produced metallic hydrogen at a pressure of 2.8 Mbar. At the transition the density changed from 1.08 to 1.3 g/cm<sup>3</sup>. Earlier, in 1972, a Livermore (California) group also reported on a similar experiment in which they observed a pressure-volume point centered at 2 Mbar. It has been predicted that metallic hydrogen may be metastable; others have predicted it would be a superconductor at room temperature.



**Figure 3** | Primitive phase diagram for hydrogen (adapted from W. B. Leung, N. H. March and H. Motz, *Physics Letters* 56A (6) (1976), pp. 425–426)

On earth, hydrogen occurs chiefly in combination with oxygen in water, but it is also present in organic matter such as living plants, petroleum, coal, etc. It is present as a free element in the atmosphere, but only to the extent of less than 1 ppm by volume originates from water splitting by UV-light. It is the lightest of all gases, and combines with other elements, sometimes explosively, to form compounds. Great quantities of hydrogen are required commercially for the fixation of nitrogen from the air in the Haber-Bosch ammonia process and for the hydrogenation of fats and oils. It is also used

in large quantities in organic chemistry e.g. in methanol production, in hydrodealkylation, hydro-cracking, and hydrodesulfurization. It is also used as a rocket fuel, for welding, for production of hydrochloric acid, for the reduction of metallic ores, and for filling balloons. The lifting power of 1 m<sup>3</sup> of hydrogen gas is about 1.16 kg at 0°C and 1 bar pressure.

Production of hydrogen worldwide now amounts to about 5 · 10<sup>10</sup> kg per year. It is prepared by the reaction of steam on heated carbon, by thermal decomposition of certain hydrocarbons, by the electrolysis of water, or by the displacement from acids by certain metals. It is also produced by the reaction of sodium or potassium hydroxide with aluminum. Liquid hydrogen is important in cryogenics and in the study of superconductivity, as its melting point is only 20 K.

**Table 1** | Vapor pressure and density of p-hydrogen at low temperatures. <sup>a</sup> Triple point. <sup>b</sup> 101.3 kPa. <sup>c</sup> Critical point.

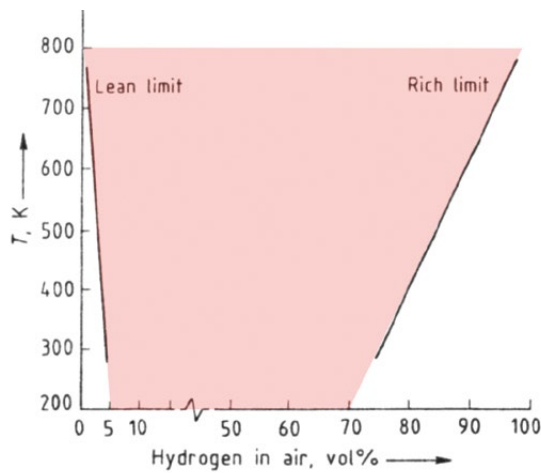
Temperature [K]	Vapor pressure [kPa]	Density [kg/m <sup>3</sup> ]		
		$\rho_s$	$\rho_L$	$\rho_G$
1	$11 \cdot 10^{-37}$	89.024		
5	$4.76 \cdot 10^{-3}$	88.965		
10	255.6	88.136		0.006
12	1837	87.532		0.037
13.803 <sup>a</sup>	7.0	86.503	77.019	0.126
20	93.5	71.086		1.247
20.268 <sup>b</sup>	101.3	70.779		1.338
30	822.5	53.93		10.887
32.976 <sup>c</sup>	1293	31.43		

The ordinary isotope of hydrogen, H is known protium. In 1932, Urey announced the preparation of a stable isotope, deuterium (D) with an atomic weight of 2. Two years later an unstable isotope, tritium (T), with an atomic weight of 3 was discovered. Tritium has a half-life of about 12.5 years. One atom of deuterium is found in about 6,000 ordinary hydrogen atoms. Tritium atoms are also present but in much smaller proportion. Tritium is readily produced in nuclear reactors and is used in the production of the hydrogen bomb. It is also used as a radioactive agent in making luminous paints, and as a tracer.

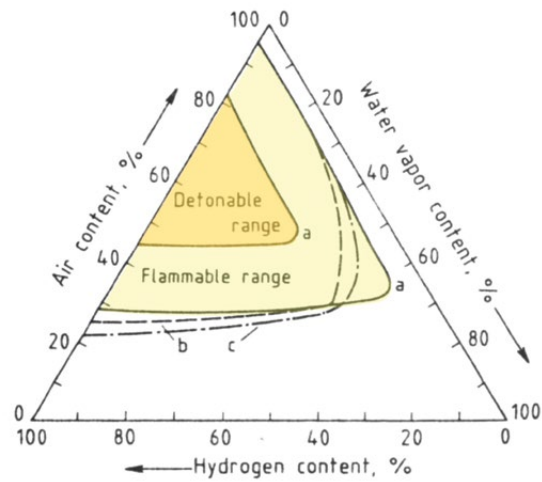
The current price of tritium, to authorised personnel only, is about 2 €/Ci; deuterium gas is readily available, without permit, at about 10,000 €/kg. Heavy water, deuterium oxide (D<sub>2</sub>O), which is used as a moderator to slow down neutrons, is available without permit at a cost of 500 €/kg, depending on quantity and purity. The price of hydrogen is directly bound to the price of electricity (0.05 €/kWh) and therefore around 2.5 €/kg.

