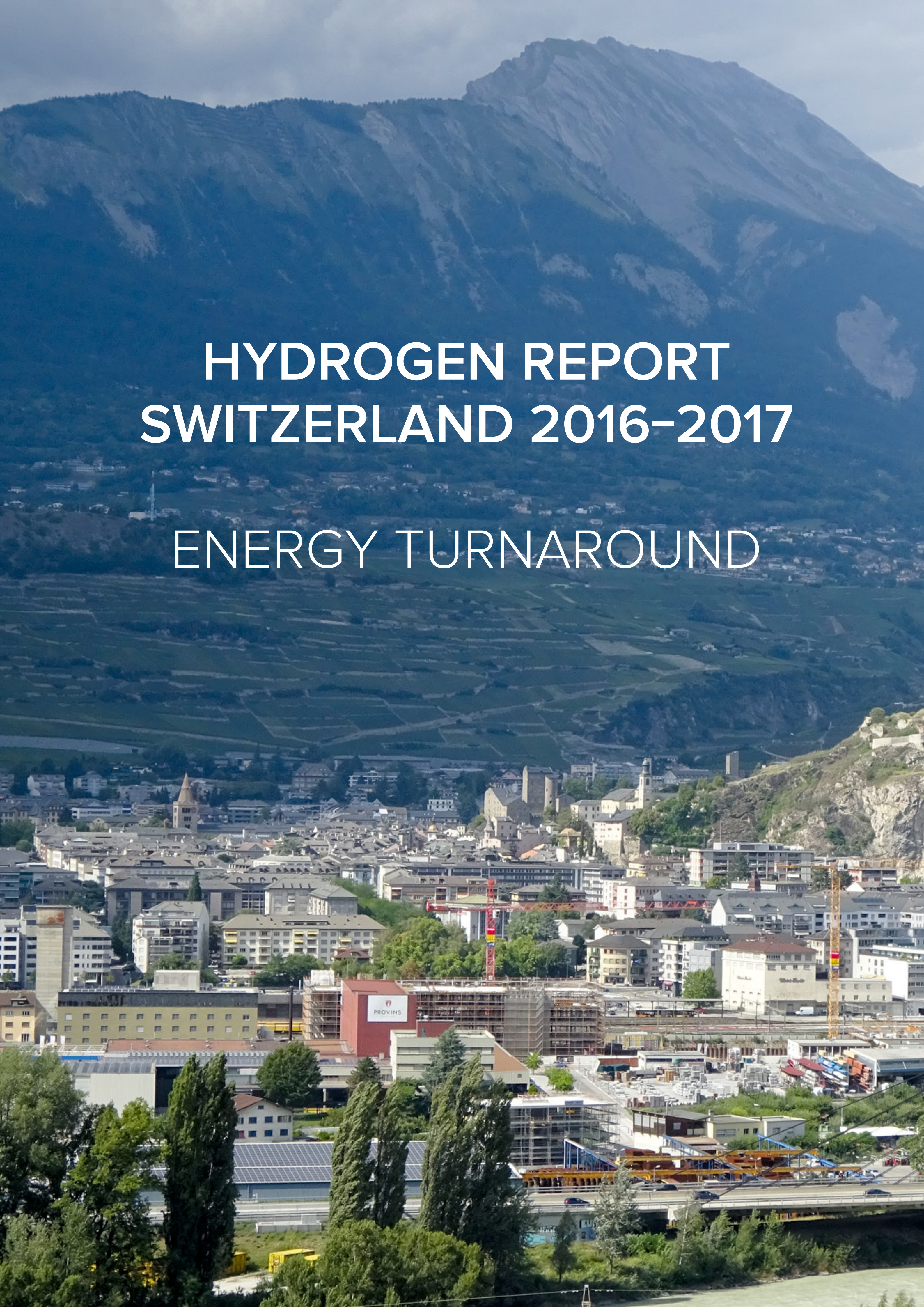
HYDROGEN REPORT SWITZERLAND 2016–2017

ENERGY TURNAROUND



ENERGY TURNAROUND

The earthquake close to island followed by the tsunami on the east coast of Japan and the nuclear accident Fukushima on 11. March 2011 has motivated the Swiss parliament to plan the phase out of nuclear power in Switzerland. In order to create the technological background it was decided to increase the research activity on renewable energy in order to enable a sustainable energy economy for the future. The approx. 3 GW of nuclear power in Switzerland have to be replaced with renewable energy and not with fossil fuels in order to avoid further increase of the CO_2 emission and as a consequence suffer from the climate change. Furthermore, the energy consumption is expected to increase globally due to the growing population and in order to increase wealth. Economic growth is increasing with increasing efficiency of the energy conversion, however, the increase of efficiency will not lower the energy demand as it is sometimes assumed.

Several infrastructure projects have been realized in Switzerland, e.g. hydrogen fueling stations, methanation reactors and Toyota has released the first newly developed hydrogen powered car. The development of hydrogen technologies is much advanced in Asia compared to Europe and USA. China, Korea and Japan offer fully designed hydrogen infrastructures and various vehicles for competitive market prices. The two major challenges in storing renewable energy are the mobility and the seasonal storage. Both require high energy density in materials for affordable prices.

EPFL has created a new institute in Sion called Energypolis, where the research groups focus on the conversion and storage of renewable energy. The major challenge is to close the materials cycle for energy by the production of hydrogen and the reduction of CO_2 from the atmosphere in order to produce synthetic fuels (hydrocarbons). Hydrocarbons offer a high gravimetric and volumetric energy density and are liquid at room temperature, i.e. storage and transport is simple and efficient. This unique energy research center performing world leading research work and forms a bridge between science, industry and the government with a close collaboration with the University of applied science in Sion (HES-SO). The research groups are covering all-important topics to enable mass storage of renewable energy, from solar hydrogen production with new photocatalytic materials over hydrogen storage in hydrides and nanoporous materials to the CO_2 capture in metal organic frameworks and finally the reduction of CO_2 to synthetic hydrocarbons by heterogeneous catalysis as well as in an electrochemical reaction. EPFL is building up the scientific and technical capacity in order to educate the engineers for the future post fossil energy economy, where Switzerland plays an important role in view of the chemical technology, e.g. catalysts, as well as the functional nano-materials, which allow new processes to be technologically implemented. Furthermore, the location of Energypolis in Sion, Valais/Wallis is ideal since large hydropower stations are located just around the town and traditionally chemical industry in the Valais was of great importance for the development of Switzerland.

The inauguration of Energypolis was on 19. December 2014, and the labs became fully operational at the end of 2015, when already more than 150 researchers were working in Energypolis. It represents the largest and most promising research activity on the future energy technology for the storage of renewable energy in Switzerland. It has the potential to make a global impact by realizing the closed cycle from solar energy to hydrogen and to hydrocarbons, i.e. the technical synthesis of hydrocarbons by efficient technical means.

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HYDROPOLE

The Swiss Hydrogen Association Hydropole is the Swiss national platform for the exchange of knowledge, stimulation of collaborations and the promotion of achieve-ments in the field of renewable energy, especially hydrogen production, storage and the use of hydrogen e.g. fuel cells. Hydropole serves as a network for fundamental and applied research, development, industry and other public or private organizations. The association maintains close links with other hydrogen associations in Europe and worldwide, the international energy agency (IEA) and the international association for hydrogen energy (IAHE) and the European hydrogen association (EHA).

The association was founded on 23. November 2001 and is legally located in Monthey. The first president of Hydropole was Bernard Mudry the former director of Djeva, a company producing synthetic saphire in a hydrogen / oxygen flame. During the last ten years a solid network of actors in the field of hydrogen in Switzerland was built up and the association has approx. 50 members today. Approximately one third from industry, one third academic institutions and the remaining third are individual members. The board consists of seven members, the president, the vice-president and five work group leaders.

Since 2006, Hydropole is in close contact the European Hydrogen Association (EHA). The association is represented through his board members in several political and international organizations in order to actively connect the members with the key players in the field of hydrogen worldwide.

Hydropole produces every second year a hydrogen report. The first report was devoted to the industry in Switzerland and was published in 2006. Followed by the second report about the hydrogen research in Switzerland published in

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Lab.

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Industry

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Fig. 1: The board of hydropole

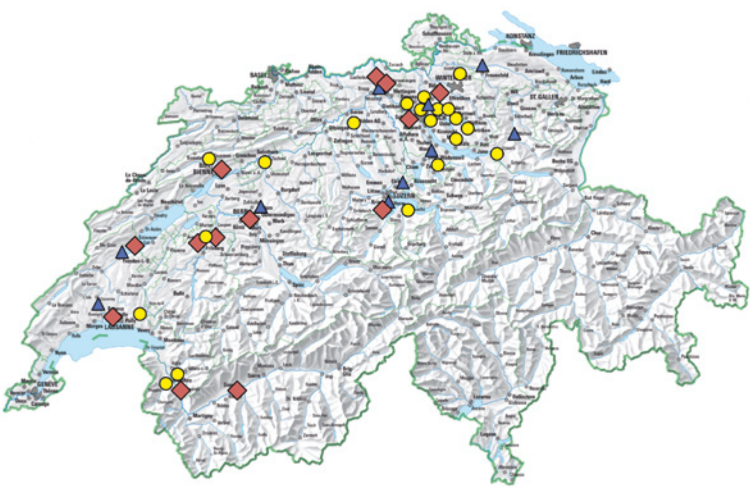

Fig. 2: Members of Hydropole: ○ individual members, △ small companies and groups, ◇ large companies and group

2008. The current report presents the major achivements in the field of hydrogen science and technology in Switzerland.

Fig. 3: H. J. Vock explaining the electrolyser from Diamond Lite SA

Hydropole as a network stimulates the collaboration between universities, institutions and industry. Numerous research and development project have been created between the members. Examples are the light weight SAM fuel cell car with a metal hydride storage system, the mini bar with a hydrogen/fuel cell energy system, the living unit SELF with an electrolyzer, a metal hydride storage and a fuel cell, the research and development project on new membranes for alkaline electrolyzers, the CCEM project HyTech on hydrogen production by photoelectrolysis and hydrogen storage. In 2012 the Postauto AG introduced five hydrogen buses and operates a hydrogen fueling station in Brugg (AG). The buses are part of the regular service and work over the whole year. Postauto AG received in January 2013 together with its partners the Watt d'Or prize, a very prestigious award from the federal office of energy (OFEN) in Switzerland for projects, which contribute significantly to the reduction of fossil energy consumption.

Since the foundation of the hydrogen association Hydropole in 2001 it has brought the hydrogen community in Switzerland close together and became the most important platform and network for the development of hydrogen technologies in Switzerland. The personal contacts and the exchange of information within the association are of great value for the members.

Furthermore, the association is well known outside of Switzerland and makes a significant impact in research and industry in Europe and Asia.

Hydropole produces the bianual Hydrogen Report Switzerland (HRS), where an excellent summary of the activities and achievements in the field of hydrogen in Switzerland is presented. This report is free available as a PDF on the Hydropole's web page **hydropole.ch/publications**.

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Fig. 4: General Assembly 2016

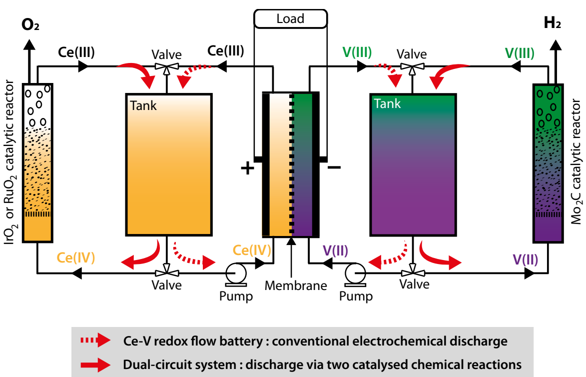
STEP MARTIGNY HYDROGEN PRODUCTION USING A REDOX FLOW BATTERY

One of the main challenges of the energetic transition for a wide use of renewable energies is that of storage. Electrochemical methods can partially answer this key challenge. Megabatteries, i.e. batteries having a power in the Megawatt range, are being developed worldwide. Two main types of batteries are being developed: lithium (or other alkali-metal) batteries and redox flow batteries.

The major difference is that in a lithium battery the electricity is stored within the electrodes and that power and energy are directly proportional to the electrode areas. In a redox flow battery, the electricity is stored in electrolyte solutions and as a consequence the energy of the battery is proportional to the volume of the storage tanks whereas the power is proportional to the surface area of the electrodes.

Whereas megalithium batteries have an energy corresponding to under 1 hour of discharge, megaredox flow batteries can deliver for many hours.

The key question is what happens when a battery is fully charged but the production of renewable electricity is still active. In Martigny, the Laboratory of Analytical and Physical Chemistry from the new Energypolis-EPFL campus in Sion (Valais) has developed a process to chemically discharge a redox flow battery to produce hydrogen in order to store energy from excess electricity production, so-called "junk electricity", as its price is very low or even negative. The principle of the process is shown in the diagram below.



Upon charging, Vanadium (III) is reduced to Vanadium (II) and stored in the right tank while Cerium (III) is oxidised to Cerium (IV) and stored in the left tank.

To chemically discharge the battery in order to keep its state-of-charge above 80% and simultaneously to maintain it always ready to supply electricity, we have developed an external circuit with two catalytic beds to carry out the following chemical reactions:

$$2\,V^{2+} + 2\,H^{+} \xrightarrow{Mo_2C} 2\,V^{3+} + H_2$$

$$4\,Ce^{4+} + 2\,H_2O \xrightarrow{RuO_2} 4\,Ce^{3+} + 4\,H^{+} + O_2$$

In this way, we have a net consumption of water. This process is an indirect water electrolysis where the water reduction and oxidation do not occur directly on electrodes as in a classical electrolyser but these reactions are mediated by the Vanadium (II/III) couple for the production of hydrogen and by the Cerium (III/IV) couple for the production of oxygen.

