Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

Wasserstoff Hydrogène Idrogeno Hydrogen
H_2YDROPOLE

HYDROGEN
REPORT SWITZERLAND
13/14

Projects and Products

EDITORIAL


Urs Elber

To use energy whenever and in whatever amount is part of our free society and considered a fundamental right. However, energy has its price, not only monetary. The impact on our environment and the risks for our future are becoming evident. Transition to a sustainable energy supply and sufficiency is not an option any more, it is inevitable.

Most people do not want to go back to the sustainable world which existed until a few centuries ago and was reality for thousands of years. Hardly anybody would like to abandon the amenities of today's energy world. However, in the past, fast and fundamental changes in societies often were the result of crisis. The options to avoid future disasters caused by unmanaged energy consumption are few. The solutions can not be postponed to generations ahead. Sustainable resources need to be combined with efficient technologies in production and clever usage. Assessing the impacts on environment must be part of this chain.

Renewable energies like wind and solar power experience massive growths. On one hand, the potential is becoming widely evident now. On the other hand, many new questions arise, because these energies can be best produced at times and at places where local demand is low. The triangle of production, consumption and grids in between needs additional elements: Conversion into other energies and storage for direct use and transport.

With hydrogen as an energy carrier a variety of applications with a minimum of efficiency loss open up. Production of hydrogen out of excess photovoltaic electricity, storing it and using this hydrogen directly for local mobility needs is part of future "Smart Cities". Increasingly, industry is developing hydrogen driven vehicles and is implementing the results from basic research. Broad networks of hydrogen fueling stations are in planning phase already.

Synthetic natural gas formed of hydrogen and CO_2 from fossil fuel combustion allows transport and storage in natural gas pipelines. Besides this huge potential, there are a lot more concrete paths to produce, store, transport and use hydrogen.

Hydropole is networking hydrogen ideas, research, industry, products and consumers. The progress made in the past years is incredible, as you can see in this report. Based on the excellent work by all partners, more P&D and lighthouse projects will be in place soon. These visible options then broadly enable decision makers to adopt hydrogen solutions as a significant part of our energy future. As HYDROPOLE has been doing for years.

Villigen PSI, 28. 9. 2012

Urs Elber.
Managing Director, Competence Center for Energy and Mobility CCEM

TABLE OF CONTENTS

Editorial	3
Energy vision for Switzerland	6
Hydropole	10
Hydrogen production via solar gasification of carbonaceous materials	12
Applied sciences on PEM - Fuel cells in Biel	14
High Temperature Steam Electrolysis (HTSE): A material challenge	16
Synthesis of complex hydrides	18
Hydrogen for navigation	20
FITUP – Fuel cell systems for backup power applications	22
PEM Fuel cell systems	23
Public transport with fuel cell drive	26
HyTech-PECHouse2 project	28
Fuel cell research at PSI	32
Agency for pioneer and troop equipment - WTD 51	34
H_2 fuelling station at the Fraunhofer ISE	36
Hydrogen as centre piece in Power-to-Gas	38
Hydrogen and fuel cell projects Switzerland	40
Hydrogen facts	70

ENERGY VISION FOR SWITZERLAND

Andreas Züttel

ENERGY HISTORY

The wealth of today is a result of industrialization during the last century. Industrialization was enabled in Great Britain with the invention of the steam engine in 1700 by Thomas Savary and Thomas Newcomen [1] and developments by James Watt [2] around 1800. He turned the steam engine in an automatic machine delivering rotational power and improved efficiency by an order of magnitude.

From 1850 on, coal was mined in order to fuel steam engines and to heat homes. In 1900, approximately the same amount of energy ($9 \cdot 10^{12}$ kWh a^{-1}) was consumed from biomass and from coal. After the Second World War, energy demand worldwide increased more than exponentially to about $120 \cdot 10^{12}$ kWh a^{-1}, corresponding to 2.0 kW per capita continuous power today. This development has created the wealth of the industrialized countries. From a physical point of view, wealth is the availability of energy and materials. Another measure of wealth is the working time necessary for maintaining the standard of life, which is in the industrialized world on average only five hours per day. The economic system today is dependent on the availability of fossil fuels. The world economy produces 0.4 US$/kWh [4] and, therefore, increasing energy consumption increases income.

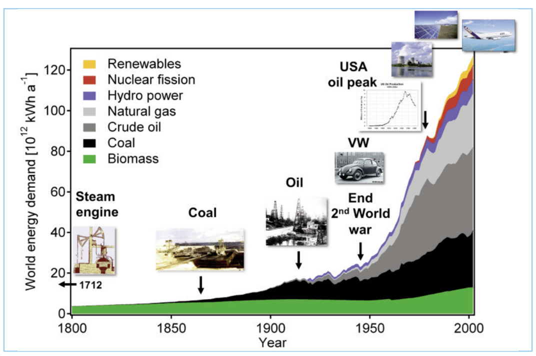


Fig.1: Energy demand [3] from 1800–2000 by type of energy carrier

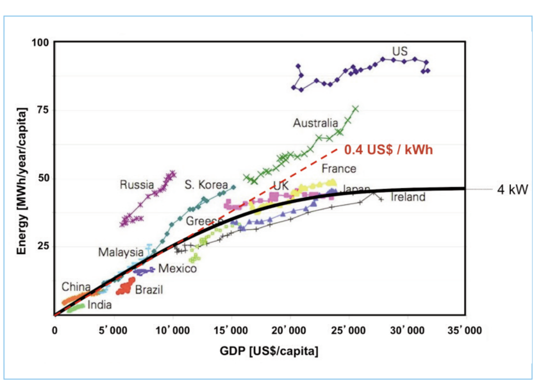


Fig. 2: Primary energy demand vs. Gross Domestic Product (GDP) per capita

In 1865, William Stanley Jevons [5] analysed the relationship between energy demand and efficiency of the energy converter. He described the efficiency paradox: with increasing efficiency, energy demand increases, because the use of energy becomes more economically beneficial. Therefore, in the current economic system, energy demand is increased for economic growth.

The resources used today are minerals and fossil fuels mined in the earth's crust. The products produced by industry are used and finally deposited or released into the air or water. Some materials are treated and recycled, such as glass, aluminum steel and vegetal biomaterial. As a consequence of the current economic system, carbon dioxide concentration in the atmosphere is increasing, the rivers, lakes and sea are increasingly contaminated, the amount of waste deposits (chemical and ashes, slag) is growing and nuclear waste deposits are being installed. The current industrial system is not sustainable and was established in order to create wealth as quickly as possible in a situation where the limitation of resources did not affect the growth of the economy. However, today the limitation of resources is beginning to affect the economy and the release of waste is a growing environmental problem, which cannot entirely be left to future generations to be solved. In particular, the limitation of fossil fuels (coal, oil and gas) and the release of carbon dioxide requires a solution in the near future.

CLOSING THE CYCLE

According to statistical considerations, the world population will stabilize at approx. 10 billion humans [6] in 2050, thanks to growing wealth in the developing countries and, therefore, a reduction of the number of children per family to two. That results in an increase of 25% in the number of people, and a large increase (approx. factor of four) in demand for resources if all reach the living standards of western Europe. A sustainable future economic system requires the technology to close the cycle, i.e. to provide renewable sources of energy and entirely recyclable or avoided waste. As a consequence, garbage-burning stations must be replaced with recycling plants, nuclear waste deposits with reprocessing plants and carbon capture and sequestration with CO_2 extracted from the atmosphere and reduction to hydrocarbons with hydrogen. Only products which are naturally recycled at the same rate as they are released and neutral products, e.g. water, can be released or deposited without affecting the sustainability of development.