Quite apart from isotopes, it has been shown that hydrogen gas under ordinary conditions is a mixture of two kinds of molecules, known as ortho- and para-hydrogen, which differ from one another by the spins of their electrons and nuclei. Normal hydrogen at room temperature contains 25% of the para form and 75% of the ortho form. Consideration is being given to an entire economy based on solar- and nuclear-

generated hydrogen. Located in remote regions, power plants would electrolyze sea water: the hydrogen produced would travel to distant cities by pipelines. Pollution-free hydrogen could replace natural gas, gasoline, etc., and could serve as a reducing agent in metallurgy, chemical processing, refining, etc. It could also be used to convert organic waste into methane and ethylene.



**Figure 4** | Effect of temperature on flammability limits of hydrogen in air (pressure 100 kPa).



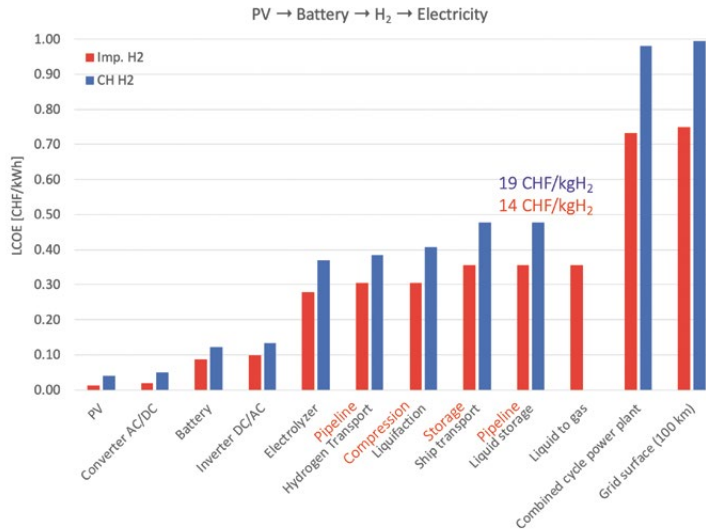
**Figure 5** | Flammability and detonability limits of the three component system hydrogen-air-water a) 42°C, 100 kPa; b) 167°C, 100 kPa; c) 167°C, 800 kPa.

**Table 2** | Combustion and explosion properties of hydrogen, methane, propane and gasoline. <sup>a</sup> 100 kPa and 15.5°C. <sup>b</sup> Average value for a mixture of C1-C4 and higher hydrocarbons including benzene. <sup>c</sup> Based on the properties of n-pentane and benzene. <sup>d</sup> Theoretical explosive yields.

	Hydrogen	Methane	Propane	Gasoline
Density of gas at standard conditions [kg/m <sup>3</sup> (STP)]	0.084	0.65	2.42	4.4 <sup>a</sup>
Heat of vaporisation [kWh/kg]	0.1237	0.1416		0.07–0.11
Lower heating value [kWh/kg]	33.314	13.894	12.875	12.361
Higher heating value [kWh/kg]	39.389	15.361	14.003	13.333
Thermal conductivity of gas at standard conditions [mW/(cm·K)]	1.897	0.33	0.18	0.112
Diffusion coefficient in air at standard conditions [cm <sup>2</sup> /s]	0.61	0.16	0.12	0.05
Flammability limits in air [vol%]	4.0–75	5.3–15	2.1–9.5	1–7.6
Detonability limits in air [vol%]	18.3–59	6.3–13.5		1.1–3.3
Limiting oxygen index [vol%]	5	12.1		11.6 <sup>b</sup>
Stoichiometric composition in air [vol%]	29.53	9.48	4.03	1.76
Minimum energy for ignition in air [mJ]	0.02	0.29	0.26	0.24
Autoignition temperature [K]	858	813	760	500–744
Flame temperature in air [K]	2318	2148	2385	2470
Maximum burning velocity in air at standard conditions [m/s]	3.46	0.45	0.47	1.76
Detonation velocity in air at standard conditions [km/s]	1.48–2.15	1.4–1.64	1.85	1.4–1.7 <sup>c</sup>
Energy <sup>d</sup> of explosion, mass-related [gTNT/g]	24	11	10	10
Energy <sup>d</sup> of explosion, volume-related [gTNT·m <sup>3</sup> (STP)]	2.02	7.03	20.5	44.2

## HYDROGEN ECONOMY

The cost of green hydrogen produced from renewable electricity depends on the cost of electricity, the CAPEX and OPEX of the electrolyzer, the efficiency of the electrolyzer and the utilization. At 100%, 50% and 25% utilization the cost hydrogen is the cost of electricity plus 3 CHF/kg, 6.5 CHF/kg and 13.5 CHF/kg, respectively.



**Figure 6** | LCOE across the conversion chain from PV electricity to hydrogen and back to electricity at a utilization of 100%.

The main cost contributions are the electrolysis and the combined cycle power plant due to the the efficiencies of the conversion processes. The electrolysis efficiency could theoretically be increased to 100% while the production of electricity from hydrogen is limited by thermodynamics and reaches technically 50%. The cost of hydrogen production is dominated by the efficiency and cost of electrolysis.

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# Member introduction



German, French, English

## Prof. Andreas ZÜTTEL

LMER Director & President of Hydropole

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Andreas Züttel has a degree in Chemical Engineering and in Physics. He received the Dr rer. nat. from the Science Faculty of the University of Fribourg in 1993. He was a post doc in AT&T Bell Labs in Murray Hill, New Jersey, USA and received the Habilitation in Physics from the University of Fribourg in 2004. He was a guest professor at the Vrije Universiteit Amsterdam, Delft Technical University and at IMR, Tohoku University in Sendai, Japan.