The pilot plant installed in Martigny is based on a 10kW–40kWh commercial all-vanadium redox flow battery as illustrated below.

The main aim of this demonstration project, carried out with the collaboration of Sinergy, the CREM and the district of Martigny, is to scale-up the reaction of the hydrogen evolution. The electrolyte solutions are pumped from the main storage tanks to smaller tanks located below the catalytic bed reactors as shown below.

At the end of the reaction, the discharged electrolytes are returned to the main storage tanks thereby controlling the state-of-charge of the battery. This process circumvents one of the weaknesses of redox flow batteries, namely the low energy density of the electrolyte solutions, storing excess electricity under the form of hydrogen with a much higher energy density.

This process allows performing intermittent water electrolysis. Indeed, a key drawback of electrolysis to meet the challenge of excess electricity storage is that most electrolysers being either alkaline electrolysers or polymer membranes (PEM) electrolysers cannot meet the intermittency of electricity production.

In the present process, the redox flow battery acts as a buffer that can adsorb irregular electricity supply, for example when peak shaving the grid.

Furthermore, all the electrochemical reactions are one electron reactions with aqueous species and the overhavas

Taten statt Worte Nr. 326

Wir arbeiten jetzt schon daran, dass Ihre Enkel nicht mehr wissen, was Benzin war.

Seit November 2016 betreiben wir die erste öffentliche Wasserstofftankstelle der Schweiz. Unser Beitrag zu einer erneuerbaren, abgasfreien und komfortablen Zukunft der Mobilität. Der einzige Unterschied zu einem Benziner ist, aus dem Auspuff eines mit Wasserstoff betriebenen Elektroautos kommt nichts anderes als Wasserdampf. Eine saubere Sache: weil wir den Wasserstoff für unsere Tankstelle umweltfreundlich bei einem Schweizer Laufwasserkraftwerk produzieren lassen. So schliesst sich der Kreislauf vom Regen bis zum Auspuff. Das finden wir so gut, dass wir auch Teile unserer Geschäftsauto- und LKW-Flotte auf Wasserstoffantrieb umstellen.

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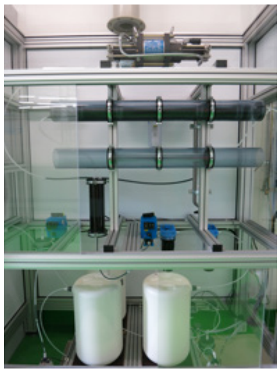
voltage is minimum where compared to multi-electron electrochemical reactions such as water oxidation where the overvoltage is rather large.

The present process is also envisaged as a platform for service stations for electric cars, where the redox flow battery can act as a supercharger for lithium battery based cars and the hydrogen produced can be delivered to fuel cell based cars.

This process circumvents one of the weaknesses of redox flow batteries, namely the low energy density of the electrolyte solutions, storing excess electricity under the form of hydrogen with a much higher energy density.



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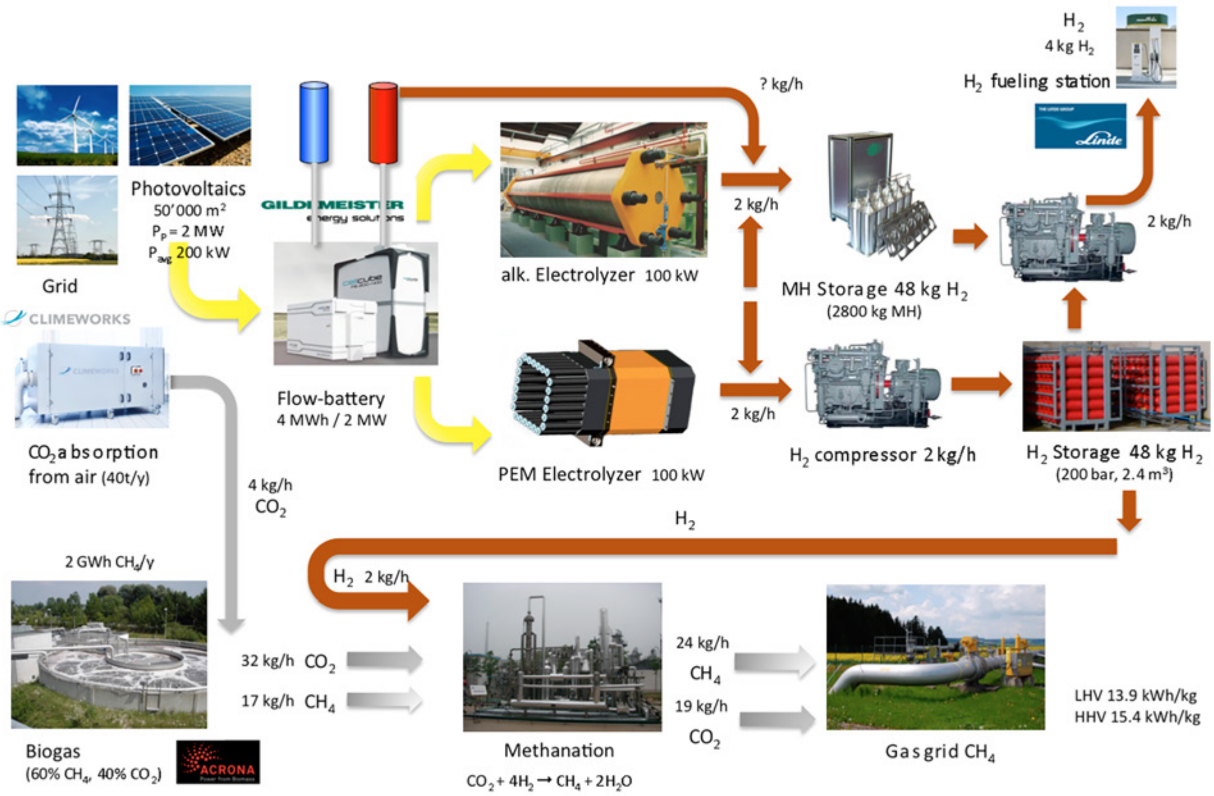

Renewable energy for biogaz upgrade

SCCER HEAT & ELECTRICITY STORAGE

A decarbonization of the energy system requires temporal and spatial flexibility of production and consumption. Energy storage acts as a buffer to relax the constraints. Short-term and long-term energy storage for heat, electricity and chemical energy, centralized and decentralized will help to enable a completely renewable energy system. E.g. hydrogen can play a significant a role in future energy scenario as an eclectic fuel and chemical feedstock. Within the Swiss Competence Center for Energy Research Heat and Electricity Storage (SCCER HaE), activities involving hydrogen production, storage and conversion are manifold.

This article gives an overview on the SCCER HaE research lines.

SCCER Heat & Electricity Storage

The Swiss Competence Center for Energy Research (SCCER) "Heat and Electricity Storage" (HaE) is one of eight centers, which have been established in the research fields of mobility (SCCER Mobility), efficiency (SCCER FEEB+D, SCCER EIP), power supply (SCCER SoE), grids (SCCER Furies), biomass (SCCER Biosweet), as well as economy and environment (SCCER CREST) in light of the Swiss Government's Energy Strategy 2050. The implementation of the SCCERs is supervised by the Commission for Technology and Innovation (CTI).

The declared aim of this energy strategy is the transition from nuclear power to a power supply system based on renewable sources to meet the CO2 emission targets. An important factor is to expand and strengthen the knowledge in the energy field through the increase of personnel resources, e.g., scientists, engineers, technicians alongside with technology development.

The centers are organized as virtual consortia of industrial and academic institutions (cantonal universities, federal universities, federal research centers and universities of applied science) distributed all across Switzerland with the intention to maximize the outcome by combining the strongest competencies in each area of expertise. To maintain a long-lasting effect on the Swiss power supply system, the competence centers will receive financial support until 2020.

Within the framework of these eight SCCER, the SCCER on Heat and Electricity Storage is dedicated to active research on:

- **Thermal Energy Storage**, with a focus on buildings and processes by exploring advanced adiabatic compressed air storage (AA-CAES), pumped heat electric storage (PHES), high-temperature process heat.
- **Advanced Battery and Battery Materials** with focus on Li- and Na-type batteries. In terms of energy density, cost and the high explorative area of beyond Li-ion technologies.
- **Hydrogen Production and Storage** by exploring emerging technologies in the field including redox flow batteries, radically lower cost catalysts, and high energy density liquid storage routes.
- **The development of advanced catalysts for CO_2 reduction** (catalytic and electrocatalytic) aiming at an efficiency of > 30% and with a selectivity of > 60% for syngas / hydro-carbons is planned. Hydrogen Production and Storage by exploring emerging technologies in the field including redox flow batteries, radically lower cost catalysts, and high energy density liquid storage routes.
- **Assessment of Energy Storage Systems** explores the storage technology in a wider context to make the SCCER more powerful. Questions of technology interaction is part of the research, covering a wide range of aspects from socio-economical aspects to system integration and modeling.

The declared aim of the SCCERs is to bring technologies to the next level towards the implementation. The long term vision of our consortium is illustrated in the innovation chart (Fig. 1) in can be seen that there is a true commitment to provide a portfolio of "ready to use" technologies for the 2030 timeframe.

Energy storage is a key element the future renewable energy system, since energy, sourced from renewable sources like wind, sun or tidal energy is only available on a stochastic basis, therefore the aim is to store the surplus energy during times of low demand and release during times of high demand. With an increasing contribution of the aforementioned renewable energy sources to the power mix, the significance of energy storage increases. Large intermittent discrepancies between electricity production and demand are being observed with the consequence of strongly fluctuating electricity prizes and challenges for the stability of the power supply system. In order to stabilize the grid, an increase in short term electricity storage capac-

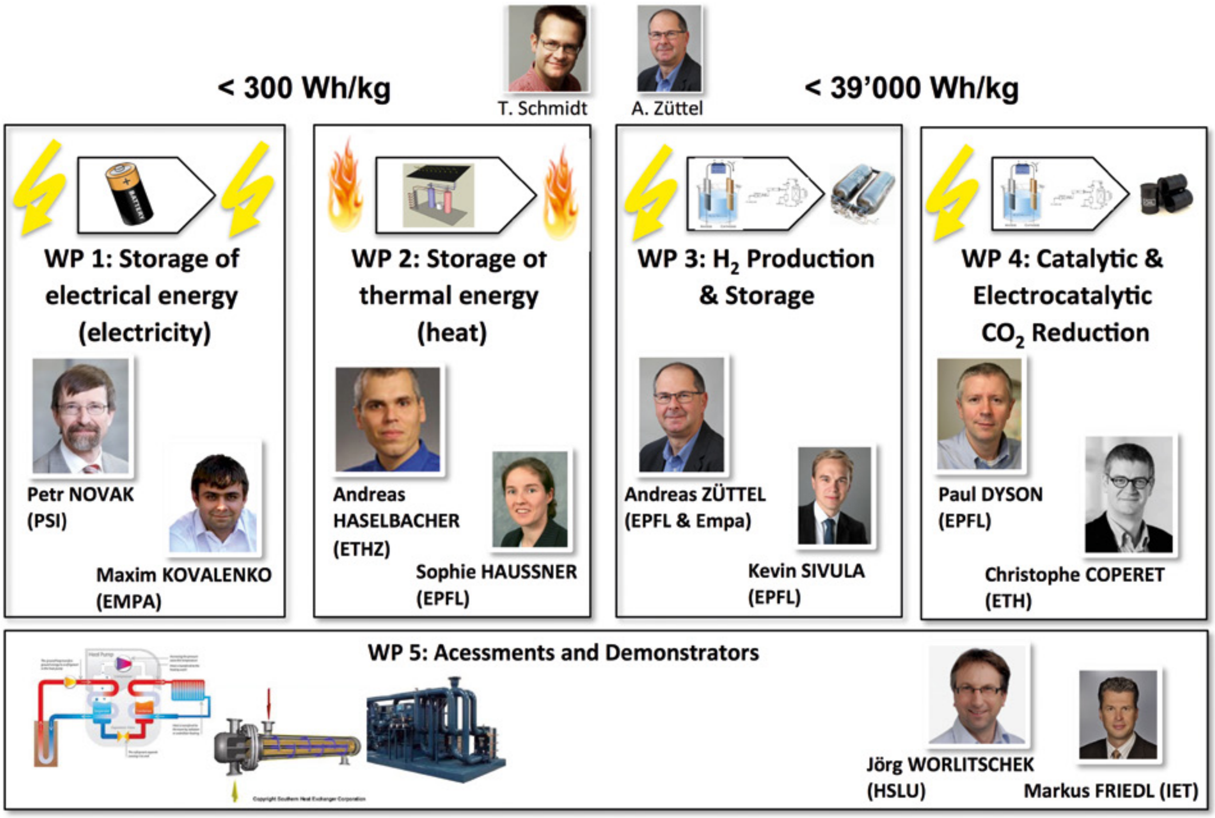

Fig. 1: SCCER Heat and Electricity Storagev

ity (hrs) with high response time is needed within the next years. In the long run, seasonal storage becomes important to ensure constant electricity supply without «gray» power generation. Besides electricity, about 50% of the primary energy carriers are transformed to heat by modern industrialized societies required for space heating, hot water and process heat. Thus, it becomes obvious that heat storage plays also an important role to meet the CO_2 reduction goals of Paris.

Besides of the short term fluctuations in the order of hours or day/night load management, which can be covered already by heat- and battery storage systems, the most demanding challenges, even on European scale, are the two- to – three weeks long periods in fall (November) and spring (February) with low sun and wind contributions [1]. In order to secure the energy supply in those periods, biomass and renewable fuel technologies become important. Also for the long distance (and airborne) transportation power to fuel/gas is a solution for the CO_2 emission free society.