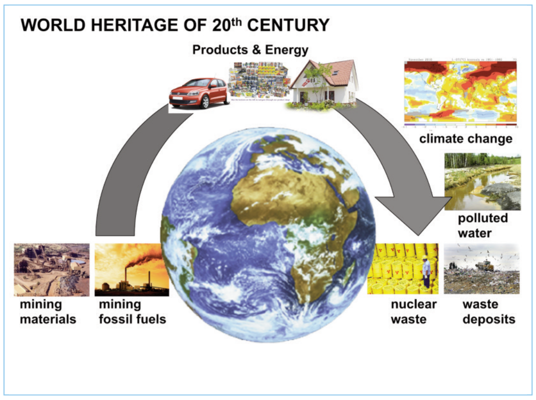


Fig. 3: Current economic system based on mining and depositing

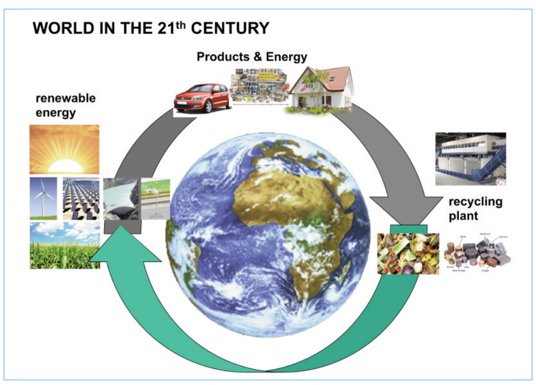


Fig. 4: Future sustainable economy based on the closed cycle

The main difference between the current and the future economic systems is establishing a technical link between waste and resources with the introduction of renewable energy.

ENERGY SOURCES AND STORAGE

The only natural 'sources' of energy are the sun, by nuclear fusion; the earth's crust, by nuclear fission; and the tide, by planetary movement. The latter is only feasible in certain coastal regions coast and is not of global importance. The sun delivers energy in many forms (heat radiation, wind, precipitation, waves), all of them varying in time and in geographical location, while the earth's crust delivers continuous and constant heat. The solar irradiation in Switzerland (100 kWh/m^2 per year) corresponds to world energy consumption today – i.e. with a technical system with 10% conversion efficiency, a surface area of ten times the size of Switzerland (700 km x 700 km) has to be covered in order to produce sufficient energy to meet global demand.

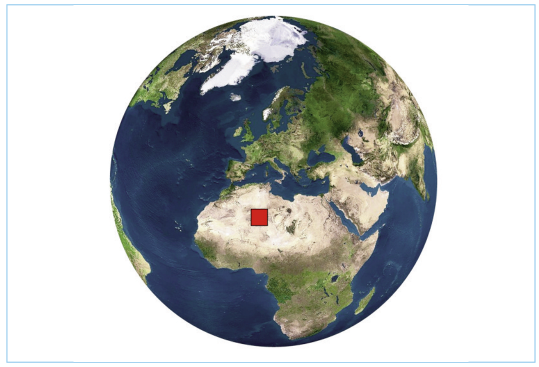


Fig. 5: Globe with the surface area of 500'000 km^2 as a red square in the Sahara

Fossil fuels represent energy carriers while renewable energy sources are energy fluxes which have to be stored; instead, or in addition, synthetic energy carriers have to be produced. A number of energy carriers are used today, depending on the specific application. The crucial parameters of the energy storage system are volumetric and gravimetric energy density. Most of energy today is stored in fossil energy carriers with an energy density of approx. 10 kWh/kg and 10000 kWh/m^3. Only hydrides, ammonia and biomass come close (approx. 50%) to the energy density of the fossil fuels. Other storage systems – especially batteries, with 0.2 kWh/kg and 200 kWh/m^3 – store 50 times less energy than fossil fuels.

The conversion of renewable energy requires an installation, i.e. an investment of approx. five years' worth of produced energy. For example, the replacement of all nuclear power plants in Switzerland with photovoltaics would require the same area as the surface area of all apartments (50 m^2/capita = 400 km^2) and would cost about 100 billion CHF. Solar energy has to be stored on two different time scales, i.e. day/night and summer/winter, which corresponds to 10^9 kWh and $3 \cdot 10^{11}$ kWh respectively in Switzerland. Approx. half of the annual energy demand needs to be stored during the year. By far the most cost effective forms of storage today are fossil fuels and hydropower, at less than 0.1 €/kWh.

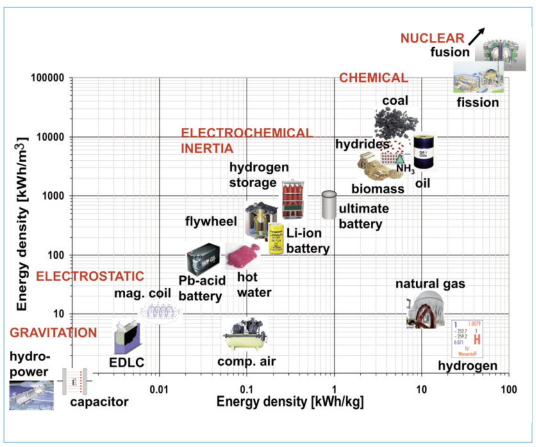


Fig. 6: Volumetric vs. gravimetric energy density for common energy stores

CHALLENGES FOR THE FUTURE

Renewable energy requires efficient conversion of the energy available into electricity or usable heat. The produced heat or electricity then needs to be stored in an efficient way and in large quantities. The conversion of solar energy into an energy carrier, e.g. biomass, alleges or photoelectrolysis of water to hydrogen, directly delivers a storable energy material; however, the solar to fuel conversion efficiency is only in the order of 1%, which corresponds to 10 kWh/m^2 per year. Theoretically, at the thermodynamic limit, more than 20% efficiency can be achieved by the reduction of CO_2 to hydrocarbons with hydrogen produced from solar energy.

Hydrogen can be produced from water by technical means, i.e. electrolysis. Large-scale electrolyzers reach efficiency greater than 80% and a power density of approx. 40 kW/m^2. The upper heating value of hydrogen is 39 kW/kg, three times the energy density of the fossil fuels. Hydrogen can be stored as compressed gas at high pressure (<900 bar), as a liquid at -252°C, and as a solid in metal or complex hydrides; however, the storage density of hydrogen is limited to 20 mass% (except for liquid hydrogen) and 70 kg/m^3. Therefore, the maximum energy density of stored hydrogen is in the same range as biomass and alcohol, i.e. approx. 5 kWh/kg. Finally, hydrogen can be combusted in internal combustion engines, turbines and fuel cells to produce work and heat and water vapor is released into the atmosphere, where it condenses and falls back to the surface of the earth. The hydrogen cycle is, therefore, a closed cycle and realized by purely technical means: no living matter is needed; i.e. no cultivation and harvesting is necessary.

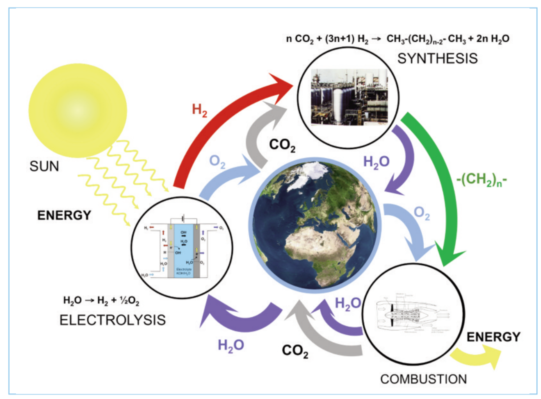


Fig. 7: The closed hydrocarbon cycle: Hydrogen is produced from renewable energy and water and used to reduce CO_2 from the atmosphere to produce synthetic hydrocarbons

In order to close the gap in energy density between hydrocarbons (fossil fuels) and hydrogen, the hydrogen has to be stored in the form of hydrocarbons. Unlike water, CO_2 in the atmosphere does not naturally condense, and therefore has to be extracted from the air (79%N2, 21%O_2, 400 ppm CO_2). Currently approx. $5 \cdot 10^{12}$ kg C in the form of CO_2 is released into the atmosphere from fossil fuels each year and less than half of it is reabsorbed by natural processes, leading to a continuous (with seasonal oscillations) increase of the CO_2 concentration in the atmosphere. This can only be changed by extracting the same quantity of CO_2 from the atmosphere.