He is president of Hydropole since 2004. He built up the section Hydrogen and Energy at Empa in 2006, founded the International Symposium Hydrogen and Energy in 2007. Since 2014 he is a full professor for physical chemistry at the Institute of Chemical Sciences and Engineering (ISIC) of EPFL. In 2017 he was co-founder of GRZ Technologies Ltd. In 2020 he became a member of the Swiss Academy of Technical Science.

## LMER, EPFL Valais-Wallis

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The Laboratory of Materials for Renewable Energy (LMER) was founded in 2014 at EPFL Valais-Wallis in Sion/Sitten, where one third of the Institute of Chemical Sciences and Engineering (ISIC) of EPFL is located. The main focus of the activities is on the storage of renewable energy by conversion of renewable electricity to hydrogen and products containing hydrogen (Power to X). The main achievements of the research are the application of metal hydrides for hydrogen storage and hydrogen compression, the mechanism of borohydrides for hydrogen storage, the heterogeneous catalysts and single stage reactor construction for the Sabatier reaction with a yield of >99%, and the efficient electrochemical CO<sub>2</sub> reduction to C<sub>1</sub> products. Recent activities concentrate on new metal hydrides with a gravimetric hydrogen capacity exceeding 2.5 mass% and the investigation of the controlled selective hydriding of biological oil for the energy efficient, high yield synthesis of sustainable aviation fuels. The laboratory has built the small scale demonstrator in Sion in 2014, a demonstrator of renewable energy conversion with the size of the average energy demand of one Swiss person. Application like large metal hydride hydrogen storage unit, metal hydride compressor and methanation reactor have been developed and successfully demonstrated.



Materials Science and Technology



French, English, German

## Prof. Jean-François AFFOLTER

Professor, retired

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Jean-François Affolter was professor at HEIG-VD specializing in electrical systems, power systems, and renewable energies.

He conducted applied research in fuel cells and hydrogen applications, notably contributing to the development of fuel cell-propelled boats. His work also encompasses energy storage and the operation of power systems with renewable energy sources



German, English

### Andres HEGGLIN

Managing Director at Ejector AG

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Andres Hegglin is the managing director at Ejector AG, a Swiss company that specializes in the development and manufacturing of ejectors and valves for refrigeration and heat pump technology.

### Ejector AG

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Ejector AG focuses on improving the efficiency of cooling and heating systems, particularly those using natural refrigerants, through their innovative ejector and valve solutions.



French, German, English

### Bernard MUDRY

Honorary Chairman of Hydropole

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Bernard Mudry was the first chairman of Hydropole when it was founded. At the end of his term, he was appointed honorary member.

synthetic crystals (corundum and spinel) for the jewelry and watchmaking industries, using a hydrogen/oxygen fusion process.

### Professional activities related to hydrogen

**Grand Djvahirdjian SA.** Managing director, then director of this company, which is renowned worldwide for the production of

**IHT.** Chairman of the Board of Directors of this company, which specializes in the manufacture of high-capacity pressurized electrolyzers based on the Zandsky/Lonza system.



English, Greek

### Prof. em. Demetri PSALTIS

Professor Emeritus

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Demetri Psaltis (Greek: Δημήτρης Ψάλτης) is a Greek-American electrical engineer who was the dean of the School of Engineering at EPFL from 2007 to 2017.

Since 2024 he is a professor emeritus at EPFL.

He is one of the founders of the term and the field of optofluidics. He is also well known for his past work in holography, especially with regards to optical computing, holographic data storage, and neural networks. He is an author of over 1,100 publications, contributed more than twenty book chapters, invented more than fifty patents, and currently has a h-index of 105.



German, French, Italian, Dutch, English

## Barbara WUYTS

Regulatory Manager at FluxSwiss

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With a long background in energy, Barbara Wuyts currently is Regulatory Manager at FluxSwiss, leveraging her expertise to navigate the complex landscape of the gas and hydrogen sector. In her role she puts to use her skills and experience in Swiss and EU regulation, Security of Supply and the development of the Swiss Hydrogen Landscape.



### FluxSwiss Sagi

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FluxSwiss, part of the Fluxys group and 46% owner of Transitgas AG, markets around 90% of the Transitgas pipeline capacity, focusing on cross-border gas flows. In 2024, FluxSwiss joined Transitgas, OGE, Fluxys TENP, and Snam in an MoU to develop hydrogen infrastructure linking Germany via Baden-Württemberg and northwestern Italy. The Alpine Hydrogen Corridor aims to repurpose existing pipelines to enable hydrogen imports from North Africa, supporting supply diversification and decarbonization. The project was submitted as a Project of Mutual Interest under the TEN-E Regulation to seek EU funding and foster stakeholder collaboration.



English, French

## Vincent BOUCAND

Expert for hydrogen engine performance and emissions

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Vincent Boucand is an expert on performance and emission, and engine application for hydrogen engines development at Liebherr Machines Bulle SA. He has fifteen years of professional experience in five countries as a powertrain engineer specialized in internal combustion engines with various fuels: diesel, natural gas, hydrogen.

### Liebherr Machines Bulle SA

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Liebherr Machines Bulle SA, a company established in 1978 in the canton of Fribourg in Bulle, designs and produces combustion engines, injection systems, as well as hydraulic pumps and motors. These high-quality components and systems are not only used

within the Liebherr Group. In fact, they are also integrated into machines from other manufacturers.