Within the SCCER HaE, research on hydrogen technologies and CO_2 reduction is ongoing. Hydrogen production from renewable energy and storage has a long tradition in Switzerland. With the growing amount of renewable energy, the demand for H_2 production and storage increases. New and competitive conversion and storage systems on the scale of pilot and demonstrator units are developed to enable the transition from fossil to renewable energy. H_2 production by electrolysis is an especially important issue since this is the first step in the conversion of electricity to synthetic fuels and realizes a closed material cycle for energy. Inexpensive and safe storage of hydrogen is also crucial in order to enable a hydrogen economy. The emerging technologies in the field including redox flow batteries radically lower cost catalysts, and high energy density liquid storage routes are in focus. A high impact on industry is expected by focusing on these promising routes. Redox flow battery for hydrogen production is already established successfully on the laboratory scale (funded and patented by EOS Holding), and will be implemented as a largescale demonstrator at Martigny, in collaboration with Sinergy and CREM (both of Martigny, Vallais). The concept of the flow battery separates the electrochemical conversion from the hydrogen production, which enables continuous hydrogen production, required for a good balance of plant and utilization of investment – independent from the availability of surplus electricity. More details can be found in this report (Chapter STEP Martigny, H. Girault).

The second of the more explorative research topics within the SCCER HaE is the catalytic and electrocatalytic reduction of CO_2 to form either syngas or hydrocarbons are highly challenging processes with respect to catalyst activity and selectivity. This project will mainly focus on the development of advanced catalysts within the timeframe of this SCCER. In addition, the demonstration the feasibility of the processes on the laboratory scale reactor level (for catalytic CO_2 reduction) and on the full cell level (the electrocatalytic CO_2 reduction, also called co-electrolysis) with an efficiency of > 30% and with a selectivity of > 60% for syngas/hydrocarbons is planned. During phase I of the SCCERs (2014-2016) the feasibility of this approach was demonstrated on the lab scale [2] and a demonstrator system will be designed by 2020.

A complete summary of the ongoing activities within the SCCER Heat & Electricity Storage can be found in references [3] and [4].

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THE KEY ROLE OF HYDROGEN IN A MULTIPLE ENERGY CARRIER ENVIRONMENT

A "Lighthouse Project" for municipality utilities

In 2013, the Swiss government mandated the Swiss Federal Office of Energy to launch the "Lighthouse program" to demonstrate the practical feasibility of the Energy Strategy 2050 of the Swiss Confederation.

Within the program, some lighthouse projects focus on key technologies to improve the energy efficiency in several domains e.g. in the industry, in the services and in the mobility.

Regio Energie Solothurn (RES) took the opportunity as a public utility company to align its own energy supply strategy with the Energy Strategy 2050 of the Swiss Confederation.

With a turnover of about 100 Mio CHF, RES provides the city of Solothurn and its surrounding municipalities with electricity, natural gas, biogas, district heating and water.

RES installs and maintains photovoltaic panels for its client's base. Most likely, an energetic overproduction from photovoltaic electricity during the months of June/July needs to be stored for further use later in the year. At the same time, the efficiency of district heating depends on production / consumption fluctuations of the industry connected to the network. Natural gas would compensate the fluctuation of district heating, but would increase the dependency of RES from this external resource.

To compensate the fluctuations and optimise the mix of all energy carriers the hybrid power plant Aarmatt (Fig. 1) was realized (**hybridwerk.ch**).

At the core of the power plant (Fig. 2), two PEM electrolysers (C30 by **proton-onsite.com**) are installed, with a total

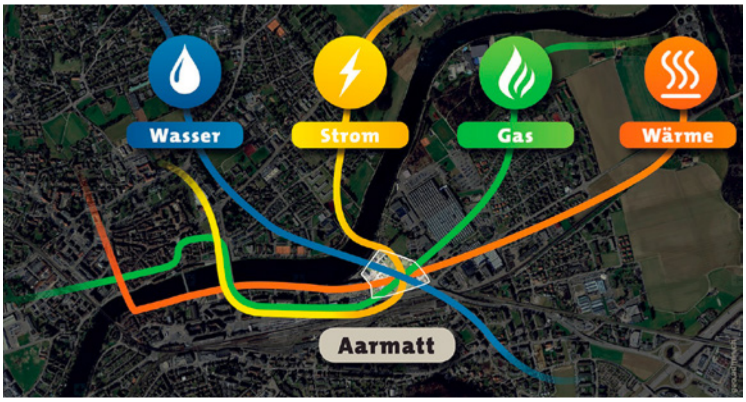

Fig. 1: Four utility networks (water, electricity, natural gas, district heating) as an opportunity to monitor between different energy resources

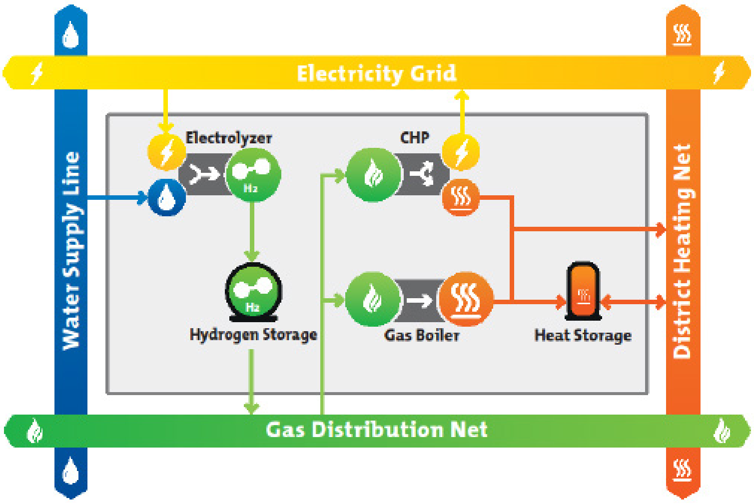

Fig. 2: The electrolyser as a key component to absorb electricity overproduction and use it in form of power to gas

input of 350 kW. The electrolysers operate based on the power availability i.e. the overproduction of electricity in the network.

The produced hydrogen is stored and later on blended with the natural gas (power to gas, PtG or P2G), to increase the combustion capacity in the gas network. This combustion capacity is then available to compensate the fluctuation of the district heating. In the future, the hydrogen will be used for a methanation process based on carbon dioxide from a sewage and biogas plant close to Aarmatt. After an in depth evaluation of the technology and a public tender, RES decided to buy two electrolysers from Diamond Lite SA, **diamondlite.com**.

One of the key selection criteria was to use existing, safe, clean and well proven technology. The PEM process within the Proton OnSite electrolyser is safe due to its electrochemical differential pressurisa-

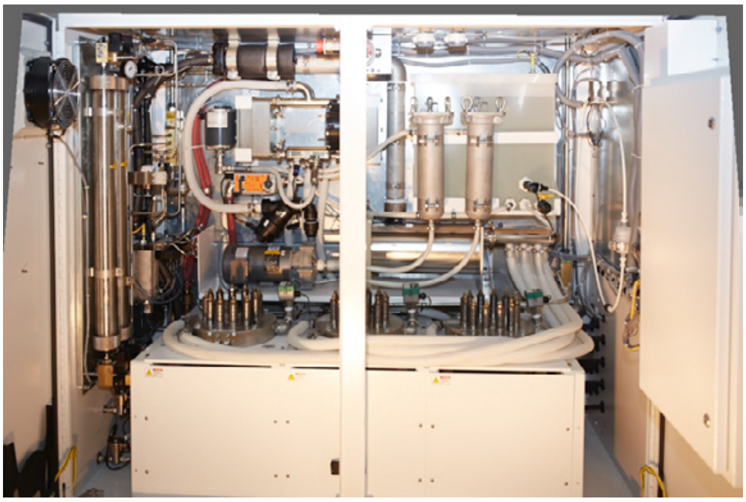

Fig. 3: The cell stacks of the C30 at RES produce in a differential pressurisation the hydrogen at the necessary pressure to maintain safety within the plant

Fig. 4: Delivery and installation of the electrolyzers

tion process within the cell stacks (Fig. 3), which releases Hydrogen at 30 bar and oxygen at atmospheric pressure. The system never releases hydrogen and oxygen at the same pressure, which could lead to a combustible atmosphere.

The installation of the electrolysers on the first floor of the Aarmatt hybrid plant building was spectacular. The delivery of the boxes containing the electrolysers and the mounting of the electrolyser in the plant took not more than half a day (Fig. 4).

Now thanks to the basic and easy to handle principle of hydrogen production "on demand", the Proton OnSite Electrolysers play the requested key role to monitor the optimisation process of all energy carriers at RES: electricity, natural gas and district heating.

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HYDROGEN FOR THE ENERGY AUTONOMOUS RESIDENTIAL BUILDING

How nine apartments without any utility grid connection become reality

"Technologies have been enough tested, they all work. But the combination of technologies is the key success factor for such a project." as Walter Schmid explains in an Interview. He is founder of the Umwelt Arena AG in Spreitenbach (**umweltarena.ch**) , and initiator of the autonomous residential building in Brütten (Fig. 1).

Fig. 1: Autonomous residential building without connection to any public utility

To achieve an energy autonomous building, following three topics are important in view of a better energy efficiency: the production, the storage and the consumption of energy.

For the production of energy, thin–film solar cells are covering the facades of the building and crystalline photovoltaic modules cover the roofs. One hour of sunshine is sufficient for the daily energy power need of the 9 resident families. Even on foggy days, the photovoltaic installation will still provide the residence with a minimum of electricity. The building is packed with a mix of innovative but proven technologies like performance electronics, building automation, gas process engineering, heat storage management, hydrogen electrolyser and finally a fuel cell.

For the storage of energy overproduction – up to 8 hours per day during summertime – short term and long term (seasonal) storage concepts are applied. The short-term storage need will be managed by batteries and long-term storage need will be managed by thermal energy storage and hydrogen produced by a Proton Onsite electrolyser (Fig. 2) delivered by Diamond Lite SA (**diamondlite.com**).

Fig. 2: The Proton OnSite Electrolyser will convert electricity overproduction into hydrogen

The electrolyser will be equipped with a "Start/Stop" remote control to be able to synchronize the hydrogen production with the available electricity overproduction of the photovoltaic installation.

Electricity shortage will probably happen for a maximum of 25 to 30 days mainly in December and January.

On those days, a fuel cell generator will convert the stored hydrogen into electricity. To increase the efficiency, the thermal encess will be used for the domestic heating needs – water and radiator. Which leads to 90% of total energy efficiency. To monitor the consumption, every resident will have access to an information system where he controls his individual energy consumption.

Moreover, biological waste from the households will be converted to biogas in an external plant of "AXPO

Kompogas". The resulting biogas of this process can be used for fuelling a car equipped with a biogas engine.

The equivalent of this gas will result in a driving range for the residents of about 10 000 km per year. A second car available for the residents is a battery fuelled electrical vehicle with also approx. 10 000 km per year driving range. The PV panels installed on the building charge the batteries of this car. Hydrogen has begun to be an obvious energy carrier in residential building projects.

The Brütten project team decided to buy a Proton Onsite electrolyser (**protononsite.com**) for this project due to following factors:

- The electrolysers made by Proton OnSite are based on a technology proven for more than 18 years.
- The electrochemical differential pressurisation process within the cell stacks (Fig. 3) and the ATEX conformity of the electrolyser makes it easy and safe to be integrated in a residential building.
- The pressurized hydrogen at 30 bar flows directly from the electrolyser to the storage tank. No intermediate pressurisation step has been necessary.

Thanks to the Brütten autonomous building project of Umwelt Arena AG, hydrogen becomes a standard energy carrier for domestic use now. More information about this project can be gathered during a visit at Umwelt Arena exhibition hall.

Fig. 3: Proton OnSite safety standard – electrochemical differential pressurisation process within the cell stacks any explosive mix impossible

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WE ARE STEPPING UP TO MEGAWATT
PROTON ON SITE

H2 ENERGY INC IS SUPPORTING COOP TO ESTABLISH AN INTEGRAL HYDROGEN SYSTEM IN A CLOSED CYCLE

Supported by H2 Energy and in cooperation with ESORO and IBAarau, Coop has established an integral hydrogen system consisting of Switzerland's first public hydrogen fueling station, a fuel cell 35 tonnes truck with trailer and a hydrogen production facility located at IBAarau's run-of-the-river plant. This system set-up allows Coop to use hydrogen produced with 100% renewable energy only and is the first of it's kind – worldwide.

In recent years, efforts to reduce greenhouse gas emissions have produced a number of new drive systems in the field of mobility. For decades, researchers have been working on vehicles that emit less or even no CO_2. Hydrogen technology has shown great promise. As major global automotive s manufacturers, Hyundai, Toyota, Honda and Mercedes have already unveiled their first mass-produced fuel cell cars to the public. These cars are powered by hydrogen.

Coop's fueling station infrastructure and commercial fleet

Despite many recent press announcements about launches, prototypes or plans for hydrogen powered passenger cars by several OEMs all involved parties are well aware that the ramp-up and market penetration for this segment will absorb quite some time.

It will not only depend on individual product and marketing strategies of leading OEMs but also on the market acceptance, alternative new technologies, politics, permissions and many other factors that cannot be steered or managed by individual companies only. Nevertheless, this process can be accelerated and supported massively by a systematic infrastructure ramp-up on the back of Coop's future hydrogen heavy duty truck fleet.

Coop and its partners have all ingredients to dissolve the chicken and egg dilemma:

- An existing Coop Mineraloel network of fueling stations
- A commercial fleet with the potential to create initial demand for hydrogen
- Supply of climate-neutral hydrogen thanks to the CO_2-free hydrogen production by H2 Energy.

With its dense network of fueling stations Coop Mineraloel AG is well positioned to initiate a hydrogen infrastructure for Switzerland.

After the opening of the first hydrogen fueling station in Hunzenschwil AG further stations will be added to the network in stages, depending on demand. Coop on the other hand will use the technology for part of its commercial fleet and immediately secure sufficient utilization of this infrastructure. Industry expert H2 Energy Inc is not only supporting this initiative by advising Coop and it's project partner but also by investing in and operating the hydrogen production plant at the hydro plant in Aarau.