The major challenge for the future renewable energy economy is the efficient production of synthetic fuels from CO_2 extracted from the atmosphere and water. The theoretical energy [7] required for the extraction of CO_2 is less than 0.5 kWh/kg C, but current available technologies based on an absorption reaction consume much more. New low energy processes for the separation of CO_2 from N_2, O_2 have to be developed.

In Switzerland the main sources for renewable energy are photovoltaics and hydropower for electricity, solar collectors for heat, biomass for food and carbon hydrates as energy carriers. The technology to convert electricity in hydrocarbons will become increasingly important for the storage of large amounts of renewable energy for seasonal storage, e.g power to gas and power to fuel. Furthermore, mobile applications, especially airplanes, require fuel with a energy density comparable to that of fossil fuels. The only sustainable solution for the future is to close the cycle by synthesizing fuels from CO_2 (atmosphere) and hydrogen (water) by means of solar energy!

References:

[1] Jenkins, Rhys (1936). Savery, Newcomen and the Early History of the Steam Engine, in The Collected Papers of Rhys Jenkins. Cambridge: Newcomen Society. pp. 48–93.
[2] Brown, Richard (1991). Society and Economy in Modern Britain 1700-1850. London: Routledge. p. 60. ISBN 978-0-203-40252-8.
[3] Jean-Marie Martin-Amouroux, IEPE, Grenoble, France.
[4] http://muller.lbl.gov/teaching/physics10/PffP_textbook/PffP-10-climate_files/image022.gif
[5] Jeff Rubin and Benjamin Tal, „Does Energy Efficiency Save Energy?“, CIBC World Markets InC. StrategEcon - November 27, 2007
[6] Hans Rosling (2006). Global Health: An Introductory Textbook. Sweden: Studentlitteratur AB. ISBN 91-44-02198-4.
[7] K.S. Lackner, “Capture of carbon dioxide from ambient air”, Eur. Phys. J. Special Topics 176 (2009), pp. 93–106; David W. Keith, Minh Ha-Duong and Joshuah K. Stolaroff, “Climate Strategy with CO2 Capture From the Air”, Climatic Change 74 (2006), pp. 17–45.

Contact:

Prof. Dr. Andreas Züttel (President)
Empa Materials Sciences & Technology
Dept. Environment, Energy and Mobility
“Hydrogen & Energy”
Überlandstrasse 129
CH-8600 Dübendorf, Switzerland

e-mail: andreas.zuettel@empa.ch
Phone: +41 58 765 4692

URL: http://www.empa.ch/h2e

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. Nov. 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 10 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 9 members, the president, the vice-president and 7 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 2008. The current report presents the major achivements in the field of hydrogen science and technology in Switzerland.
Hydropole has organized the „Swiss village" at the World Hydrogen Energy Conference (WHEC) in June 2006 in Lyon, France. 7 members have represented the activities in Switzerland. The exhibition was a big success and has significantly increased the visi-

Fig. 1: The board of HYDROPOLE

bility of our members. Hydropole was represented by A. Luzzi and F. Holdener at the WHEC in Brisbane, Australia in June 2008. In February 2008 and 2009 Hydropole participated in the Swiss Pavillion organized by the Swiss embassy in Japan (Dr. Felix Mösner) at the Hydrogen and Fuel Cell exhibition (FC Expo) in Tokyo, Japan. The exhibition had more than 24'000 visitors and was a very impressive event. The WHEC 2010 has taken place in May 2010 in Essen, Germany. Hydropole organized a Swiss Village with 8 members from industry, research and academia.

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 .
In the first ten years of the existance of the hydrogen association Hydropole it has brought the hydrogen community in Switzerland close together. 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.

Fig. 2: Watt d'Or Award for the hydrogen Postauto project in Bern on 10.1.2013

2011 – 2012: 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 5 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,

Contact:

Prof. Dr. Andreas Züttel (President)
Mrs. Sara Rebsamen (Secretary)
Empa Materials Sciences & Technology
Dept. Environment, Energy and Mobility
"Hydrogen & Energy"
Überlandstrasse 129
CH-8600 Dübendorf, Switzerland

e-mail: info@hydropole.ch

URL: http://www.hydropole.ch

HYDROGEN PRODUCTION VIA SOLAR GASIFICATION OF CARBONACEOUS MATERIALS

Aldo Steinfeld

Christian Wieckert

Thermochemical gasification of carbonaceous materials using concentrated solar energy offers a promising route for clean hydrogen production. A 200 kW solar gasification pilot plant has been successfully demonstrated at the solar tower of the Plataforma Solar de Almeria in Spain. Coal, biomass, and carbonaceous wastes (e.g. tires, plastics, sludges) were thermochemically converted to high-quality syngas – mainly H_2 and CO – with a calorific value upgraded over that of the input feedstock and suited for further processing into pure hydrogen.

The concept of solar steam-based gasification of carbonaceous materials for hydrogen production is schematically shown in Fig. 1. Concentrated solar energy provides the high-temperature process heat required for thermochemically converting solid carbonaceous feedstocks (e.g. coal, biomass, or carbon-containing wastes) into high-quality synthesis gas (syngas, mainly H_2 and CO) [1]. This syngas can be further processed to pure hydrogen via water-gas shift of CO and separation of CO_2 with conventional technologies. Other syngas applications include direct combustion for high-temperature heat (e.g. in cement kilns), power generation in efficient combined cycles and fuel cells, and further processing via the Fischer-Tropsch into liquid hydrocarbon fuels.

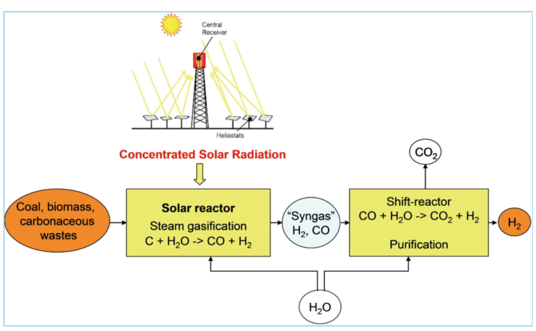


Fig.1: The solar gasification process for clean hydrogen production

Conventional autothermal gasification requires about one-third of the feedstock to be combusted to supply process heat for the endothermic gasification reaction, which inherently decreases carbon utilization and contaminates the product gases. In contrast, syngas from solar-driven steam gasification is free of combustion by-products and has a lower CO_2 output, because its calorific value is solar-upgraded over that of the original feedstock by an amount equal to the enthalpy change of the reaction. Solar gasification further eliminates the need for an upstream air separation unit because steam is the only gasifying agent, which further facilitates economic competitiveness.

Solar reactor concept for solar steam gasification

The solar gasification process was investigated in the framework of a joint PSI-ETH-Holcim R&D project co-financed by CTI. The solar reactor configuration is shown in Fig. 2. It consists of two cavities in series. The upper cavity functions as the solar absorber and contains a windowed aperture to let in concentrated solar radiation. The lower cavity functions as the reaction chamber and contains the packed bed on top of the steam injector. An SiC-coated graphite plate separates both cavities. This arrangement offers efficient absorption of concentrated solar radiation and heat transfer to the reaction site and enables the acceptance of a wide range of bulk carbonaceous feedstock of any shape and size without prior processing.