Liebherr-Components product segment has made a significant investment in the development of our hydrogen engine and the respective test facilities since 2021, at our Liebherr engine competence centre in Bulle. The Liebherr Machines Bulle team is committed to the development of hydrogen internal combustion engine technology for a more environmentally friendly future of construction equipment machines. Looking ahead, Liebherr-Components has set an ambitious goal to begin the serial production of these hydrogen engines by the end of the decade.

# LIEBHERR



French, English, Japanese, German, Armenian

## Aris MAROONIAN

Founder & CEO of Neology

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An engineer by training, Aris Maroonian brings over a decade of industrial experience at the crossroads of advanced energy systems, automotive system engineering, and sustainable technology.

Before founding Neology, Aris served as Senior Manager at Toyota Gazoo Racing Europe in Germany, where he led the System Engineering Department, overseeing major R&D programs in chassis and powertrain system development. His career began in Japan as a senior engineer at JTEKT Corporation (a member of the Toyota Group), where he worked on next-generation mobility solutions, with a focus on mechatronic systems, simulation, test bench development, and advanced control strategies.

These experiences forged his commitment to precision engineering, lean innovation, and multicultural collaboration — all of which are core to Neology's DNA.

Aris brings hands-on expertise in fuel cells, energy management, control systems, and thermal integration, paired with a clear strategic vision to decarbonize hard-to-abate sectors. He is fluent in five languages and actively works with partners across Europe and Asia to scale Neology's impact on the global energy transition.

## Neology Hydrogen SA

Route de Taillepie 125, 1095 Lutry, Switz.  
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The company specializes in innovative ammonia-to-power technology, offering a carbon-free alternative to traditional fossil fuel-based generators. Its focus is on developing scalable solutions for off-grid power and heavy-duty stationary applications, particularly where batteries or hydrogen logistics fall short.

By efficiently cracking ammonia into hydrogen on-site and coupling it with fuel cells or hydrogen engines, Neology enables quiet, emission-free, and cost-effective power generation. The company is currently preparing a pilot rollout of its 50 kW Ammonia Power Generator (APG), with broader deployments expected across Europe and Japan. Neology is also forming strategic alliances with green ammonia producers to support global implementation.



## H2 Energy AG

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H2 Energy was founded in 2014 with the goal of playing an active role related to climate change. The decarbonization of our energy system is a massive undertaking and we are proud to work alongside likeminded individuals and organizations to make a difference. We are active in the entire hydrogen value chain, offering our know-how and engineering along each link. Especially in the realization of hydro-

gen production plants, the implementation of hydrogen refueling stations and in the engineering of hydrogen fuel cell applications we draw on many years of experience.





German, English, French

## Prof. Christopher ELLERT

Green Chemistry group Director

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Christoph Ellert obtained his PhD in 2015 from the University of Freiburg, Germany.

1996–1999: postdoc as Feodor-Lynen fellow at NRC, Ottawa, and Marie-Curie stipend at CEA Saclay, Paris, on the interaction of intense femto-second laser fields with atoms, molecules and clusters.

2000–2010: thin film deposition and plasma development for Solar industry at TiNO<sub>x</sub>, München, and Oerlikon Solar, Switzerland.

Since 2010: professor at HES-SO Valais-Wallis in Sion, specializing in plasma technology for treatment of surfaces in medical and material science applications; setup of a DC-microgrid with predictive regulation of auto-consumption, integration of photovoltaics, battery storage and green hydrogen: generation, storage and applications.

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### Green Chemistry group, HES-SO Valais-Wallis

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The Green Chemistry group of the Institute of Sustainable Energy at the university of applied sciences HES-SO Valais-Wallis engages in hydrogen development, i.e. production, storage and reconversion, with the aim of seasonal storage to facilitate the transition towards carbon-neutral energy systems.



German, French, English

## Hansruedi ARNOLD

Electrical Engineer HES, retired

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Hansruedi Arnold, born 1939, apprenticeship mechanic, five years development in a physical laboratory for solid states laser, apparatus, measure systems, laser cavity, power supply, mobile demonstrate equipment (any missing instruments at that time), developed laser boring machine for watch stones (own construction) 0.015–0.4 mm in Rubis stone for. The heart of Light Pumping Systems (Laser cavity) is still working after fifty years without maintenance also the feed up energy and equipment for access distribution systems.

Then working manager, development mono-crystals with the Skull-Melting process (Kalttiegelverfahren), HF furnace, 200 kW HF-Power, 2700 C° Zirconium-Oxide. Accompaniment from the New Lurgi Pressure Cell pilot plant. Electrolyzer, maintenance

systems analysis and revisions in foreign countries. Developed own pressure laboratory electrolyzer as a pallet kit for test membranes and electrodes equipment.

Together with a friend 40 years private physical laboratory for thin layers for UV light filters. Research for power lamps to realize monochromatic light. Equipment's high vacuum machine, mobile photo-spectrometers to analyze specters of light from sun and snow reflection or glacier on high mountains. Mechanical workshop was also necessary.

Leisure hobbies, earlier mountaineering, hiking, swimming, reading, and a lot of activities in public societies. Initiator of a Swiss hydrogen association.



English, French

### Christopher BRANDON

EH Group Director

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English, French

### Dr Mardit MATIAN

EH Group Director

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Christopher Brandon is the co-founder and director of EH Group. He is responsible for finance and business strategy. Prior to his role at EH Group, Christopher Brandon had a career in finance, co-founding a Singapore-based currency hedge fund in 2002 after working in FX trading at UBS/Swiss Bank Corp from 1995.