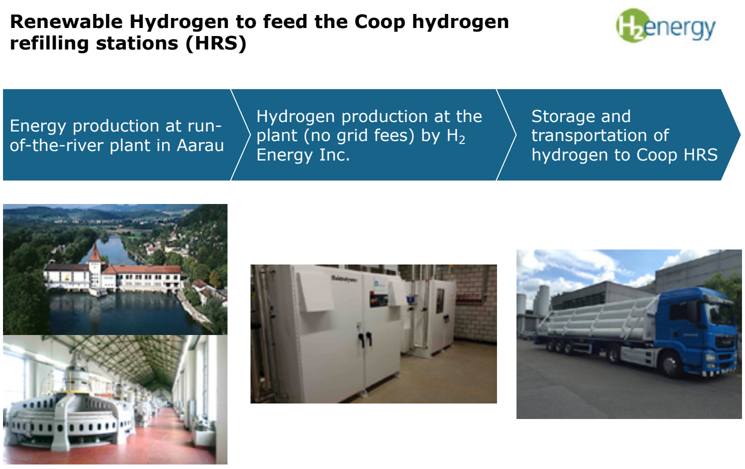

Fig. 1: Hydrogen supply chain based on renewable energy

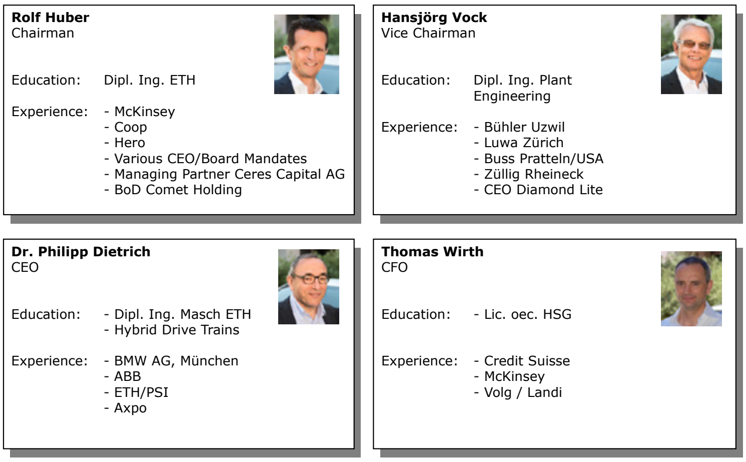

Fig. 2: Owners and managers H2 Energy Inc

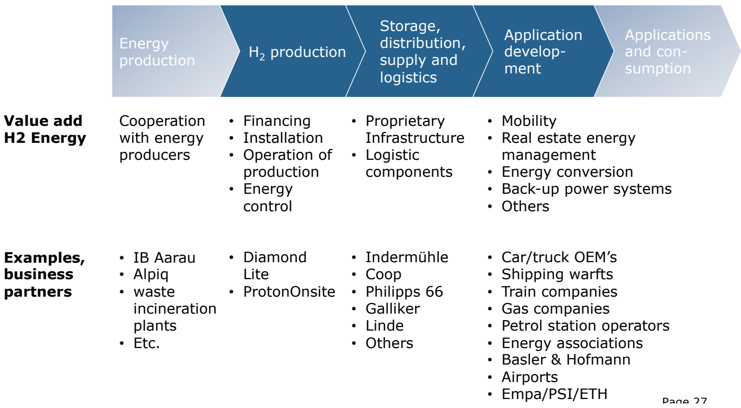

Fig. 3: Value chain H2 Energy Inc

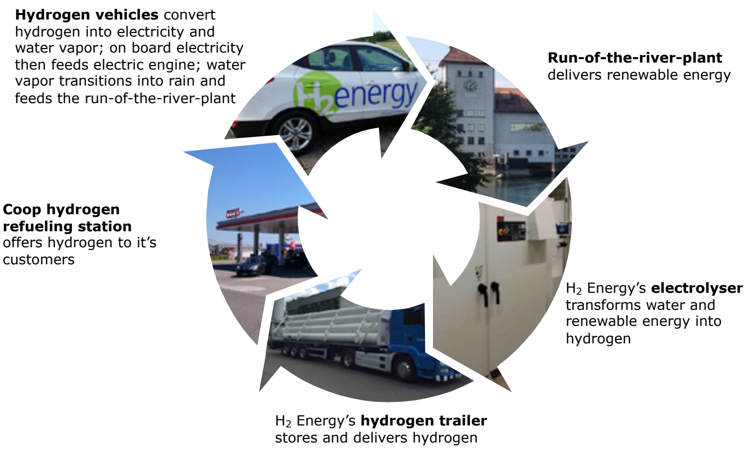

Fig. 4: Coop's closed hydrogen system

CO_2 free production of hydrogen by H2 Energy

Since Coop intents to leverage this technology to help reaching its target of becoming carbon-neutral by 2023 it is essential to secure a supply chain for hydrogen produced on a CO_2 free basis.

Hydrogen will be produced fully CO_2 free in IBAarau's hydroelectric power plant in Aarau, Switzerland. Via a ProtonOnsite-PEM Electrolyser delivered by Diamond Lite SA the water will be split into oxygen and hydrogen. The hydrogen will then be delivered to the fueling stations in a point-to-point delivery chain mode. Coop is thus enabling passenger car users and commercial truck companies using a closed hydrological cycle for the first time.

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POLYMER ELECTROLYTE ELECTROLYSIS

At the Heart of Power-to-Gas

Local storage of excess renewable electricity helps to prevent curtailment and supports grid stability. The storage concept of power-to-gas, transforming electric power into hydrogen and eventually synthetic natural gas is based on water electrolysis. Polymer electrolyte electrolysis is very well suited for this application due to its operating dynamics.

Polymer electrolyte electrolysis research at PSI is based on two pillars. On the one hand fundamentals and materials are investigated and developed, aiming at increasing efficiency and durability, as well as reduction of the cost of the technology. On the other hand in the context of the Energy System Integration platform (ESI) at PSI, investigation of the technology at industrial scale aims at supporting industry when establishing power-to-gas installations.

Polymer electrolyte electrolysis cells (PEEC) are able react to changes of the input power on very short timescales, i.e. milliseconds. This renders the technology suitable for load-following applications such as power-to-gas. The PEEC consists of few main components only, as shown in Figure 1.

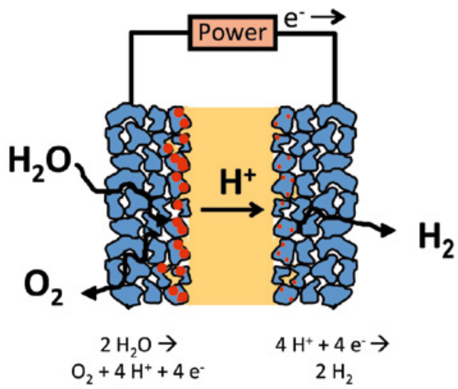

Fig. 1: Schematic of polymer electrolyte electrolysis cell; red dots symbolize the electrocatalyst

Electrocatalysts (shown schematically as red dots) are required for the electrochemical reactions, a membrane electrolyte separates the two gas compartments and porous current collectors allow simultaneous mass, charge and heat transport to and from the catalyst.In the Electrochemistry Laboratory at PSI fundamental research is directed towards the following topics, critical for PEEC development:

- Catalyst development – Iridium oxide is used as oxygen evolution catalyst. Iridium however is a rare and expensive material. In the CCEM / BFE / Swiss Electric Research project RENERG2 alternative catalyst materials to Iridium oxide are developed and investigated.
- Membrane development – A critical property of the membrane electrolyte is the gas permeation. Hydrogen and oxygen are crossing to the opposite side. This reduces efficiency and is a potential safety threat. The figure of merit[1] of membranes is the permeation vs. conductivity ratio. Membranes with increased figure of merit1 are developed and tested in the EU JTI FCH project NOVEL.
- Imaging – The operating voltage of PEEC is higher than the thermodynamic potential, due to losses at the catalyst, ohmic overvoltage but also mass transport losses due to the two phase flow in the porous electrodes. Mass transport in the PEEC is investigated in a BFE project by imaging thetwo phase properties using neutron radiography.
- High pressure – In particular for transport applications, hydrogen at high pressure is required. In the BFE/Industry project HP-ELY the characteristics and trade-offs for PEEC operation up to 100 bar are investigated[2]. Hydrogen compression by electrochemical hydrogen pumping is also investigated.

On a pre-industrial scale of 100–200 kW, PSI builds a power-to-gas energy storage chain on the Energy System Integration (ESI) platform. The processes include a polymer electrolyte electrolyser with 200 kW max. continuous and 300 kW peak load producing hydrogen and oxygen at up to 50 bar, a gas drying and cleaning process step, storage of hydrogen and oxygen without mechanical compression at up to 50 bar with an energy equivalent of about 4 MWh (chemical) and hydrogen/oxygen fuel cell systems for efficient reconversion of the gases to power[3].

In the power-to-gas process hydrogen is often further converted to synthetic natural gas by methanation of carbon dioxide. Therefore the ESI platform also comprises a 300 kW methanation reactor and two gasification paths for biomass. The schematic and an illustration of the platform is shown in Figures 2 and 3.

All processes of the hydrogen path of power-to-gas and gas-to-power chains are realised as container solutions A control centre and visitor station are also included.

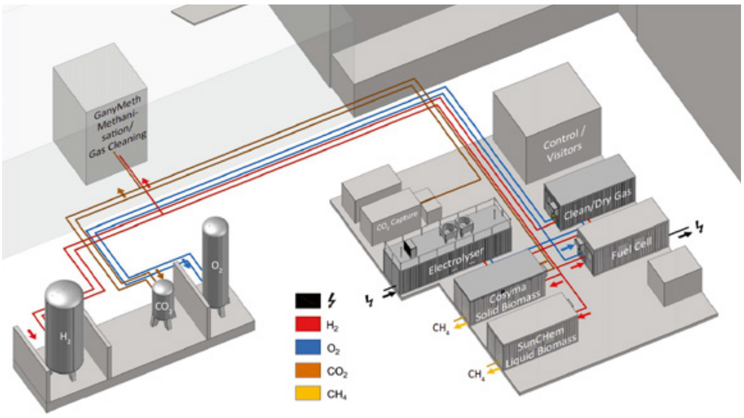

Fig. 2: ESI platform at PSI – Schematic layout with all components

Fig. 3: ESI platform at PSI – Illustration of the platform including one gas tank.

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[1] A. Albert, A. O. Barnett, M. S. Thomassen, T. J. Schmidt, L. Gubler, Radiation-grafted polymer electrolyte membranes for water electrolysis cells: evaluation of key membrane properties, ACS Applied Mate Trials & Interfaces, 7, 22203 (2015).

[2] M. Suermann, T.J. Schmidt, F.N. Büchi, Investigation of Mass Transport Losses in Polymer Electrolyte Electrolysis Cells, ECS Transactions, 69, 1141 (2015).

[3] F. N. Büchi, M. Hofer, C. Peter, U. D. Cabalzar, J. Bernard, U. Hannesen, T. J. Schmidt, A. Closset and P. Dietrich, Towards re-electrification of hydrogen obtained from the power-to-gas process by highly efficient H_2 / O_2 polymer electrolyte fuel cells, RSC Advances, 4, 56139 (2014).

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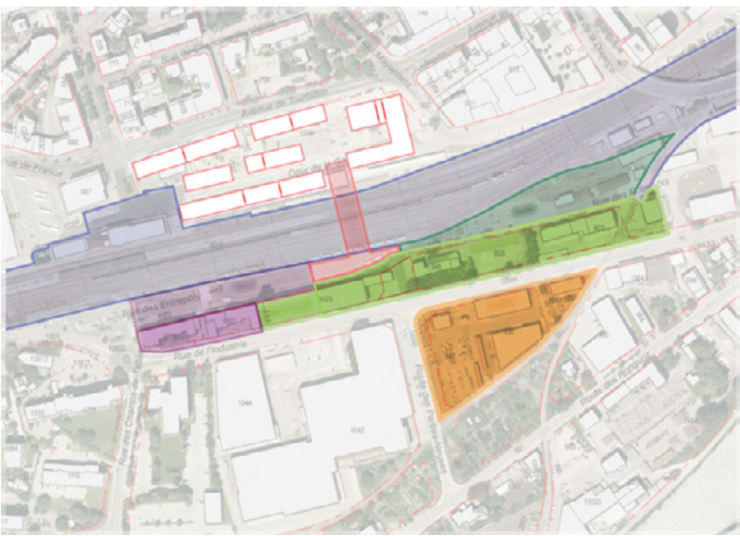
EPFL BOOSTS HYDROGEN AND OTHER RESEARCH IN VALAIS-WALLIS

The EPFL Valais Wallis project comprises a partnership between the EPFL and the Council of State of Canton Valais which aims to develop a shared campus between the EPFL and the HES SO Valais Wallis. There are four main facets of the partnership, the main one being the construction of new research and development infrastructure, buildings, laboratories, offices, etc. to house EPFL faculty and their associated research groups in the Valais.

These new research laboratories will be supported by a number of joint EPFL – HES SO Valais Wallis platforms that will also provide support for start-ups and established industry and organizations in the region. In addition to this more traditional core business of the EPFL there will be a science park where both new companies will be launched and companies from other regions / countries will be attracted, in particularly those with close connections to the on-going EPFL – HES SO Valais Wallis research undertaken in the Valais. Demonstrators are also a key part of the activities, especially with respect to the energy-related research and development that will be undertaken at the new campus to be based in Sion. A key feature of the EPFL Valais Wallis is to address key questions for the welfare and the economic development of Valais and beyond. Of the various themes being developed, one of the major initiatives is known as the ENERGYPOLIS, part of which is concerned with research, development and teaching in sustainable chemistry and, in particular, renewable energy.