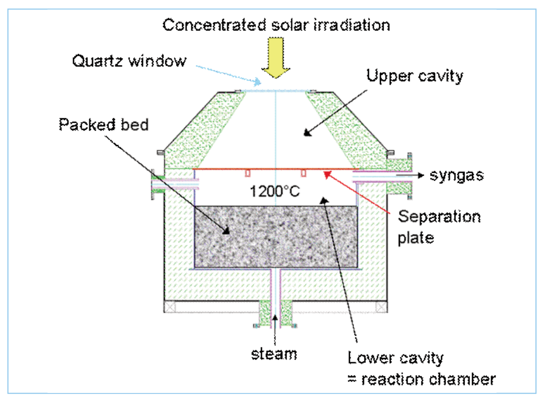


Fig. 2: Schematic of solar gasification reactor

Demonstration on pilot scale

Based on laboratory-scale tests with a 5 kW solar reactor prototype [2], a 200 kW pilot plant for up to 200 kg feedstock capacity (one batch per day) was designed. The solar reactor, along with the peripheral equipment, was installed at the solar tower of the Plataforma Solar de Almeria in Spain. Concentrated solar radiation collected by a field of 70 heliostats was focused onto the solar reactor at an operational temperature in the range 1000 - 1200 °C (Fig. 3). The carbonaceous feedstocks tested (Fig. 4) were characterized by having a wide range of volatile, ash, fixed carbon and moisture content, elemental composition, as well as particle size and morphology [2]. All feedstocks were successfully transformed into syngas with a H_2/CO molar ratio of typically 2 and low CO_2 content. Thanks to the solar energy input, higher syngas output per unit of feedstock was produced, as no portion of the feedstock was combusted for process heat. Consequently, about 50% more H_2 can be derived by water-gas shifting the produced high-quality syngas as compared to that obtained by conventional autothermal gasification.

Fig. 3: A field of heliostats concentrates solar radiation into the solar gasification reactor located 45m above ground on the solar tower of the Plataforma Solar de Almeria, Spain.

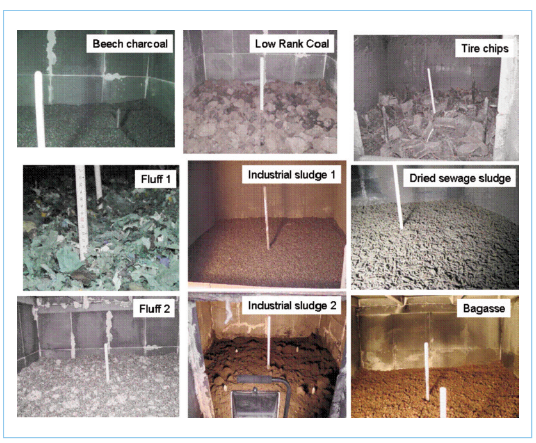


Fig. 4: Packed bed of the 200 kW solar gasification reactor with different feedstocks prior to solar gasification tests.

Hydrogen production via electrolysis of water

In addition to solar driven hydrogen production processes - one of which outlined above - PSI performs research aimed at the developing of materials and cells for high-pressure Polymer Electrolyte Electrolyzer Cells (PEEC) for the efficient production of hydrogen from water using electricity. The development strategy involves activities on three pathways:

a) cell engineering and diagnostic to improve water and gas transport properties to achieve the long-term goal of 200bar operation pressure;

b) ultra-thin polymer electrolyte membrane development based on PSI's radiation-grafting technology for high pressure operation; and

c) research on the reaction kinetics of the oxygen electrode for advanced understanding of intrinsically limiting factors.

References:

[1] N. Piatkowski, C. Wieckert, A.W. Weimer, A. Steinfeld, "Solar-driven gasification of carbonaceous feedstock – A review", Energy & Environmental Science 4 73-82 (2011).

[2] N. Piatkowski, C. Wieckert, A. Steinfeld, "Experimental investigation of a packed-bed solar reactor for the steam-gasification of carbonaceous feedstocks", Fuel Processing Technology 90 360-366 (2009).

Contact:

Prof. Dr. Aldo Steinfeld and Dr. Christian Wieckert
Paul Scherrer Institut, Solar Technology Laboratory, CH-5232 Villigen-PSI and ETH Zurich,
Dept. Mechanical and Process Engineering,
CH-8092 Zurich

Phone: +41 56 310 4407
e-mail: Christian.wieckert@psi.ch
URL: http://solar.web.psi.ch/; www.pre.ethz.ch/

Contact for electrolysis:

Prof. Dr. Thomas J. Schmidt, PSI Electrochemistry Laboratory,
e-mail: thomasjustus.schmidt@psi.ch
URL: www.psi.ch/lec

APPLIED SCIENCES ON PEM - FUEL CELLS IN BIEL

Michael Höckel

The main objective of the fuel cell group at the University of Applied Sciences in Biel (BFH-TI) is to bring fuel cells to the people. Pursuing this goal, a small team of engineers started the fuel cells activities at the BFH-TI in Biel at the turn of the century. Ever since, the test lab for PEM fuel cells has been equipped with several self-designed testing facilities meeting academic and industrial needs, enabling scientific research and market oriented developments. The BFH-TI has developed during this time also an own stack and system concept which has found its way into commercialization together with a Swiss company. In order to make the possible applications of PEM fuel cells more tangible for the people, several demonstrators for mobile and automotive applications have also been developed. Today, the BFH-TI is able to serve an excellent infrastructure and high competence for developing and testing PEM fuel cell stacks and systems in the power range of some watts to several kW.

One of the larger projects was the development of a fuel cell - battery hybrid system and its integration in a lightweight electric vehicle called “SAM”. The SAM is a three-wheel electric vehicle which offers two seats arranged in a row and has been developed in Biel for local traffic. The PEM-stack consists of 96 cells and has a maximum power of 6 kW; in combination with lithium-polymer batteries the propulsion system can be supplied with a power of 15 kW. The Fuel Cell Hybrid SAM was tested on the roads around Biel and the results were very satisfying: low consumption of about 450g H_2/100km and a range of 130 km, which seems very interesting for an urban electric light weight vehicle.

When designing a PEM fuel cell system, one of the aspects which have a fundamental influence on the system architecture and performance is the source of oxygen: pure oxygen from gas cylinders e.g., or oxygen from the ambient air. The main focus of the fuel cell system activities at the BFH-TI lie on hydrogen-air PEM fuel cell systems. However, in order to explore and demonstrate the main characteristics and differences, a hydrogen-oxygen PEM fuel cell system was integrated into an E-Scooter. The reactant gases are both stored in pressurized 2L gas cylinders at 200 bar. To achieve the electrical dynamics demanded during acceleration in a scooter, a series of super caps is connected directly in parallel to the PEM – Stack. The performance has been proved through extensive tests on an in-house circuit, normally used by go-carts. In order to reach an adequate range for urban traffic, gas cylinders with a pressure of 700 bar would be ideal. Such cylinders are however not yet commercially available at big scale

These and other projects like the clevertrailer, equipped with a 500 Watt PEM-System in a slide-in module, are excellent examples of the fruitful collaboration of the BFH-TI with industry and other research institutes.

Driven by the motivation to tackle the problem of high fuel cell production costs, an important strategic in-house project was started in 2005 to develop a low-cost PEM fuel cell stack based on flexible materials, which can be punched and promise cheap production costs even at low scale manufacture. Instead of the solely use of conventionally milled graphite plates, the new development is based on an optimized combination of foil materials, which can be easily dye cut,

Fig. 1: Typical PEM fuel Cell demonstrator Systems at BFH-TI

ensuring low production time and hence, costs. Further focus was set on integrating the gas humidification into the individual cells and enabling a concept of edge air cooling by providing each cell with cooling fins. Thermal regulation of the cells is easily achieved by ambient air passed along these fins propelled by conventional axial ventilators.