Mardit Matian, founder of EH Group is a mechanical engineer with a PhD from Imperial College London on design of fuel cell stacks. Over 23 years fuel cell experience including PEM/SOFC, design, engineering and management, at ABB and HTCeramix/Solydera. Responsible for technical development and strategy.

### EH Group Engineering AG

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EH Group, headquartered in Switzerland, is a leading developer of hydrogen fuel cell technologies. Established in 2017, their primary focus is on the design and production of high performance and cost-effective fuel cell stacks and systems. Their products are designed to decarbonize stationary power applications such as data centers, marine vessels, and aviation and where traditional batteries are insufficient. EH Group has been deploying their fuel cell solutions in diverse projects globally since early 2020, collaborating with partners in aerospace, oil & gas, and automotive industries.



German, English, French

### Fridolin HOLDENER

Member of the Board & Vice President of Hydropole

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Fridolin Holdener is a member of the Board, the vice president of Hydropole and the founder and general manager of Shirokuma GmbH, specializing in cryogenics and hydrogen technologies. He has over four decades of experience in the field, where he developed and marketed cryogenic and hydrogen components for various applications gases.

### Shirokuma GmbH

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Shirokuma GmbH is a company based in Wetzikon, Zurich, Switzerland, specializing in cryogenics and hydrogen technologies. The company provides consulting, ideas and innovations for systems and components within these areas.





German, French, Italian, English

### Daniel PFAMMATTER

Chairman & Senior Consultant

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French, Italian, English

### Giacomo FILETTI

Project Engineer & Business Development Manager Hydrogen

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Daniel Pfammatter is a chairman and senior consultant at Easy Energy, specializing in comprehensive energy consulting, power plant development, and energy efficiency solutions. Proven expertise in entrepreneurship, corporate management, project financing, and corporate succession planning.

Giacomo Filetti is a project engineer and business development manager hydrogen at Easy Energy, contributing to the company's engineering initiatives in hydrogen.

### Easy Energy Companies & Consulting SA

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EasyEnergy is a Swiss engineering and consulting company with worldwide references. Combining knowledge and experience in the field of power, heat, gas, hydrogen and special fluids, we support customers in their hydrogen projects as system integrator. Keywords: EPC, system integrator, engineering



French, German, English

### Dr Patrick SUDAN

Director

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Patrick Sudan is a director at Gruyère Hydrogen Power SA (GHP), founded in 2021 as a spinoff of Gruyère Energie SA.

### Gruyère Hydrogen Power SA (GHP)

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GHP produces green hydrogen in Bulle, in Canton Fribourg, using renewable electricity and advanced PEM electrolyzers. With a daily capacity of up to 900 kg, GHP supplies hydrogen for industrial use, aligning with Switzerland's Energy Strategy 2050. A key partnership with Liebherr Machines Bulle SA includes direct hydrogen delivery via pipeline for testing hydrogen-powered engines. GHP also collaborated with GRZ Technologies to implement cutting-edge hydrogen storage systems, ensuring flexibility between production and consumption. Through innovation and strong local partnerships, GHP is helping to decarbonize industry and enables the use of renewable energy for hydrogen production.

Keywords: production, green hydrogen, pipeline, industry, electricity storage.





German, English

### Prof. Thomas J. SCHMIDT

Head of CEE at PSI & Professor at ETH Zurich

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Thomas Schmidt is the head of the Center for Energy and Environmental Sciences at the Paul Scherrer Institute (PSI). His research focuses on electrochemical energy conversion and storage, including fuel cells and electrolyzers. He also holds a professorship at ETH Zurich, where he contributes to education in the field of sustainable energy technologies.

### Center for Energy and Environmental Sciences, Paul Scherrer Institute (PSI)

Paul Scherrer Institut, 5232 Villigen, Switzerland  
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The Center for Energy and Environmental Sciences at the Paul Scherrer Institute (PSI) conducts research across all aspects of human energy use, aiming to promote a sustainable energy supply system. Their work focuses on advancing technologies for renewable energy utilization, efficient energy storage and conversion, and low-emission energy use. PSI's activities in hydrogen encompass various aspects, including the development of efficient electrolyzers for hydrogen production and the analysis of future hydrogen production regions globally. They also explore hydrogen as an energy storage medium and investigate catalytic processes relevant to hydrogen production and utilization.



German, English, French, Italian

### Hanspeter ROSENBERG

Partner at Inerso

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Hanspeter Rosenberg is one of the founding partners of Inerso GmbH. He holds a MS in mechanical engineering and business development of ETH Zürich and has held various leadership roles in engineering and technology companies in Europe, USA and Asia.

He is currently the CEO of the Perigon Group, a Swiss based management and consulting firm with focus on Swiss industrial SMEs.

### Inerso GmbH

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Inerso GmbH was founded in 2016 in Zug, Switzerland, with a focus on innovative and sustainable energy solutions. Today the company has three business activities:

- Energy technology consulting;
- Energy project development, in cooperation with contracting partners;
- Development and industrialization of modular p-to-p energy systems.

Inerso has been a long-term business partner of GRZ technologies SA, employing their innovative and patented hydrogen energy storage technology and engineering expertise. Inerso offers its customers a wide range of technology services, application knowhow and industrial solutions expertise, with a strong focus on sustainability and project efficiency. The company also facilitates partnerships and collaborations within the energy industry, aiming to drive innovation and sustainability in the energy landscape.