A building in the very heart of Sion, known locally as industrie 17, has been transformed at a cost of around CHF 20 million into approximately 8 000 m^2 of state-of-the-art research laboratories and offices and will be home to around 10 research groups working at the interface of chemistry and chemical engineering, and also to host the Ark, a Valasian foundation that promotes innovation in the region. More than 150 researcher will eventually work in the building. Indeed, the EPFL inaugurated the building in December 2014, two years to the day after the signing of the implementation agreement of the EPFL Valais-Wallis pole, an event described as 'historic' by Marcel Maurer, the president of the town of Sion.



Research and development of key technologies spanning the molecular level to the industrial scale will help to bring Switzerland to the forefront of expertise in renewable hydrogen, carbon capture, synthetic fuels and sustainable resource utilization. These topics are of intense interest due to the decision to close Switzerland nuclear reactors. From the molecular point of view, exploration and discovery of new carbon capture materials, new catalysts and electrocatalysts and reaction pathways will pioneer new routes for resource conversion, while on an integrated systems level processes will be optimized and scaled to an industrially relevant dimension.

The key areas of focus are:

- Renewable hydrogen production and storage
- Carbon capture materials
- Synthetic fuels including photocatalytic processes
- Energy systems control and optimization
- Analytical chemistry

Research groups that will be based in industrie 17 include those of Hubert Girault, Francois Maréchal, Mohammed Nazeeruddin, Wendy Queen, Berend Smit, Jan van Herle and Andreas Züttel (for further information about their specific research program please see **isic.epfl.ch**). Further chairs are currently being filled.

Energypolis EPFL Valais Wallis

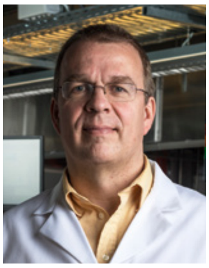
H_2

Andreas Züttel
Hybrides, surface sciences, thermo-dynamics and mechanism

Hubert Girault
Analytical and physical electrochemistry

Mohammed Khaja Nazeeruddin
Molecular engineering of dye-sensitized solar cells

$CO_2 + H_2$



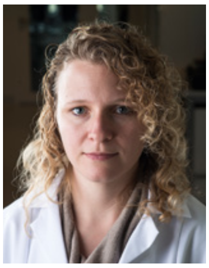
Jan Van Herle
SOEC of steam and CO_2

System

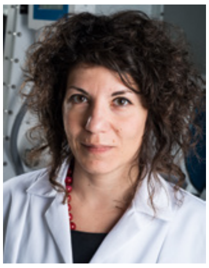
François Maréchal
Computer aided process and energy conversation systems analysis and synthesis

CO_2

Berend Smit
Molecular simulations, multi-scale modeling, catalysts, soft-condensed matter, biological membranes, clays



Wendy Queen
MOF's for gas separations



Raffaela Bonsanti
Nanocrystal synthesis and studies of reaction mechanisms, nucleation and growth

Kumar Varoon Agrawal
Zeolite nanosheets and their application in high performance zeolite membranes

The research areas listed above will be tackled via close cooperation between the faculty based at the EPFL Valais Wallis, other research groups at the EPFL, the HES SO Valais Wallis and through other national and international collaborations.

Analytical chemistry is also highly important to underpin the research and facilitate synergies with the HES SO Valais and other institutes, businesses and enterprises in the region.

Interactions with industry and the economy are key features of this project and will be done in collaboration with the Ark (a foundation for innovation in Valais), CREM (a research center in energies and munici palities) as well as other organizations. The Valais region is one of the main regions in Switzerland for chemical and associated industries; the region solid fuels using carbon dioxide as the template.

The global concept is simple since we have all the hydrogen we need in water and plentiful (increasing) levels of carbon dioxide in the atmosphere. However, the challenge is enormous as the synthetic fuels must be economically viable and ultimately comparable in price to fuels obtained from fossil fuels.

The belief is that Switzerland should lead the way in this area of research to maintain its status as one of the world's most environmentally driven economies. Control and optimization of the energy landscape, especially in an economy where renewables are already very is also a major player in renewable energy.

Similar to the EPFL in Lausanne that has created many start-ups and attracted many companies to the region, it is expected that the EPFL Valais Wallis will have the same effect. Indeed, the process has already started with one company wanting to establish a site in Sion specifically attracted by the EPFL and other international foundations and companies investigating in new research projects that will be undertaken in Industrie 17. In proximity to Industrie 17 further building will be constructed and new chairs will be created. Another part of the EPFL Valais Wallis will be installed in the central Valais Health Pole with research activities in the field of neuroprosthetics and motor rehabilitation.

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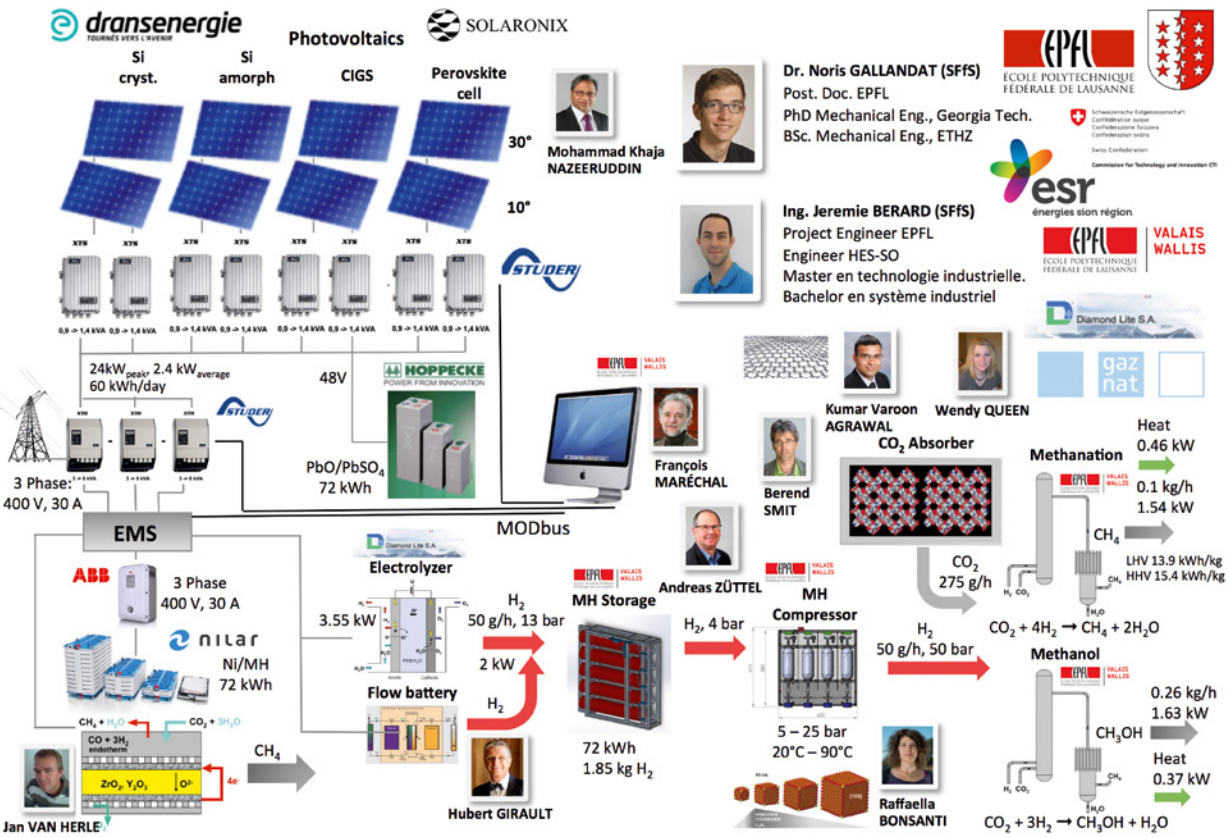

Small scale demonstration projet – Experimental platform

MOVE: THE FUTURE MOBILITY DEMONSTRATOR AT EMPA

Utilizing excess electricity in the mobility sector

With the increasing share of renewables in the electricity production sector the supplied power becomes subject to strong fluctuations particularly stemming from unsteady solar irradiance or wind speed. In order to be able to fit production and demand and avoid wasting electricity from renewable sources, storage technologies increasingly gain significance. In this respect, the conversion of excess electricity into chemical energy carriers proves to be a promising approach which is already pursued intensively under the keyword Power-to-Gas (PtG, P2G).

The demonstration plant "move" located on the Empa Campus aims at showing the opportunities of this technology. Temporary electricity surpluses can be stored on a decentralized level and used in the mobility sector, namely for electric, fuel cell and gas-powered vehicles. For hydrogen production a PEM-electrolyzer capable of rapid load changes and including a remote start / stop function is employed which allows for attenuation of grid fluctuations. The gas obtained is compressed and stored in high pressure vessels for later dispensing.

Apart from using hydrogen to fuel FC-vehicles it can also be added to natural gas/biogas to form the mixture HCNG (hydrogen compressed natural gas) which has proven to significantly reduce pollution and CO_2-emissions in conventional internal combustion engines. Furthermore, employing a CO_2-source and a methanation plant, hydrogen can be converted into synthetic methane with the strong benefit to attain the possibility of seasonal storage in the existing gas grid.

Within the scope of the project "move" investigations towards optimization of a PtG-plant's operation strategy will be conducted. Alongside energetic considerations also economic aspects will be addressed. Additionally, dispensers for each above-mentioned fuel type have been installed including a blending-dispenser for HCNG developed by Empa.

Project timeline and technical data of the "move"

In fall 2014 the building accommodating the PtG-Demonstration plant on the Empa campus has received an optical facelift as well as alterations to meet safety regulations (Fig. 2).

The plants components for hydrogen production, compression, storage and dispensing have been delivered and installed throughout

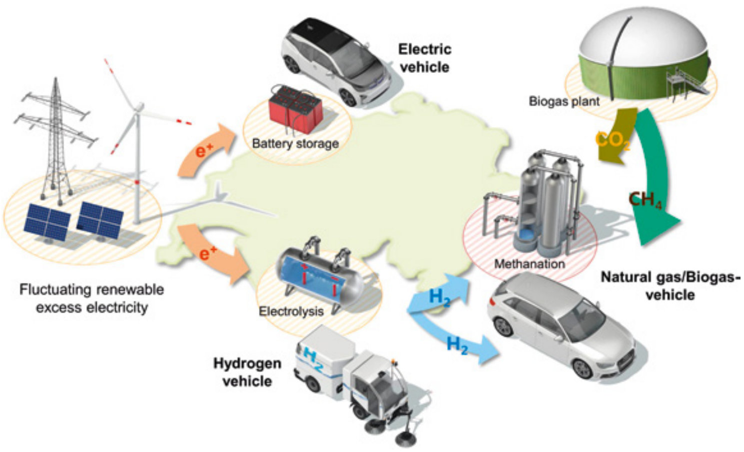

Fig. 1: Pathways of renewable excess electricity to the mobility sector

Fig. 2: Building accommodating the "move" (Future Mobility Demonstrator)

2015 concluding with the official inauguration of the “move” on the 23rd November 2015. Since then the plant is in operation.

The hydrogen is be generated by an electrolyzer of the Hogen© C-series of Proton OnSite (supplier Diamond Lite) with a nominal production rate of 30 Nm^3/h. Thanks to PEM-technology the electrical load can be varied within the complete range of 0 to 100 % in a fraction of a second allowing for quick adaptions to changes in electricity production from renewables.

To increase the volumetric storage capacity and enable short refilling times at the fueling station, hydrogen is compressed to a pressure of 44 MPa. This task is performed by an air-cooled high pressure piston compressor of type DM manufactured by Atlas Copco. Employing an inverter the throughput of the compressor may be varied from 30 to 65 Nm^3/h whereby the compressor-motor-unit with magnetic coupling prevents from oil carry-over into the hydrogen.

At the north-eastern front of the building, facilities for refueling natural gas / biogas exist since 2010.

Dispensers for hydrogen as well as the gas mixture HCNG were now installed alongside to complete the supply of alternative gaseous fuels (Fig 3). Thereby, hydrogen is refueled according to the protocol SAE J2601 which specifies refilling times below 3 minutes. In a first step hydrogen was solely available at a pressure of 35 MPa which represents the standard for utility vehicles or buses.

In the course of an extension project further components (2nd compressor, 100 MPa storage, pre-cooler, dispenser) were installed and taken into operation during the 3rd quarter of 2016 to also enable refueling at 70 MPa as required for passenger cars.

Moreover, within the scope of follow-up projects the fast and cable-free recharging of electric vehicles as well as the conversion of hydrogen into synthetic methane (in cooperation with PSI) are planned to be addressed also. The “move” will serve as a platform for various research endeavors linking electricity to the gas market and thus securing the growth of sustainable energies to help accomplish the energy turnaround.

Project partners: ETH board, SFOE-Swiss Federal Office of Energy, Atlas Copco-Crepelle, Glattwerk-Dübendorf, City of Dübendorf, H2 Energy AG, Hyundai Suisse.

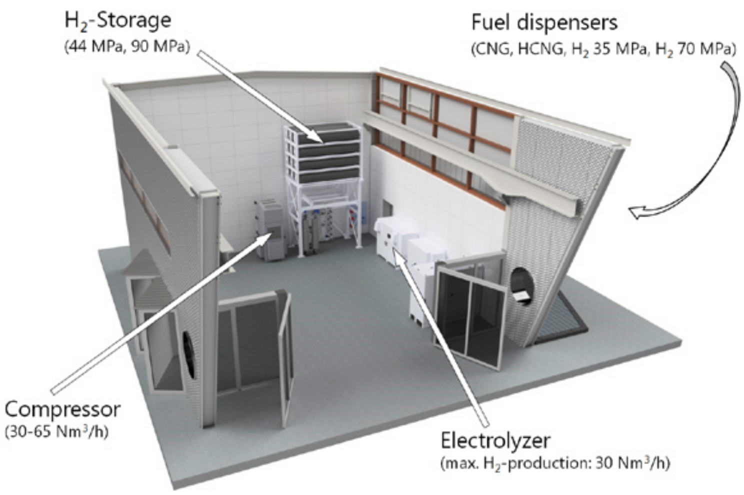

Fig. 3: 3D layout chart of the “move” (Future Mobility Demonstrator)

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PUBLIC TRANSPORT WITH FUEL CELL DRIVE

PostBus is the first company in Switzerland to use fuel cell technology in public transport. Since the end of 2011 five fuel cell postbuses are operating in and around Brugg in the Swiss canton of Aargau.