In close collaboration with the company CEKAtec AG, a Swiss company with main competences in high quality electromechanical devices, and supported by research institutes of PSI and EMPA, the fuel cell team of BFH-TI developed an industrialized fuel cell system ready for market entry. The companies SERTO and PanGas provided knowhow and materials for gas systems and hydrogen infrastructure. Initial research and industrialization development had been previously financed by the Swiss Federal Office of Energy (SFOE) and by the Commission for Technology and Innovation (CTI).

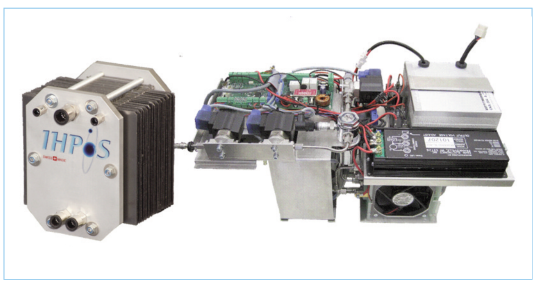


Fig. 2: IHPoS – Stack and System by BFH-TI and CEKAtec AG

The result of this collaboration between academia and industry is a Swiss Fuel Cell Product Family with the brand name IHPoS – Independent Hydrogen Power Systems, commercialized by the company CEKAtec. "Naked" PEM Fuel Cell Stacks in the power range of 200 W up to 750 Watt can be ordered since 2009 and a certified 500 Watt fuel cell system will be available in fall 2012. The core of the IHPoS-Fuel Cell Systems technology consists of an innovative electronic developed at the BFH-TI, which enables short time to market industrialization of systems in the range of 200 Watt up to 1 kW, making it a full modular concept. The application of the IHPoS modularity has been demonstrated in several prototype systems like the Hy-Bike, a trailer with an integrated 250 Watt IHPoS – range extender system, guarantying a good range for an E-Bike; also the battery charger IHPoSCamp, with a power output of 300 Watts.

On the commercial side, the certified 500 Watt IHPoS System from CEKAtec can be integrated in applications with high safety standards, like minibars, as used by the railway companies. These minibars can be equipped with an IHPoS System to provide power for preparing hot beverages and food.

Fig. 3: Typical applications of the IHPoS-System

Contact:

Prof. Michael Höckel
University of Applied Sciences
Institute for Energy and Mobility Research
Quellgasse 21
CH-2501 Biel, Switzerland

Phone: +41 32 321 6416
e-mail: michael.hoeckel@bfh.ch
URL: www.ti.bfh.ch

HIGH TEMPERATURE STEAM ELECTROLYSIS (HTSE): A MATERIAL CHALLENGE

Ulrich Vogt

High Temperature Steam Electrolysis (HTSE) stands for a promising process of large-scale centralised hydrogen production. It is also considered as an excellent perspective for efficient use of renewable solar or geothermal energy sources (Fig. 1). The European ADEL project (ADvanced **EL**ectrolyser for Hydrogen Production with Renewable Energy Sources**) proposes to develop a new steam electrolyser concept. This so-called Intermediate Temperature Steam Electrolysis (ITSE) aims at optimizing the electrolyser life time by decreasing its operating temperature while maintaining satisfactory performance level and high energy efficiency at the level of the complete system, including the heat and power source and the electrolyser unit.**

Most of the water electrolysis technologies to date have used alkaline or acidic electrolyte systems for hydrogen generation [1-2].

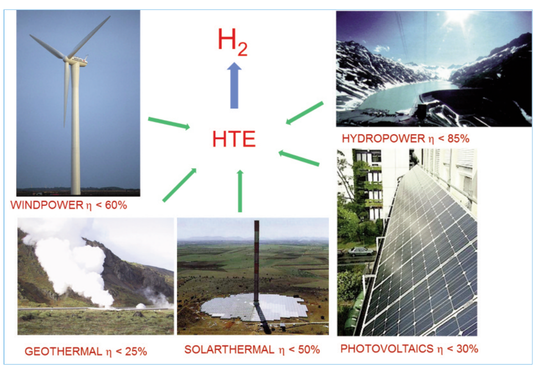


Fig. 1: Integration of high temperature electrolysis with various energy sources

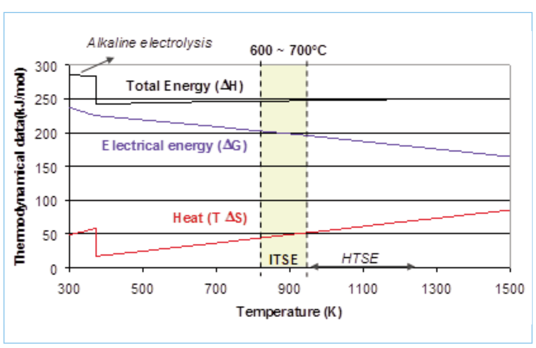


Fig. 2: High Temperature Steam Electrolysis (HTSE) presents the advantage to accept direct heat (TΔS) in addition to the electrical energy (ΔG) in the overall energy needed (ΔH) for hydrogen production HTSE heat requests $\Delta H = \Delta G + T\Delta S$

Typical system efficiencies quoted are in the 55-75% range. The current density is typically around 0.2-0.4 A/cm^2 and there are technical difficulties in maintaining the electrolyte balance and keeping hydrogen and oxygen separated. The electrolysis technology based on polymer electrolyte membranes does not use a corrosive electrolyte.

The PEM electrolyser can accept large power input variations allowing direct integration with intermittent energy sources. However, cost of such systems is expensive making this coupling acceptable only for limited cases.

Electrolysers based on solid-oxide fuel-cell technology offer the possibility of using heat generated from various sources in order to reduce the electric energy input and enhance the electrolysis efficiency (Fig. 2). However, this technology will bring significant economical improvement and will be competitive only if an increase of the electrolyser life time can be obtained.

Sources of degradation that affect the solid oxide electrolyser cells and stack lifetime come from the high operating temperature (800 – 1000°C). Indeed, this temperature range enhances chemical species evaporation and diffusion, resulting in the formation of secondary isolating phases, as well as in a decrease of the mechanical stability of ceramic and metal components.

To increase the electrolyser durability, one possible solution is to decrease the operating temperature of the electrolyser. The resistances of cells, interconnects and contact layers will tend to increase and to limit the electrolyser performance, but at the same time, all parasitic phenomena such as interdiffusion, corrosion or vaporisation responsible for cell and stack degradation will be significantly slowed down. Moreover, thanks to the progress achieved in the field of SOFC, cells and interconnect coatings are now available that allow reaching at 600°C equivalent performance that classically are obtained at 800°C [3].

The work task lead by Empa is related to advanced micro- and nanostructural analysis for better understanding the structural changes, poisoning effects and degradation mechanisms of SOECs (4, 5), as shown by some examples below (Fig. 3-4).

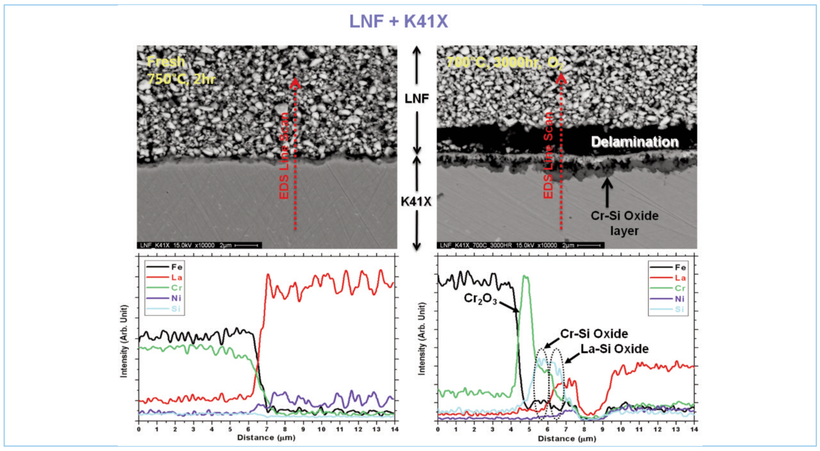


Fig. 3: Example of delamination at interconnect – interlayer interface after 3000 h at 700°C (right), fresh sample on the left.