French, English, German

### Gilles VERDAN

CEO of Gaznat SA

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Gilles Verdán is the CEO of Gaznat SA, a Swiss company focused on natural and renewable gas supply and transport. Previously, he directed the Network Department since 2008, overseeing engineering, transport, and operations. He is actively driving Gaznat's energy transition, leading projects for decarbonization and the development of renewable gases like hydrogen and synthetic methane.



#### Gaznat SA

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Gaznat SA is a Swiss company established in 1968, specializing in high-pressure natural gas and renewable gas supply and transport in Western Switzerland through a 600 km pipeline network. They are actively engaged in the energy transition, including developing power-to-gas technology. This involves converting renewable electricity into hydrogen via electrolysis, which is then combined with CO<sub>2</sub> to produce synthetic methane for injection into their gas grid. Gaznat leads projects like the Innovation Lab, aiming to develop innovative technologies for carbon capture and renewable gases storage.



German, English, Spanish

### Dr Hans Michael KELLNER

CEO of Messer Schweiz AG

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Dr Hans Michael Kellner is the chief executive officer of Messer Schweiz AG, a Swiss gas company within the Messer Group, overseeing their operations and strategic direction in the Swiss market, including their growing activities in the hydrogen sector.

#### Messer Schweiz AG

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Messer Schweiz AG, based in Lenzburg, is a prominent Swiss gas company and a part of the global Messer Group. They produce and supply a wide array of gases, including industrial, medical, specialty, and food-grade options, catering to diverse industries across Switzerland. They also offer gas related processes, installations, and hardware. Notably, Messer Schweiz AG is actively involved in the hydrogen sector. They offer hydrogen in various purities and for diverse applications, positioning themselves for the growing hydrogen economy. In July 2024, they presented an innovative, noise and vibration-free hydrogen filling station in Lenzburg, highlighting their commitment to advancing hydrogen technology.





German, English

### Veronika SCHELLING

Hydrogen Mobility and Energy Leader

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Veronika Schelling is the Hydrogen Mobility and Energy leader at Burckhardt Compression and is passionate about driving the global energy transition. She specializes in developing and implementing strategic initiatives that leverage leading compression technology for hydrogen and other renewable gases.

### Burckhardt Compression AG

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Burckhardt Compression AG, headquartered in Winterthur, Switzerland, is a global leader in reciprocating compressor technologies and services. With a history dating back to 1844, they offer a full range of compressor solutions and are the only manufacturer covering all types of reciprocating compressors. Their systems are vital in various industries, including gas transport and storage, refineries, and the chemical and petrochemical sectors. Recognizing the importance of energy transition, Burckhardt Compression is actively involved in the renewable energy sector with a dedicated team focusing on the hydrogen mobility and energy market segment. They are providing compression solutions & services for hydrogen mobility, energy storage, pipeline injection and industrial applications, contributing to a sustainable energy future.



German, English

### Ulrike TRACHTÉ

Researcher at HSLU

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Ulrike Trachte is a researcher at HSLU in the Center of Thermal Energy Systems and Process Engineering. Her work focuses on thermal energy systems and process engineering related to hydrogen technology and fuel cells.

### Lucerne University of Applied Sciences and Arts (HSLU)

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The Lucerne University of Applied Sciences and Arts (HSLU) is the largest educational institution in Central Switzerland, comprising six departments that cover a wide array of subjects from engineering and architecture to design, film, and art. Within its research activities, HSLU is actively involved in hydrogen technology, including the development of hydrogen-powered cooking stoves for Nepal to utilize micro-hydroelectricity and reduce reliance on biomass, as well as analyzing the economic potential of fuel cell micro-cogeneration in European energy markets. These projects demonstrate HSLU's commitment to exploring sustainable energy solutions and their practical applications.





German, English

## Lutz DECKER

Linde Technologist

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Lutz Decker is a Linde Technologist at Linde Kryotechnik AG, based in the Zurich area, where he has worked since 1991. He holds a Master's degree in Process Engineering from ETH Zurich (1990). He has extensive experience in cryogenic engineering, focusing on development, commissioning, and innovation of helium and hydrogen liquefiers, as well as turbomachinery and control systems. As a Linde Technologist he is the nominated expert for deep cryogenics within the Linde Group. His current work emphasizes strategic development, networking, fundamental research, and intellectual property in cryogenics, particularly for hydrogen infrastructure and applications below 80 K. He is recognized for his expertise in the field, as well as for his advisory role in both industrial and academic collaborations.

## Linde Kryotechnik AG

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Linde Kryotechnik, based near Zurich and Winterthur in Switzerland, is a world-leading manufacturer specializing in the planning, design, and construction of cryogenic equipment, particularly helium and hydrogen liquefiers and refrigerators. Their systems operate in the extreme temperature range from  $-193^{\circ}\text{C}$  (80 K) down to  $-271.5^{\circ}\text{C}$  (1.65 K), serving customers such as gas producers, industrial companies, research institutes, and universities. With over 600 cryogenic systems installed worldwide, Linde Kryotechnik is recognized for its expertise in advanced cryogenic technology, including recovery, cleaning, liquefaction, and storage of helium and hydrogen. The company is a subsidiary of Linde plc and plays a key role in supporting scientific research and the development of sustainable hydrogen infrastructure globally.



German, English, French

## Uwe HANNESSEN

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Uwe Hannesen is a fuel cell system technical expert and head of the Technical Center Fribourg.