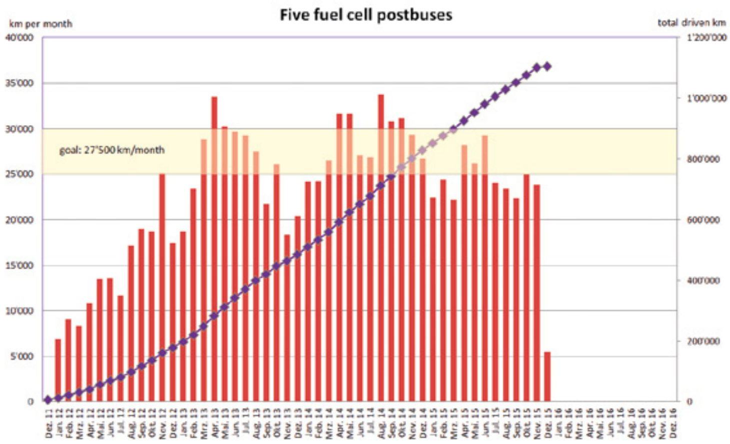
They convert hydrogen fuel into electrical driving energy. Consequently the electrically operated postbuses run very quietly. PostBus is also operating a hydrogen fuelling station.

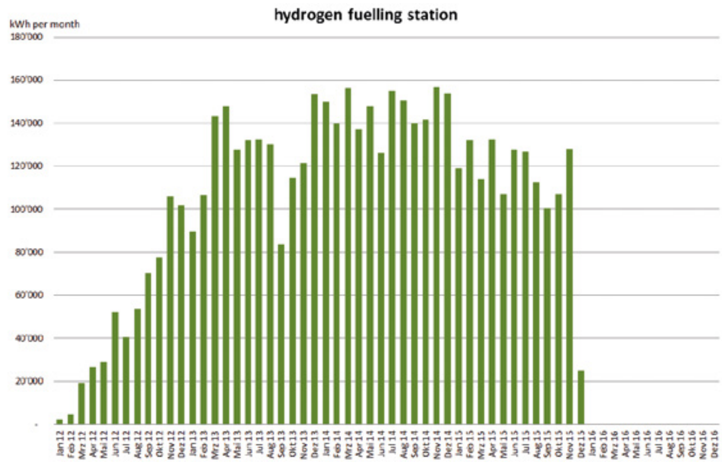
Since four years, five fuel cell postbuses are operating in public transport. The project will be completed at the end of 2016. Time to show up some of the results.

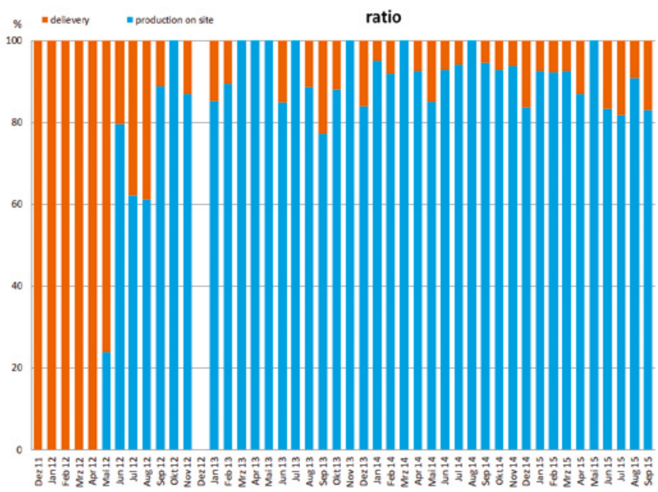
After a gradual introduction of the buses have the task of getting every month to drive 5000–5500 km. The fuel cell postbuses are taken very positive by the passengers and the bus driver. Passengers appreciate the quiet vehicle.

The fuel cell postbuses were used at special events, such as the Film Festival Lucarno or the World Economic Forum (WEF) Davos. Even the neighboring country shows interest so that the buses were already several times in France.

In summer 2015, the buses have reached one million kilometre mark. With an average consumption of 8 kg-H_2 / 100 km they have consumed 95 000 kg-H_2. Approximately 80 000 kg-H_2 were produced with the own hydrogen fuelling station in Brugg. For the production 4 900 000 kWh were needed.







100% of the hydrogen used to fill the fuel cell postbuses is obtained from renewable energy sources such as hydroelectricity, solar power, wind power and biomass energy. The project is carried out in cooperation with the European project CHIC – Clean Hydrogen In European Cities.

PostBus has proven: Yes, the use of fuel cell buses in public transport is possible!

Partners

- PostBus Switzerland Ltd
- Swiss Post
- EU project CHIC – Clean Hydrogen In European
- Cities (JU FCH)
- Swisslos Fund of the Ct. Aargau
- Swiss Federal Office of energy
- Empa
- Paul Scherrer Institute, Villingen
- Daimler Buses: EvoBus GmbH
- IBB Holding Ltd., Brugg
- Carbagas Ltd., Gümlingenv

Hydrogenbus at WEF 2013, Davos

Hydrogen fuelling station in Brugg

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HYDROGEN FACTS

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^3. 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.

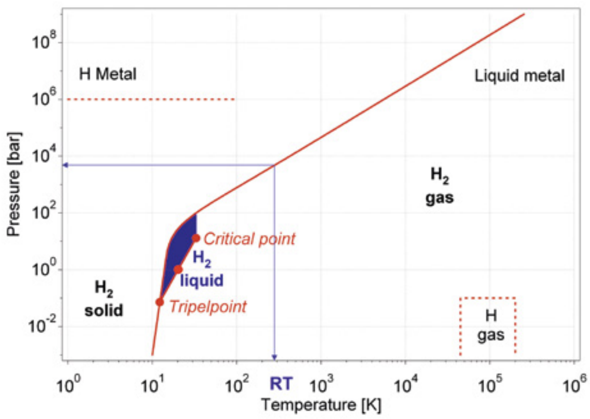

Fig. 1: Primitive phase diagram for hydrogen [1]

It has been predicted that metallic hydrogen may be metastable; others have predicted it would be a superconductor at room temperature.

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

Table 1: Vapor pressure and density of p-hydrogen at low temperatures. (a) Triple point, (b) 101.3 kPa, (c) Critical point

Temperature [K]	Vapor pressure [kPa]	Density	[kg/m^3]	
		ρ_S	ρ_L	ρ_G
1	11·10-37	89.024		
5	4.76·10-3	88.965		
10	255.6	88.136		0.006
12	1837	87.532		0.037
13.803[a]	7.0	86.503	77.019	0.126
20	93.5		71.086	1.247
20.268[b]	101.3		70.779	1.338
30	822.3		53.930	10.887
32.976[c]	1293			31.43

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^3 of hydrogen gas is about 1.16 kg at 0°C and 1 bar pressure.

Production of hydrogen worldwide now amounts to about 5 · 1010 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. 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 6000 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 (D2O), 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 2.50 €/kg.

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

	Hydrogen	Methane	Propane	Gasoline
Density of gas at standard conditions [kg/m^3(STP)]	0.084	0.65	2.42	4.4[a]
Heat of vaporisation [kWh·kg^{-1}]	0.01237	0.1416		0.07-0.11
Lower heating value [kWh·kg^{-1}]	33.314	13.894	12.875	12.361
Higher heating value [kWh·kg^{-1}]	39.389	15.361	14.003	13.333
Thermal conductivity of gas at standard conditions [mW·cm^{-1} K^{-1}]	1.897	0.33	0.18	0.112
Diffusion coefficient in air at standard conditions [cm^2·s^{-1}]	0.61	0.16	0.12	0.05
Flammability limits in air [vol%]	4.0-75	5.3.15	2.1-9.5	1-7-06
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[b]
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^{-1}]	3.46	0.45	0.47	1.76
Detonation velocity in air at standard conditions [km·s^{-1}]	1.48-2.15	1.4-1.64	1.85	1.4-1.7[c]
Energy[d] of explosion, mass-related [gTNT/g]	24	11	10	10
Energy[d] of explosion, volume-related [gTNT·m^3(STP)]	2.02	7.03	20.5	44.2

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.

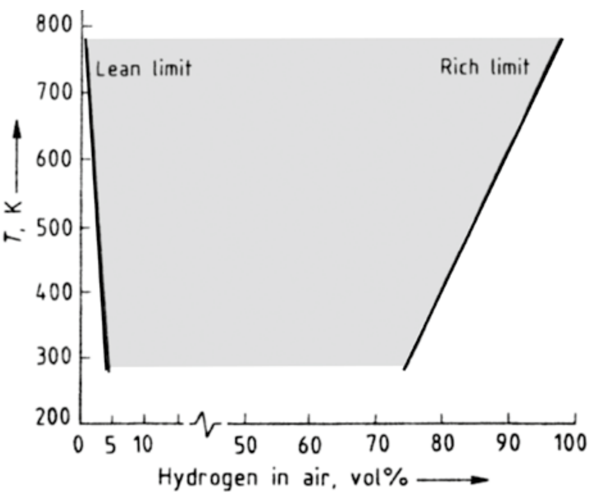

Fig. 2: Effect of temperature on flammability limits of hydrogen in air (pressure 100 kPa).

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.

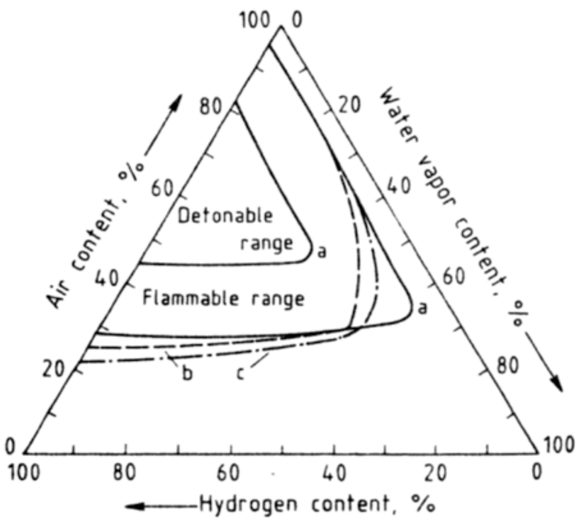

Fig. 3: Flammability and detonability limits of the three component system hydrogen-air-water
(a) 42°C, 100 kPa (b) 167°C, 100 kPa (c) 167°C, 800 kPa

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ACH
Advanced Complex Hydrides

Lead Empa & EPFL / Funding BFE / Period 2010–2014

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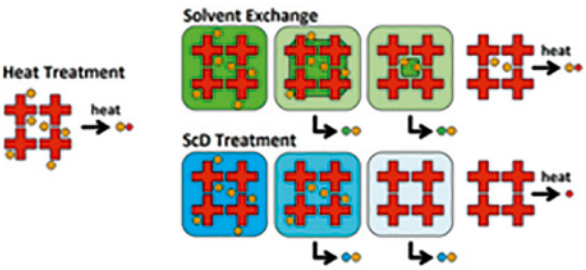
The goal of the project is to explore all simple and binary complex borohydrides by means of the empirical model in order to identify interesting compounds for hydrogen storage, which are less stable than required. Furthermore, a special focus will be on compounds, which are liquids at room temperature. The interesting compounds will be synthesized directly from the elements and investigated by means of spectroscopic methods for there local structure and there thermodynamic properties.



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ADEL
Advanced Electrolyser for Hydrogen Production with Renewable Energy Sources

Lead Htcearmix / Funding EU FCH JU / Period 2011–2014

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The project aims at developing a new steam electrolyser concept, the so-called Intermediate Temperature Steam Electrolysis (ITSE). The new concept will increase the electrolyser lifetime by decreasing its operation temperature while maintaining a satisfactory performance level. This will allow a significant part of the required energy to be provided as heat, the rest being provided as electricity (**adel-energy.eu**).

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Bio-Mimetic Chemistry of [Fe]-Hydrogenase

Lead EPFL / Funding SNF / Period 2011–2014

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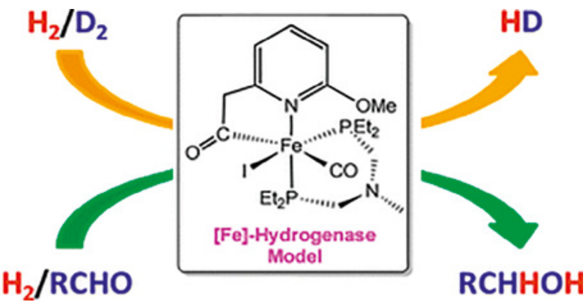
Hydrogenases are enzymes that efficiently catalyze the production and/or utilization of hydrogen (H_2). In light of the central role of H_2 in technologies (fuel cell) and industries (hydrogenation), studies on the structure and function of hydrogenases are of significant current interest. Bio-mimetic chemistry plays an important role here because it provides important chemical precedents and insights.



Optimierung und Charakterisierung der NEP Solar Parabolrinnenkollektoren für Prozesswarme

Lead NEP Solar / Funding SPF KTI / Period 2012–2014

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NEP Solar AG hat einen Parabolrinnenkollektor zur solaren Erzeugung von industrieller Prozesswarme entwickelt. Fi.ir den Marktdurchbruch muss der Kollektor kostenoptimiert und industrialisiert werden. Hierzu wird die SPF Kompetenz für Modellierung und Komponentencharakterisierung genutzt. Am SPF wird ein neuer Hochtemperatur-Teststand aufgebaut. Dieser erlaubt prazise Wirkungsgradmessungen am Kollektor.