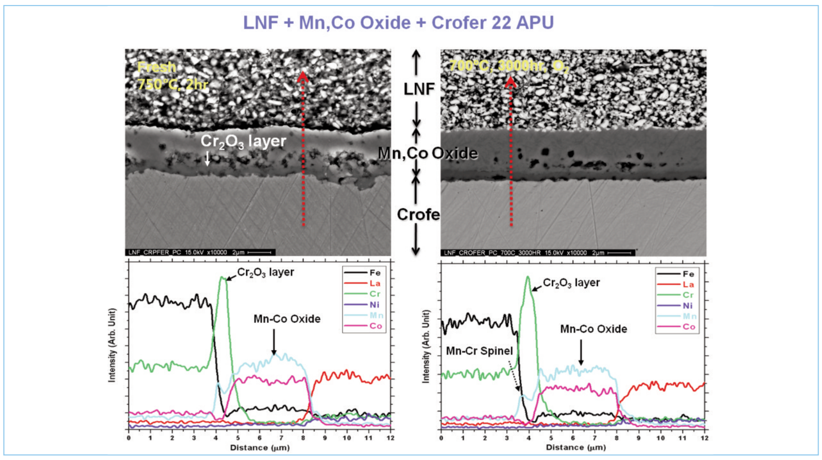


Fig. 4: Example of an intact interconnect – interlayer interface after 3000 h at 700°C (right) due to a Mn, Co Oxide interlayer, fresh sample on the left.

References:

[1] K. McHugh, Hydrogen production methods MPR-WP-0001, MPR Associates, Inc., Alexandria Virginia, USA (2005)

*[2] S.P.S. Badwal, S. Giddey and F.T. Ciacchi, Hydrogen and oxygen generation with polymer electrolyte membrane (PEM) based electrolytic technology, Ionics **12** (1) (2006), pp. 7–14*

*[3] B. G. Rietveld et al., The Integrated Project SOFC600 Development of Low-temperature SOFC, ECS Trans. **25** (2), 29 (2009)*

[4] D. Wiedenmann, A. Hauch, B. Grobéty, M. Mogensen, U.F. Vogt; Complementary techniques for solid oxide cell characterisation on micro- and nano-scale, International Journal of Hydrogen Energy 35 (2010) 5053-5060

[5] U. F. Vogt, P. Holtappels, J. Sfeir, J. Richter, S. Duval, D. Wiedenmann and A. Züttel; Influence of A-Site Variation and B-Site Substitution of (La,Sr)FeO_3 Based Perovskites, Fuel Cells 09, 2009, No. 6, 899-906

Contact and further information:

Dr. Ulrich Vogt, Prof. Dr. Andreas Züttel
Empa, Swiss Federal Laboratories for Materials Testing and Research,Laboratory for Hydrogen & Energy, CH-8600 Dübendorf

Phone: (+41) 58765 4160
e-mail: Ulrich.vogt@empa.ch
URL:http://www.empa.ch/h2e

SYNTHESIS OF COMPLEX HYDRIDES

Arndt Remhof

Among the various methods to prepare borohydrides, the direct, mechanically assisted gas-solid reactions offer solvent free routes, circumventing the necessity to remove solvents or unwanted by-products that are unavoidable in metathesis reactions. Combining diffraction, spectroscopy and imaging techniques, the fundamental reaction mechanisms could be unveiled. The formation of the B-H bonds is the crucial step, mainly responsible for the activation energy needed for the direct synthesis from the elements. Lower barriers can be achieved by using additives that destabilize the stable borohydrides and that prevent the formation of B-B bonds during hydrogen desorption. Room temperature synthesis can be achieved starting from diborane, where the B-H bonds are already established.

Tetraborohydrides $M(BH_4)_n$ (n being the valence of the metal) are currently discussed as synthetic energy carriers [1]. Especially the lightweight alkali and alkaline earth metal borohydrides such as $LiBH_4$ which has a high gravimetric (18wt%) and volumetric hydrogen density (122kg/m^3), are promising candidates for mobile applications. They form ionic crystals composed of positively charged metal ions $[M]^{n+}$, and negatively charged borohydride $[BH_4]^-$ ions. To exploit the high hydrogen content, the material ought to have convenient working conditions in terms of desorption temperature, equilibrium pressure and sorption kinetics. Furthermore, it should be easy to regenerate: technical application requires an efficient way to synthesize the borohydrides either on-board or off-board.

The first borohydrides were isolated by Stock et al. in 1935 [2-3] from the reaction of potassium amalgam and sodium amalgam with diborane. The reaction products were mistaken to be "disodium-diborane" $Na_2B_2H_6$ and "dipotassium diborane" $K_2B_2H_6$. In 1949 Kasper et al. identified "disodium-diborane" to be sodium borohydride $NaBH_4$ by its X-ray diffraction pattern [4]. The synthesis of $LiBH_4$ from the reaction of gaseous diborane (B_2H_6) with ethyllithium (C_2H_5Li) was reported by Schlesinger and Brown in 1940 [5]. More conveniently, $LiBH_4$ can be produced either by the reaction of LiH and B_2H_6 (suspended in diethyl ether) or by the metathesis reaction of $NaBH_4$ and LiCl, respectively [6].

To obtain the pure borohydride, by-products of the reaction and the solvent have to be removed. Within the last years several methods for the solvent-free synthesis were applied. These methods comprise (a) the high temperature / high pressure direct synthesis from the elements, (b) high temperature / high pressure reactions involving binary metal hydrides and binary metal borides and finally (c) the reaction of gaseous B_2H_6 with the respective solid metal hydride. All aforementioned routes were followed within the last years at Empa.

The results of our research suggest that the boron supply is crucial for the synthesis. Breaking of the B-B or the B-metal bonds and the formation of B-H seem to be the limiting steps. Consequently, reaction paths involving diborane (B_2H_6), in which the B-H bonds are already established, should further facilitate the formation of $LiBH_4$ at lower temperatures and pressures.

Exposing LiH to a diborane 10 bar at 100°C leads to the formation of $LiBH_4$. The reaction stops after about 50% of LiH is consumed for the formation of $LiBH_4$. The reaction proceeds in one step, no intermediate products are visible [7]. A core-shell structure of lithium hydride surrounded by lithium borohydride is observed, as shown in figure 1 [8].

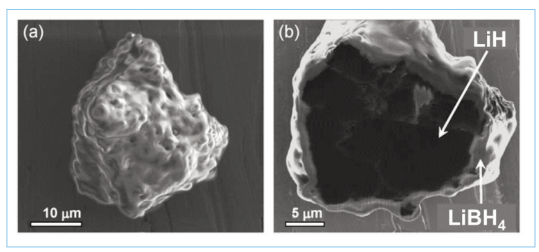


Fig. 1: Secondary electron images (induced by 30 keV ion beam) of LiH after reaction with diborane showing a grain (a) with its corresponding cross sectional view (b) of a core shell structure. The chemical composition of the inner part of the grain and the outer layer were determined by electron loss spectroscopy [9].

The reaction stops due to kinetic constrains originating from the increased diffusion path of either B–H species into the grain or Li towards the exterior. The results are in agreement with the passivation layer proposed by Schlesinger et al., who synthesized different borohydrides in solvents in order to prevent the formation of the passivation layer [6].