## OPmobility

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OPmobility, formerly known as Plastic Omnium, is a French automotive supplier with a presence in Fribourg, Switzerland. The company focuses on the

development and production of automotive components, mainly exterior elements such as bumpers, front end modules including lighting, fuel tanks, SCR systems and, recently, battery systems and hydrogen solutions including high pressure vessels and fuel cell systems. In Fribourg, OPmobility has acquired Swiss Hydrogen SA in 2017, to enforce their competencies in fuel cell technologies. Swiss Hydrogen was a start up founded in Fribourg in 2014 as a successor of the hydrogen and fuel cell development activities at Belenos Clean Power Ltd, a subsidiary of the Swatch Group founded by Nicolas G. Hayek in 2007.





German, English, French, Italian

### Prof. Markus FRIEDL

Head of IET Institute for Energy Technology

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Prof. Dr Markus Friedl is the head of the IET Institute for Energy Technology at OST in Rapperswil, and professor for thermodynamics and fluid dynamics.

Markus Friedl has published on topics such as power-to-gas, hydrogen, energy systems modeling, and decarbonization strategies for Switzerland. His recent work includes techno-economic analyses of hydrogen integration and the feasibility of carbon neutrality in Switzerland.

### IET Institute for Energy Technology, OST Eastern Switzerland University of Applied Science

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Founded in 1997, the institute is dedicated to research and teaching in the fields of energy generation, distribution, and utilization. Its work focuses on innovative solutions for a sustainable and efficient energy future, with strong collaborations with industrial partners to realize practical projects.

Key areas of expertise at IET include building technology, electrical energy technology, scientific computing, artificial intelligence (AI), wind energy, digitalization, power-to-X, power-to-gas, hydrogen, and electromagnetic field simulations. The institute is recognized for its applied research, particularly in the development and demonstration of renewable energy technologies such as power-to-methane, and operates specialized research facilities including high-voltage labs, wind tunnels, and demonstration plants for power-to-X technologies.



German, French, English

### Dr Stefan OBERHOLZER

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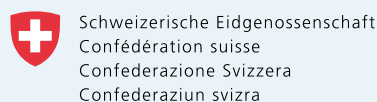
Stefan Oberholzer is the head of PV and Hydrogen Research at BFE.

### Swiss Federal Office of Energy

Bundesamt für Energie (BFE)  
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The Swiss Federal Office of Energy (BFE) is the national competence center for energy supply and use within the Federal Department of the Environment, Transport, Energy and Communications (DETEC). Recognizing hydrogen's potential in decarbonizing the energy system, the BFE actively

promotes its development and integration. The office supports research and development projects focusing on hydrogen production, storage, and application across various sectors. Furthermore, the BFE contributes to shaping the regulatory framework and fostering international collaboration in the field of hydrogen and fuel cell technologies. In December 2024, the Federal Council, with input from the BFE, adopted a national hydrogen strategy to guide the development of a Swiss hydrogen market.





French, English, Italian, German

### Prof. Massimiliano CAPEZZALI

Head of Energy Integration and Sustainability group

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Prof. Dr Massimiliano Capezzali is a full professor at HEIG-VD, leading the Energy Integration and Sustainability group within the Institute for Energies. His expertise lies in hydrogen and renewable gases, along with energy modeling and integration of combined heat and power systems. He is also active in territorial energy planning, notably in the field of local energy networks optimization (such as district heating systems and natural gas distribution infrastructure). Prof. Capezzali's team work aims at contributing to HEIG-VD's efforts in fostering low-carbon energy resources and increasing energy efficiency.



### Haute école d'ingénierie et de gestion du canton de Vaud (HEIG-VD)

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HEIG-VD is a leading Swiss University of Applied Sciences specializing in engineering and management. As part of the HES-SO network, it focuses on practical, industry-relevant education and research and development. In the hydrogen sector, HEIG-VD's Institute for Energies actively develops and integrates fuel cell systems, including those used in mobility and cogeneration applications. The institute also contributes to hydrogen storage solutions and has worked on many innovative projects like producing hydrogen from ammonia reactors. The Institute is convinced that the integration of hydrogen-based systems lies at the heart of future energy systems.



English, German, French

### Dr Noris GALLANDAT

CEO of GRZ Technologies SA

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Noris Gallandat graduated with a BSc in Mechanical Engineering from ETH Zurich in 2012. He then went on to pursue graduate studies as a Fulbright Scholar at the Georgia Institute of Technology, where he obtained MSc and PhD degrees in 2015. His doctoral thesis focused on thermal engineering. In 2016, he joined the Laboratory of Materials for Renewable Energy at EPFL Valais as a postdoctoral fellow. Since March 2017, he has been the co-founder and CEO of GRZ Technologies SA, a technological startup focusing on hydrogen technologies.



### GRZ Technologies SA

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GRZ Technologies SA, an EPFL spin-off founded in 2017, specializes in advanced hydrogen technology, utilizing metal hydrides for safe and efficient energy solutions. The Swiss company aims to replace fossil fuels with sustainable hydrogen systems, offering products like DASH hydrogen storage and thermal hydrogen compressors. They also provide hydrogen-based electricity storage and methanation solutions to convert biogas into synthetic methane. GRZ Technologies focuses on modular, containerized systems for decentralized renewable energy storage. Their innovations support industries and energy networks in transitioning to a hydrogen-fueled future. Keywords: hydrogen storage, hydrogen compression, metal hydrides, methanation



French, English

### Mathieu BOCCARD

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Mathieu Boccard is a project manager at Planair SA, leading the Renewable Gases activities and specializing in renewable energy.