BIOROBUR
Biogas robust processing with combined catalytic reformer and trap

Lead SUPSI / Funding EU FCH JU / Period 2013–2016

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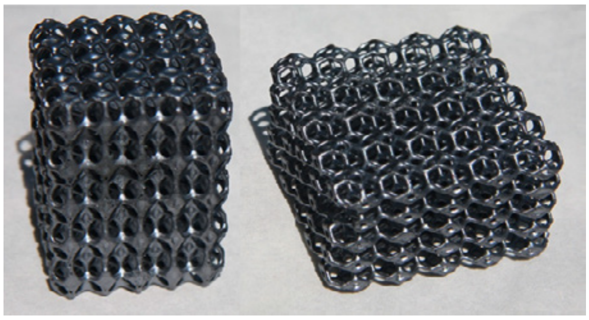
In the BioROBUR project a robust and efficient fuel processor for the direct reforming of biogas has been developed and tested at a scale equivalent to 50 Nm^3/h production of PEM-grade hydrogen to demonstrate the achievement of all the call mandates. The system energy efficiency of biogas conversion into hydrogen will be 65%, for a reference biogas composition of 60% vol CH_4 and 40% vol $C0_2$.



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BOR4STORE
Boron hydride based high capacity solid state hydrogen storage materials

Lead NEP Solar / Funding SPF KTI / Period 2012–2014

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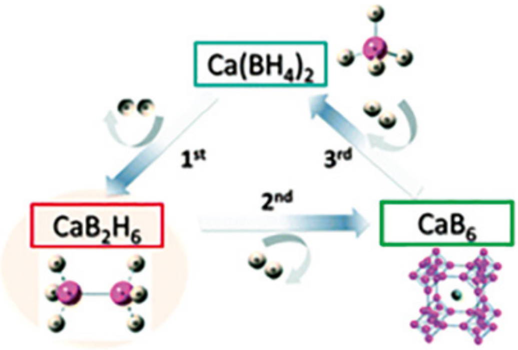
The project proposes an integrated, multidisciplinary approach for the development and testing of novel, optimised and cost-efficient boron hydride based H_2 storage materials with superior performance (capacity more than 8 wt.% and 80 kg H_2/ m^3). The most promising materia|(s), to be indicated by rigorous a down-selection processes, will be used for the development of a prototype laboratory H_2 storage system.



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Y. Yan, A. Remhof, D. Rentsch, A. Züttel. The role of $MgB_{12}H_{12}$ in the hydrogen desorption process of $Mg(BH_4)_2$. Chemical Comm. 51:4 (2015), pp. 700–702

GainBuddy
Entwicklung eines Fast Feasibility Tools für solare Prozesswéirmeanlagen

Lead SPF / Funding BFE / Period 2013–2014

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Die Kernaufgabe des Ertragsrechners « GainBuddy » ist das Berechnen von Bruttowarmeertragen von Kollektorfeldern. Der Ertragsrechner GainBuddy ist eine Erweiterung der Bruttowarmeertragsberechnung auf der SPF Info-CD. Neuartig an diesem Ertragsrechner ist, das der Rechner Bruttowarmeertrage für Kollektorfelder und nicht nur für Kollektoren rechnen kann. Der Rechner kann zudem auch Ertrage von Parabo|rinnen- und Fresnel-Kollektoranlagen berechnen.

Nanostructured materials for solid-state hydrogen storage

Lead Empa & EPFL / EU COST MP 1103 / 2011–2015

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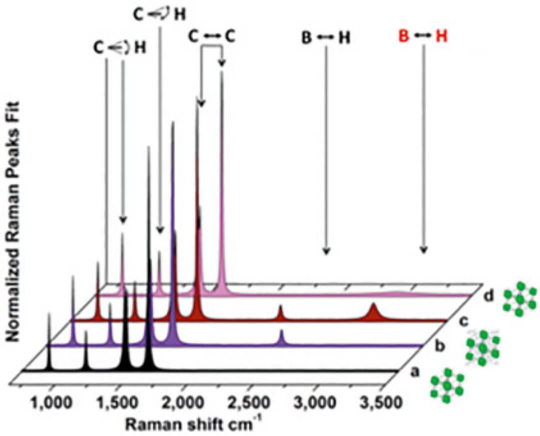
This COST Action deals with the important topic of energy storage and aims to set up a competitive and coordinated network for Hydrogen (H)-storage materials that stimulates innovative and interdisciplinary research in field of Solid State Hydrogen Storage (SSHS) within European Research Area (ERA). The Action on SSHS in light-weight nanostructured materials aims to contribute to the discovery of novel guidelines and phenomena for the design of advanced SSHS systems.



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CAT4ENSUS
Molecular Catalysts Made of Earth-Abundant Elements for Energy and Sustainability

Lead Empa & EPFL / Funding EU-FP7 / Period 2011–2015

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There are two specific aims: (i) bio-inspired sulfur-rich metal complexes as efficient and practical electro-catalyst for hydrogen production and $C0_2$ reduction, (ii) well-defined Fe complexes of chelating pincer ligands for chemo- and stereo-selective organic synthesis. An important feature of the proposed catalysts is that they are made of earth-abundant and readily available elements such as Fe, Co, Ni, S, N, etc.

Catalytic activation of small molecules: applications in molecular energy storage and delivery

Lead EPFL / Funding SNF / Period 2012–2015

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This research project is proposed for a better understanding of the fundamental aspects and the possible applications of these processes, strongly linked with the homogeneous catalytic activation of H_2, $C0_2$, CO and N_2, as well as small organic molecules (HCOOH, alkenes, alkynes, methanol, etc.) in aqueous solution and in different reaction media.

IEA-Hydrogen, Task 32
Hydrogen Based Energy Storage

Lead EPFL / Funding EPFL / Period 2011–2015

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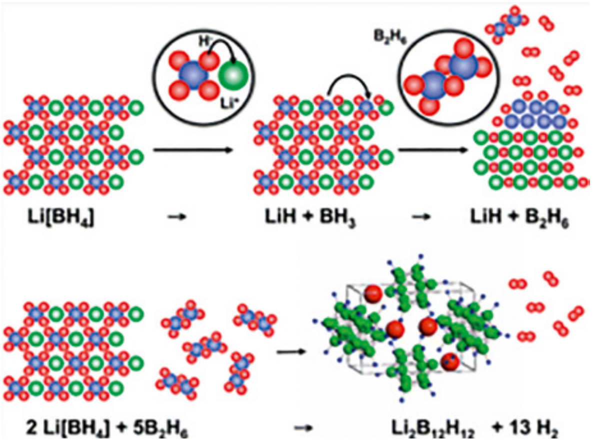
Task 32 addresses hydrogen-based energy storage by developing reversible or regenerative hydrogen storage materials. In these materials, the quantitative targets for hydrogen capacities vary significantly depending on the different applications, eg. the gravimetric density is crucial for mobile applications whereas in stationary systems it plays a minor role.



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COCHALPEC
Development of electrodes based on copper chalcogenide nanocrystals for PEC

Lead EPFL / Funding EU FP7 / Period 2013–2017

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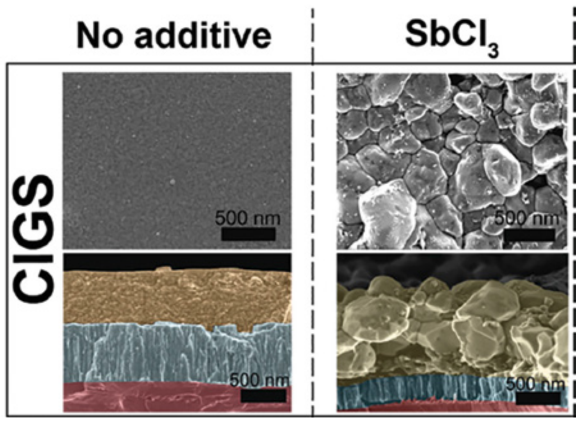
In this project, we propose the fabrication of photoelectrodes based on CZTS and ZCIS NCs to perform the water splitting. First, the control over the size, shape and composition of these NCs will be demonstrated using inexpensive solution-based techniques. Next, two photoelectrode configurations (viz. sensitized metal oxide and 3D-arrays of NCs) will be pursued applying state of the art overlayers to improve the charge separation and the catalytic activity at the interface with water.



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Defects in the bulk and on surfaces and interfaces of metal oxides with photoelectrochemical properties

Lead Empa / Funding SNF / Period 20111-2014

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In PEC anode materials, solar energy creates electron-hole pairs which separate under an external field; the holes diffuse to the anode-electrolyte interface into the electrolyte where they can oxidize water and generate oxygen gas; in return, an electron from the electrolyte enters the anode material, and at the cathode hydrogen is evolved which can be used as fuel.

Novel, synthetic, calcium-based sorbents for CO_2 capture and hydrogen production

Lead ETH Zürich / Funding SNF / Period 2013–2015

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The overall objective of this proposal is the development of novel, synthetic, calciumbased sorbents for CO_2 capture. These sorbents shall possess high cyclic reactivity and capacity, tolerance towards sulphur and a low tendency for attrition. Two advanced particle preparation techniques, i.e. co-precipitation and sol-gel, which offer the possibility to tailor key structural parameters of the sorbent, such as pore size distribution will be applied.

ELYGRID
High pressure alkaline electrolysers for electrtylH production from renewable energies

Lead Empa & IHT / Funding EU FCH JU / Period 2011–2014

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The project aims to reduce the total cost of hydrogen production via electrolysis coupled to renewable energy sources, mainly wind. It is focusing on megawatt-scale electrolysers (>05 MIN) and current objectives are to improve system efficiency by 20% (10% stack and 10% electrical conversion) and to reduce costs by 25%. The work will be divided into three pans: cell improvements, power electronics, and balance of plant (BOP).

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PEEC-HP
Investigation of high pressure membrane water electrolysis

Lead PSI / Funding BFE / Period 2013–2016

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When hydrogen is used as a fuel for mobility, high pressures >300 bar are required. In order to avoid inefficient mechanical compression, high pressure polymer electrolyte membrane electrolysis in combination with electrochemical compression of hydrogen is studied with respect to influence of pressure and dynamics on faradaic and electrical efficiency. The overall process efficiency and dynamits are assessed and compared to conventional technology.

ECOSTORE
Novel Complex Metal Hydrides for Efficient and Compact Storage of Renewable Energy as Hydrogen and Electricity

Lead HZG Geesthacht, Germany / Funding EU FP7 ITN / Period 2013–2017

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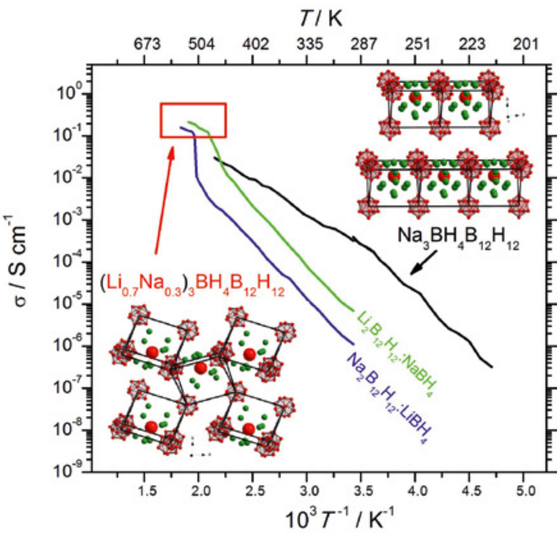
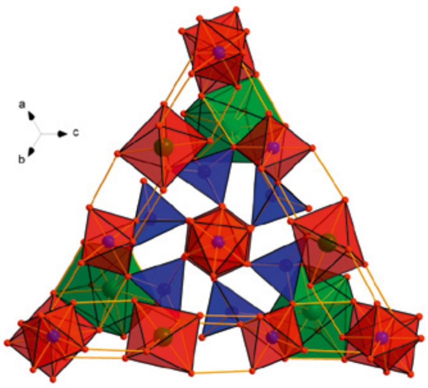
Novel borohydride- and nitride based materials, the scientific focus of ECOSTORE, are of special interest obviously for hydrogen storage, but – as recently found – also for electrochemical energy storage as novel solid state ion conductors and anode conversion materials. The objectives of ECOSTORE are therefore to obtain a fundamental understanding of metal hydride based energy storage materials, and to develop them towards industrial implementation, achieving high technical performance as well as cost effectiveness.





PEEC-NR
In situ study of water transport processes in PEM electrolysers with neutron imaging

Lead PSI / Funding BFE / Period 2013–2017

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Electrolysis of water to produce hydrogen is an interesting option to valuate the electrical energy produced by renewable sources such as solar or wind power during peak production periods. In this project, water visualization with neutron imaging will be used to obtain a better understanding of the complex two-phase (mixed water and gas) flow processes in electrolysers with the aim of optimizing their performance.

RENERG2
Renewable energies in future energy supply, WP 1 (Electrolysis)

Lead PSI / Funding BFE / Period 2013–2017

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WP 1 is focused on the study of the oxygen evolution reaction (OER) and the reduction of CO_2. In addition to the experimental work, theoretical calculations for the two processes are performed. The main target for the OER is to synthesize and characterize catalysts which are reduced in Iridium content as compared to state-of-the-art CO_2 catalysts.

LightChEC
Converting Solar Light into Chemical Energy

Lead Uni Zürich / Funding Uni Zürich, URPP / 2014–2016

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The main objectives of the URPP Solar Light to Chemical Energy Conversion are to discover and develop new molecules, materials and processes for the direct storage of solar light energy in chemical bonds. Artificial photosynthesis is the working principle: water is split directly into oxygen and hydrogen, the latter representing a highly efficient carrier for energy storage and conversion into common liquid fuels, such as methanol and gasoline.