Upon reactive ball milling the passivation layer is constantly broken and $LiBH_4$ forms already even at room temperature [9]. As long as sufficient gas is supplied, no influence on the pressure was detected. As long as fresh surface is provided, the reaction proceeds. Details of the reaction mechanism were studied by Gremaud et al. [12]. They found evidence for the heterolytic splitting of diborane on the alkali hydrides. The resulting $[BH_4]^-$ anion is subsequently exchanged with a [H]- ion of the underlying hydride. The alkali hydride surface is ionic and polarizes the B_2H_6 prior splitting, assisting the necessary charge transfer for binding of the negatively charged $[BH_4]^-$.

The synthesis of a borohydride by reactive ball milling is not limited to $LiBH_4$. The direct, solvent free method of synthesizing borohydrides from the respective binary hydride has been successfully applied to $Ca(BH_4)_2$, $Mg(BH_4)_2$ [10] and $Y(BH_4)_3$. Figure 2 shows the resulting XRD pattern of $LiBH_4$, $Ca(BH_4)_2$, $Mg(BH_4)_2$ and $Y(BH_4)_3$ (from top to bottom).

[6] Schlesinger H I, Brown H C, Abraham B, et al., 1953 J. Am. Chem. Soc. 75 186; Schlesinger H I, Brown H C, and Hyde E K 1953 J. Am. Chem. Soc. 75 20
[7] Friedrichs O, Borgschulte A, Kato S, et al., 2009 Chemistry Eur. J. 15 5531
[8] Friedrichs O, Kim J W,, Remhof A, et al., 2010 Phys. Chem. Chem. Phys., 12, 4600.
[9] Friedrichs O, Remhof A, Borgschulte A, et al., A 2010 Phys. Chem. Chem. Phys.12 10919
[10] Gremaud R, Borgschulte A, Friedrichs O,and Züttel A 2011 J. Phys. Chem. C 115 2489

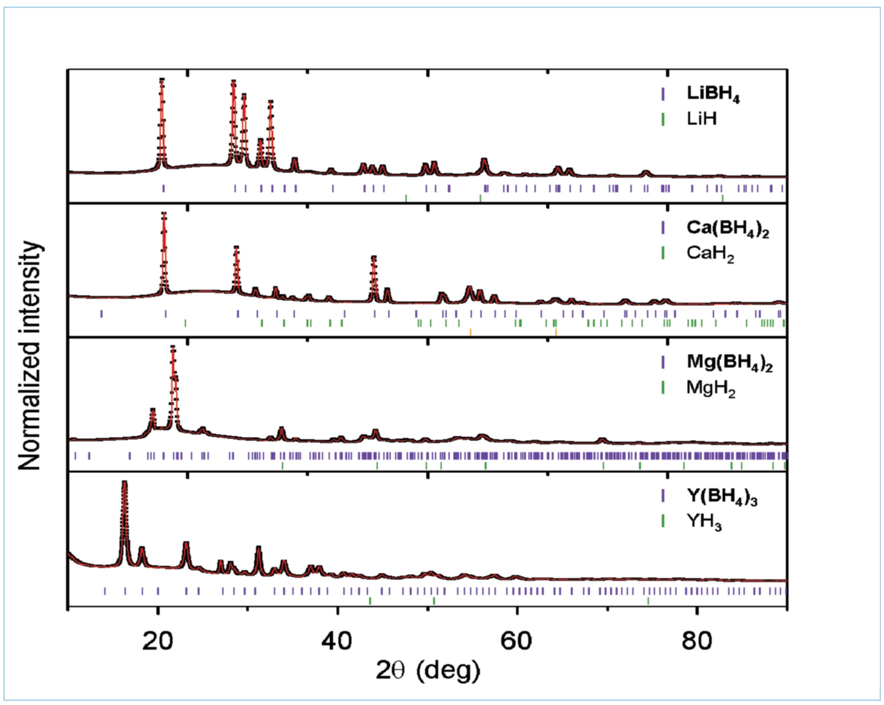


Fig. 2: X-ray diffraction pattern of the products achieved by reactive ball milling of LiH, CaH_2, MgH_2 and YH_3 (from top to bottom) in a mixed B_2H_6/H_2 atmosphere. The main product is the respective borohydride, the educt is the only detectable solid contaminant.

References:

[1] Züttel A, Borgschulte A and Orimo S I 2007 Scr. Mater. 56 823.
[2] Stock A, Sütterlin W and Kurzen F 1935 Z. Anorg. Allg. Chem. 225 225
[3] Stock A and Laudenklos H 1936 Z. Anorg. Allg. Chem. 228 178
[4] Kasper J S, McCarty L V and Newkirk A E 1949 J. Am. Chem. Soc. 71 2583
[5] Schlesinger H I and Brown H C 1940 J. Am. Chem. Soc. 75 3429

Contact:

Dr. Arndt Remhof
Empa
Hydrogen and Energy
Überlandstrasse 129
CH-8600 Dübendorf

Phone: +41 58 765 4369
Fax +41 58 765 4022
e-mail: Arndt.remhof@empa.ch
URL: www.empa.ch/h2e

HYDROGEN FOR NAVIGATION

Jean-François Affolter

Since 1997, the Institute of energy and electrical systems (IESE) of the University of Applied Sciences of Western Switzerland (HES-SO/HEIG-VD) has developed various FC boats. These were developed to test this technology, to enrich its courses with new technics, as well as to create practical applications for the students. Studies and tests are showing that fresh water FC applications are nice and practicable solutions for navigation. The main advantages are the protection of our drinkable water resources, the noiselessness and respect of wildlife.

Legislations on pollution are becoming more restrictive for lakes and fresh water. FC technology is a solution to replace "thermal" motors, often using gasoline for the small units. With a better efficiency, zero emission and almost zero noise, FC boats are a good way to protect efficiently the drinkable fresh water resources and to get a maximum of pleasure on motorized navigation. After early developments of a few small "funny-boats", IESE developed and has been operating for 10 years its third generation boat, the "Hydroxy3000" (fig.1), prefiguring the motorized boat of the future for family leisure on lakes and channels. This boat, intended for 7 passengers, sails at a speed of 13 km/h and is used as floating laboratory.

This vessel is equipped with industrial pre-serial FCs and allows tests and results under real constraint conditions. The boat is equipped with solar panels and battery buffers, allowing different tests settings, included hybrid solar-hydrogen configuration. The "Hydroxy" experience shows that gasoline engines, frequently used on lakes, may be replaced without major problems by low temperature FCs. Such systems have proven good behaviours on boats. The limitation may be the use of compressed hydrogen, what is, so far, the most common solution for storage. The pressure, the size and the number of bottles that may take place on the boat limit its autonomy. Utilisation is limited by the access of Hydrogen in the ports. The project "H_2Ports" sized the needed infrastructure for the harbors, regarding the penetration of FCs in the field of navigation. This solution would need, as well as for cars, to develop feeding infrastructures in the ports. However, ports would have the advantage of needing only two dozen stations for Switzerland, compared to approximately 4'000 road stations for cars.
Another field of exploration is the FC as APU or/and range extender for boats. A world first Atlantic crossing of a sailboat with a 300 W PEMFC as APU was realized in 2002 during the "course du Rhum". Then a 300 W FC was developed as a "range extender" for small fishing boats (Fig.2).

Fig.1: Hydroxy3000; floating laboratory for FC testing

Fig. 2: FC APU used as "range extender" for small fishermen's boats

This improved the range of use from 2 to 6 hours of sailing, with only 200 grams of hydrogen.
An ongoing project is testing a solution to feed a 2 kW PEMFC system with formic acid on the Hy-Boat "Explorer" (Fig.3).
A liter of this liquid contains 53 grams of H_2, which presents a real interest in terms of making storage and manipulation easier. A reactor, based on an adapted catalyst developed by prof. G. Laurenczy at the EPFL, releases continuously the amount of H_2 needed for the stack. This solution overcomes the H_2 gaseous limitations, gives a safer and more convenient image to the user and could be a very promising solution. The "Hy-Boat" project is a collaboration between the EPFL, the company GRANIT and the HEIG-VD. The project, as well as some of the others mentioned, is done with the support of the Federal Office of Energy.