Planair SA is a Swiss consulting engineering firm established in 1985, specializing in sustainable development. They offer expertise in energy efficiency, renewable energies, and environmental protection. Their services include consulting, planning, and project management for diverse clients. Committed to quality and environmental stewardship, Planair is independently owned, ensuring neutral and client-focused advice.

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German, English

### Prof. Michael HÖCKEL

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Prof. Michael Höckel is a leading expert and professor at BFH, specializing in power grids and hydrogen technology within the Engineering and Information Technology department. He heads the Hydrogen Systems and also the Power Grids Laboratory at BFH, actively engaging in research, development, and education related to fuel cells and hydrogen applications.

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The Bern University of Applied Sciences (BFH) actively engages in hydrogen research and development, particularly through its Hydrogen Systems Laboratory, which focuses on the development of fuel cell and electrolysis systems and offers consulting and testing services for hydrogen technologies. BFH also collaborates on projects exploring hydrogen production and its integration into the energy system



Japanese, English, German

### Dr Shunsuke KATO

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Having built his solid foundational knowledge of hydrogen energy through his research on hydrogen-materials interactions at federal institutes, he has applied this expertise with engineer-

ing consulting companies. In his practice, for example, in the fields of hydrogen production, hydrogen storage, and ammonia production, his knowledge is based on the wisdom of 'gratitude and coexistence' that is the foundation of our life.



German, English, Italian, Greek

## Dr Panayotis DIMOPOULOS EGGENSCHWILER

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Dr Panayotis Dimopoulos Eggenschwiler is a group leader at Empa, specifically within the Chemical Energy Carriers and Vehicle Systems Laboratory. His research interests and expertise lie in areas such as automotive engineering, energy engineering, and combustion analysis. Dr Dimopoulos Eggenschwiler has also worked on topics like heterogeneous catalysis and thermal engineering. He is involved in Empa's research on future mobility, including hydrogen technologies.

### Empa

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Empa is a Swiss research institute focused on developing sustainable solutions for major societal challenges in areas like energy and mobility through materials science and technology. As part of the ETH Domain, Empa bridges the gap between research and application, often collaborating with industry to foster innovation for a sustainable future. Empa has developed a Digital Twin of an H<sub>2</sub> refueling station. It accounts for the compression, the fluid dynamics and heat transfer from H<sub>2</sub> to the tank walls as well as to the ambient, computing all relevant thermodynamic properties. It can be used for the layout of a station with different storage tank configurations. In parallel, the modeling of the refueling process allows the study of the influence of a series of station, vehicle and ambient specific parameters.



**Empa**

Materials Science and Technology



German, English

## Stephan ALBRECHT

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Stephan Albrecht is a product manager at Serto AG, specializing in the strategic development and lifecycle management of high-quality quick-connect couplings. He is also responsible for Serto's activities relating to hydrogen.

### Serto

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Serto AG, headquartered in Switzerland, is a manufacturer and international supplier specializing in tube connection systems and components. Established in 1952, the company is known for its radially mountable compression ferrule union with a flat metal-to-metal seal. Serto offers a wide range of fittings, valves, and tubes in various materials, catering to diverse industries. They also provide customized system solutions, including pre-bent tubes and assembled components. With a global presence, Serto emphasizes quality, reliability, and customer-specific solutions in their offerings.





English, French, German

## Prof. Paul Joseph DYSON

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Paul Dyson joined the Institute of Chemical Sciences and Engineering at the EPFL in 2002 where he heads the Laboratory of Organometallic and Medicinal Chemistry (LCOM). In 2021 he was appointed dean of the School of Basic Sciences. Between 2008 and 2016 he chaired the Institute.

He has won several prizes including the Werner Prize of the Swiss Chemical Society in 2004, the Award for Outstanding Achievements in Bioorganometallic Chemistry in 2010, the Centennial Luigi Sacconi Medal of the Italian Chemical Society in 2011, the Bioinorganic Chemistry Award of the Royal Society of Chemistry in 2015, the European Sustainable Chemistry Award of the European Chemical Society in 2018 and the Green Chemistry Award from the Royal Society of Chemistry in 2020. He has an h-index of 128 (Google Scholar). He was elected a fellow of the Royal Society of Chemistry in 2010, a fellow of the European Academy of Science in 2019 and a life-long fellow of the American Association for the Advancement of Science in 2020. Over the years he has held visiting professorships at the University of Bourgogne, University of Pierre et Marie Curie, University of Vienna, University of Rome Tor Vergara, Chimie Paristech, Shanghai Jiao Tong University and Lanzhou Institute of Chemical Physics. Between 2016 and 2021 he was a member of the Council of the Division of Mathematics, Natural and Engineering Sciences at the Swiss National Science Foundation and also served on the International Committee.

### LCOM, EPFL

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The research at LCOM centers on organometallic chemistry at the interface with medicine, catalysis and material science. The main topics studied in his lab include:

- Synthesis of functional organometallic compounds.
- Design of new organometallic drugs and studying their mechanism of action.
- Design of new homogeneous and nanoparticle catalysts.
- Mechanistic studies of catalysed reactions.
- Ionic liquids – design, properties, reactivity and catalysis.

### Nova Swiss

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Nova Werke AG is a Swiss technology company, founded over a century ago and based in Effretikon, Switzerland. They specialize in manufacturing high-pressure components and providing innovative

high-tech solutions for the most demanding applications. Their products, under the Nova Swiss brand, are recognized globally for their high standards of quality, reliability, and safety. Their core expertise lies in high-pressure technology, engine components, and surface technology.

## Impressum

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### **Steering Committee**

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### **Photos & figures**

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