LightChEC
Converting Solar Light into Chemical Energy

Lead EPFL / Funding SER I CCEM / 2011–2014

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The HyTech project is focused on the realization of breakthroughs and advancing innovative technologies in the field of sustainable H_2 utilization. These development will have a large impact on future H_2 energy systems. To maximize the efficacy of our efforts, both the disciplines of solar H_2 production and H_2 storage will be engaged by employing the top experts in each field from Switzerland, and by pursuing pioneering approaches.

Production of ultra-pure hydrogen from woody biomass using a modified chemical looping process

Lead Uni Zürich / Funding BFE / Period 2011–2014

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This project is concerned with a novel method for the production of hydrogen from woody biomass which is of sufficient purity to be used directly in PEM fuel cells without substantial gas clean-up, using a modified chemical looping combustion process. First, a syngas derived from the gasification of woody biomass is converted to a pure stream of CO_2 and steam, achieved by passing it through a bed of Fe_2O_3 which is reduced to Fe (or FeO).

Methane for transport and mobility

Lead HSR / Funding SNF NRP70 / Period 2014–2017

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Power-to-gas is a process where excess electrical energy is used for producing hydrogen (H_2) or methane (CH_4). The transformation from electricity to methane can be achieved with an efficiency of 54 % using existing technologies. The H_2 can be stored or used locally. H_2 (up to a concentration of 2 %) and CH_4 can be fed into the existing Swiss gas grid, on the low-pressure or the high-pressure side. This grid already offers significant seasonal storage capacities in Europe today.

Ion mobility in complex hydrides

Lead Empa / Funding PSRP Polish Swiss Research Program / Period 2011–2016

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This project focuses on the development of novel lightweight complex hydrides with respect to their applicability as solid electrolytes and high performance hydrogen storage media. The hydrogen release reaction, reaction intermediates and the reversibility of these reactions as well as the ion dynamics in these compounds are investigated. Experimental work and theoretical calculations go hand in hand to gain understanding on the atomic level.

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Novel materials and methods for solar fuel generation

Lead EPFL / Funding SNF-Ambizione Energie / 2014–2017

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The splitting of water (ZHZO –> O_2+2H_2) is one the key energy-storage reactions and can be divided into its two half reactions: oxidation and reduction.Semiconductors are robust and are well-known to exhibit reliable absorption and electric properties, which makes them good candidates as light absorbers in a photo-electro-chemical cell.

NOVEL
Novel materials and system designs for low cost, efficient and durable PEM electrolysers

Lead PSI / Funding EU FCH JU / Period 2012–2016

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This project will take advantage of the progress beyond the state of the art achieved by the partners involved in the NEXPEL project. In the initial phase of this project, durability studies of electrolyser stacks developed in NEXPEL will be performed. The stacks will be run at different operating conditions (low pressure, constant load, fluctuating load coupled with RES).

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PECDEMO
Photoelectrochemical demonstrator device

Lead Empa, IHT / Funding EU FCH JU / Period 2011–2014

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To address the challenges of solar energy capture and storage in the form of a chemical fuel, we will develop a hybrid photoelectrochemical-photovoltaic (PEC-PV) tandem device for light-driven water splitting. This concept is based on a visible light- absorbing metal oxide photoelectrode, which is immersed in water and placed in front of a smaller-bandgap thin film W cell.

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PEChouse3
Photoelectrochemical water splitting for solar production of hydrogen

Lead EPFL / Funding BFE / Period 2015–2018

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The project aims to achieve efficient conversion of solar energy into hydrogen using the approach of tandem photoelectrochemical (PEC) – photovoltaic (PV) devices. The proposed PEC-PV tandems can generate hydrogen from the splitting of water, driven by light from the sun. This project will produce complete devices capable of solar-to-hydrogen conversion at high efficiency using earth-abundant materials and up-scalable design principles.

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PHOCS
Photogenerated Hydrogen by Organic Catalytic Systems

Lead EPFL / Funding EU-FP7 / Period 2012–2015

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The aim of the project is the realization of a new concept, photoelectrochemical systems for hydrogen production based on hybrid organic-inorganic and organic-liquid interfaces. The project successfully demonstrated organic-based photocathodes for PEC hydrogen evolution with high efficiency and synthesized by low-cost solution-based methods.

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SHINE
Efficient and cost effective hydrogen production system using sunlight and water

Lead EPFL / Funding SNF nano-tera / Period 2013–2016

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This project aims to develop a hydrogen production system using sunlight in an integrated manner with earth abundant materials mimicking natural photosynthesis. PhotoElectroChemical (PEC) systems use semi-conductor materials to absorb photons from the sun to generate a potential high enough (> 1.2 V) to split water and produce hydrogen and oxygen at an integrated electrolysis cell.

Renewable Hydrogen Production through Photoelectrochemical Water Splitting

Lead EPFL / Funding SNF NFP70 / Period 2014–2017

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Process by photoelectrochemical (PEC) water splitting. Using earth-abundant metal oxide materials, we will develop sunlight-absorbing semiconductor devices which, when immersed in water and illuminated, drive the splitting of water into hydrogen and oxygen. Specifically, cuprous oxide covered with thin protective oxide layers have shown promise toward the water reduction half-reaction. These materials will be advanced and optimized toward the construction of a device capable of complete water splitting at solar-to-hydrogen efficiency exceeding 7% at room temperature and wide range of light intensities.

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Solar Liquid fuels from H_20 and CO_2

Lead ETH Zürich / Funding BFE / Period 2011–2014

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A two-step solar thermochemical cycle for producing syngas from H_20 and CO_2 via Zn/ZnO redox reactions is considered. The second, non-solar, exothermic step is the reaction of Zn with mixtures of H_20 and $C0_2$ yielding high-quality syngas and Zn0. Syngas is further processed to liquid fuels via Fischer-Tropsch or other catalytic reforming processes. This research project is aimed at optimizing and scaling-up the chemical reactor technology for the 2nd step of the cycle.

SOLAR-JET
Solar chemical reactor demonstration and for Renewable JET fuel

Lead ETH Zürich / Funding EU-FP7 / Period 2011–2015

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The aim of the SOLAR-JET project is to demonstrate a carbon-neutral path for producing aviation fuel, compatible with current infrastructure, in an economically viable way. The SOLAR-JET project will demonstrate on a laboratory-scale a process that combines concentrated sunlight with CO_2 captured from air and H_20 to produce kerosene by coupling a two-step solar thermochemical cycle based on non-stoichiometric ceria redox reactions with the Fischer-Tropsch process.

SOPHIA
Solar integrated pressurized high temperature electrolysis

Lead HTceramix / Funding EU FCH JU / Period 2014–2017

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A 3 kWe-size pressurized HTE system, coupled to a concentrated solar energy source will be designed, fabricated and operated on-sun for proof of principle. Second, it will prove the concept of co-electrolysis at the stack level while operated also pressurized. The achievement of such targets needs key developments that are addressed into SOPHIA.

Sustainability assessment of the CO_2-methanation value chain

Lead ZHAW / Funding SNF NFP70 / Period 2014–2017

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In diesem Projekt wird die Methanisierung von CO_2 in Bezug auf Nachhaltigkeit analysiert: von der Wasserstoffherstellung aus photochemischer Wasserspaltung (Partnerprojekt 1), durch die katalytische Methanisierung von CO_2 aus der Zementindustrie mit erneuerbarem Wasserstoff (Partnerprojekt 2), bis zur Anwendung des generienen Methans als Brennstoff fiir die Strom- und Warmeerzeugung in neuartigen stationaren und mobilen Brennstoffzellen (Partnerprojekte 3 und 4).

PALE
Laboratory alkaline electrolysertest bench tor high pressure and temperature

Lead ZHAW / Funding SNF NFP70 / Period 2014–2017

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In the frame of the project, a fully automated pilot-laboratory electrolyser with a membrane diameter of 50 mm will be developed and built up at Empa. Therewith it is possible to test the membrane and total stack concerning efficiency, durability, cell voltage, power consumption etc. under real conditions with electrodes and membranes made of newly developed advanced materials for lower cell voltage and thus higher efficiency.

Wasserstoffproduktion aus temporar überschüssiger Elektrizitat (RENERG2, P+D-Teil «Future Mobility»)

Lead Empa / Funding Empa / Period 2013–2016

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In the frame of the project, a fully automated pilot-laboratory electrolyser with a membrane diameter of 50 mm will be developed and built up at Empa. Therewith it is possible to test the membrane and total stack concerning efficiency, durability, cell voltage, power consumption, etc. under real conditions with electrodes and membranes made of newly developed advanced materials for lower cell voltage and thus higher efficiency.

Hybridwerk Aarmatt

Lead Regio Energie Solothurn / Funding BFE / 2014–2017

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Das Leuchtturmprojekt Hybridwerk Aarmatt schafft ein innovatives System, das Strom-, Erdgas- und Fernwarme-Netz auf Basis verschiedener Energieumwandlungssysteme miteinander verbindet. Das Hybridwerk steht im Zeichen der Energiewende und ist ein Vorzeigeprojekt fur die intelligente dezentrale Energieversorgung.

Redox flow battery pilot installation for hydrogen generation and energy storage

Lead Regio Energie Solothurn / Funding BFE / 2014–2017

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The project is to develop a sustainable system for the conversion of renewable energy into hydrogen. It utilizes a dual-circuit redox flow battery to either produce fuel (primarily hydrogen), or provide electrical energy storage that can be discharged conventionally, on demand. The hydrogen is generated from the charged battery electrolyte using a low-cost catalyst, regenerating the discharged electrolyte for re-use.

DEMCAMER
Catalytic Membrane Reactors by developing nano-architectured membrane materials

Lead Quantis Sarl / Funding EU FCH JU / Period 2011–2015

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The aim of the project is to develop multifunctional Catalytic Membrane Reactors based on nano-architectured catalysts and selective membranes materials to improve their performance, cost effectiveness and sustainability over four selected chemical processes (Autothermal Reforming (ATR), Fischer-Tropsch (FTS), Water Gas Shift (INGS), and Oxidative Coupling of Methane (OCM)) for pure hydrogen, liquid hydrocarbons and ethylene production.

SCCER Hydrogen storage in Hydrides

Lead PSI EPFL / Funding KTI CTI / Period 2013–2016

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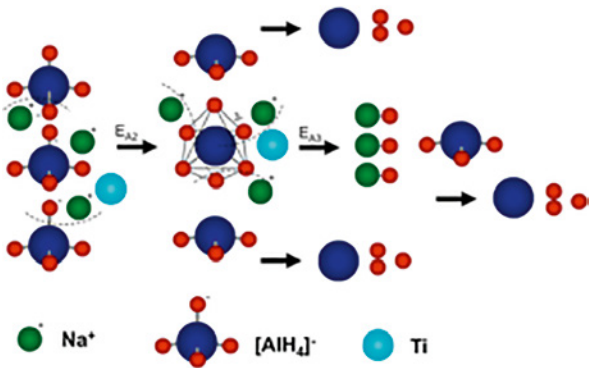
Hydrogen storage is crucial for a long term (seasonal) large scale storage system for renewable energy. Hydrides allow to store hydrogen with twice the density of liquid hydrogen and at low pressure. Therefore, low cost and abundant materials are required for the development of large scale storage. Beside solid hydrides the reduction of CO_2 from the atmosphere with hydrogen to produce synthetic hydrocarbons is an other option. The surface of metal hydrides can be used as heterogeneous catalyst for the CO_2 reduction, since metal hydrides bind CO_2 and offer atomic hydrogen on the surface.



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Alkaline Electrolysis for Renewable Energy Generation: Membrane Development for Industrial Electrolysers

Lead Empa / Funding Swisselectric / Period 2013–2016

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Development of a new type of membrane with higher efficiency and better durability at higher temperature and pressure and high gas purities for high quality H_2 and O_2. The membranes will consist of commercial low cost materials of natural (mineral) and/or synthetic composition (Olivine, Wollastonite, $BaSO_4$, TiO_2, $BaTiO_3$, ZrO_2). The new developed membranes will be characterized at Empa and tested at IHTs pilot electrolyser (Ø 130 mm).

SCCER Hydrogen Production by electrolysis

Lead PSI EPFL / Funding KTI CTI / Period 2013–2016

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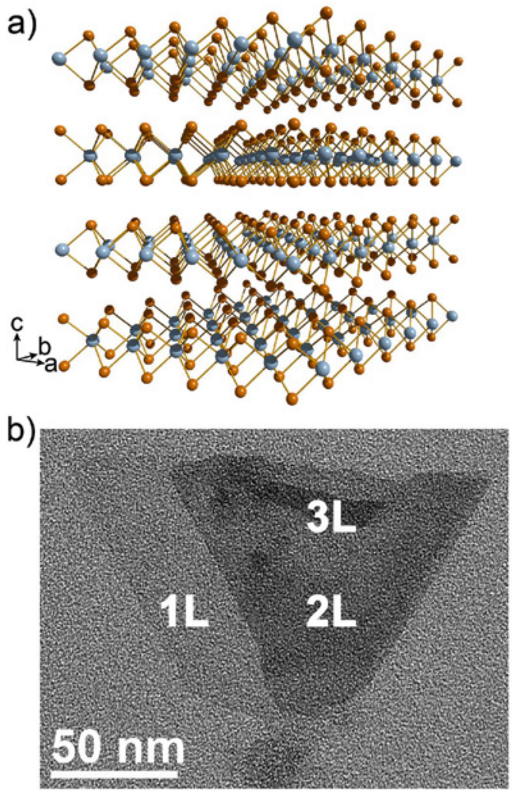
The development and characterization of novel electrodes for water electrolysis is one of the central objective of the new catalyst testing platform facilities in LIMNO at EPFL. This project aims to build expertise in the assessment of heterogeneous catalysts for both water oxidation and reduction, the analysis of produced gases, as well as in the advanced electronic characterization of (photo-)electrodes and processes. Within this framework, we have pursued our investigations on 2-D transition metal dichalcogenides (TMD, e.g. WS2 or WSe2), which are globally considered as promising catalysts for both oxygen evolution reaction (OER, water oxidation) and hydrogen evolution reaction (HER, water reduction).



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