Fig. 3: Hy-Boat; FC system provided with formic acid

Contact:

Prof. Jean-François Affolter
HES-SO / HEIG-VD
Dept. TIN
Route de Cheseaux 1
CH-1401 Yverdon, Switzerland

Phone: (+41) (24) 55 76 306
e-mail: jean-francois.affolter@heig-vd.ch
URL: http://iese.heig-vd.ch/hydroxy

FITUP – FUEL CELL SYSTEMS FOR BACKUP POWER APPLICATIONS

Ulrike Trachte

In a 3-year European demonstration project a total number of 19 market-ready fuel cell systems for uninterruptible power supply are tested in laboratory and field trials across the EU. The units should demonstrate a level of technical performance that meets customer requirements and qualifies them for market entry. 8 of these systems are installed at selected end user sites in Switzerland for telecommunications and the security network Polycom.

Lucerne University of Applied Sciences and Arts is one of 10 European partners who are engaged in the project FITUP that covers Fuel cell field test demonstration of economic and environmental viability for portable generators, backup and UPS power system applications. In the project a number of 13 FC-systems of two different suppliers are tested in the field. 8 of these systems are installed in Switzerland, among them two outdoor systems and one system in the mountains at an altitude over 2200 m. The variety of sites ensures experiences under various surrounding conditions.

Fig. 1: End user site in Grisons

The power range of the systems is between 1 and 6 kW. Hydrogen is supplied by 50 l pressure cylinders with 200 bar which are placed in outdoor cabinets. The hydrogen storages provide an autonomy time of 10 to 18 hours for telecommunications and up to 72 hours for the security network installations.
The department Lucerne School of Engineering and Architecture is assigned with the testing activities in Switzerland. A testing concept was developed within the consortium and the performance of the tests follow common testing protocols. All tests are done remotely every month. The test data are analysed continuously in terms of start-up behaviour, operational stability and reliability.

The project is funded more than 50% by the FCH-JU (Fuel cell and Hydrogen Joint Undertaking) and continues until end of 2013.

Fig. 2: Hydrogen cabinet with antenna

Projektpartner:

BZ-USV-Hersteller: Electro Power Systems, Italien; FutureE, Deutschland
BZ-USV-Anwender: Swisscom AG, Schweiz; Kantonalpolizei Nidwalden, Schweiz; WIND, Italien
Forschungsinstitute: Hochschule Luzern - Technik & Architektur, Schweiz; Environment Park, Italien; ICHET (International Centre for Hydrogen Energy Technologies), Türkei; JRC - Joint Research Centre, Niederlande
Prüfstelle: TÜV SÜD, Deutschland

Contact:

Dipl.- Ing. Ulrike Trachte
Hochschule Luzern – Technik & Architektur
CC Thermische Energiesysteme & Verfahrenstechnik TEVT
Technikumstrasse 21
CH-6048 Horw

Phone: +41 41 3493 249, Fax +41 41 3493 960
e-mail: ulrike.trachte@hslu.ch
URL: www.hslu.ch/technik-architektur

Gianmario Picciotti

Since 2002 to nowdays the core competence of the R&D Fuel Cells department of MES SA is the development, production and commercialization of PEM Fuel Cell Systems from low up to medium nominal power output (0.1 - 3 kW) suitable for portable, light mobile and UPS applications.

To cover both the power range and the relevant application needs MES realized two different kind of PEMFC Systems: one based on a 63 cm^2 cell active area (500 W, 1 kW and 1.5 kW FC stacks), the second based on 32 cm^2 cell active area (100 W and 250 W FC stacks).
The main advantages of both systems is their simplicity, which means:

- no humidification of the reactant gases (no complex humidifiers)
- close to ambient pressure in the cathode (no heavy air compressor)
- forced air cooling (no pumps and heat exchanger)
- a modular layout (wide power range with the same cell design)
- possibility to replace the single damaged cell

and their light weight due to:

- graphite based cell component
- simplified stack design
- reduced balance of plant

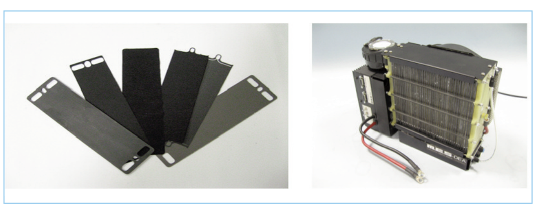
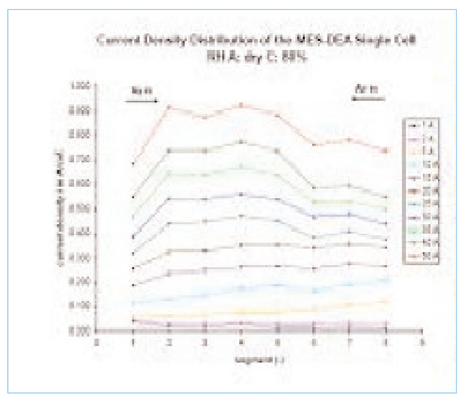


Fig. 1: Single cell components and 1 kW FC System

By means of all these features MES has reached a high net efficiency (up to 50% respect to the hydrogen LHV), stack specific power and power density (up to 480W/kg, 340 W/lt).
All Fuel Cell Systems are designed by MES as a complete solution with the devoted microprocessor that controls and manages all the auxiliaries (mainly blowers, valves and a small pump) and a powerful PC interface that can be used for monitoring, management and diagnostic purposes.
MES R&D Fuel Cell department is involved in different national scientific projects collaborating with Swiss important research institutes for the development of its own technology and for application validations.

One of the projects started in collaboration with Paul Scherrer Institute in the framework of the PEF-CH network and it was supported by the BFE. The objective of this project is to investigate MEA ageing and degradation phenomena due to transient conditions. The study was carried out by means of the most innovative diagnostic techniques as:

- segmented microstructured flow field approach for submillimeter resolved local current measurements in channel and land areas
- transient investigations in along the channel segmented cells
- neutron radiography combined with electrochemical transient techniques



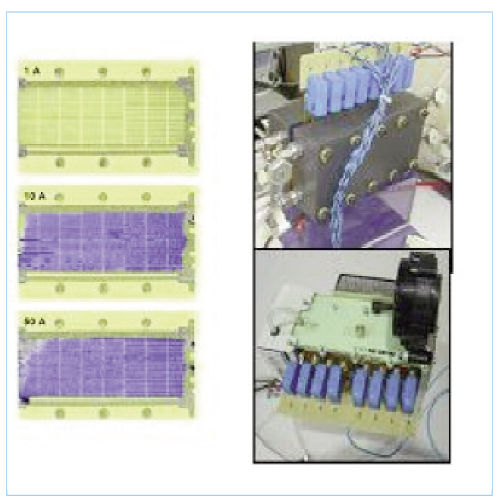


Fig. 2, 3: Single cell neutron radiography and current density distribution measurement

The project ended in December 2011 and its extent is still under discussion.

The other important national project is a KTI project named BiPCaNP in collaboration with the department ICIMSI (SUPSI) and TIMCAL. The main project goal is to develop both a further optimized material and an original process for an easier, safer and cost effective manufacturing of a new graphite/polymer composite BPP for PEM-FC. Thanks to this study many improvements has been reached as:

- development of a reliable Molecular Dynamics procedure for the investigation of material components interactions
- a lower through plane electrical resistivity and higher thermal conductivity BPP at the same mechanical resistance
- the development of a new safer and simple production process
- the development of a construction technique which allows to further increase the BPP performance

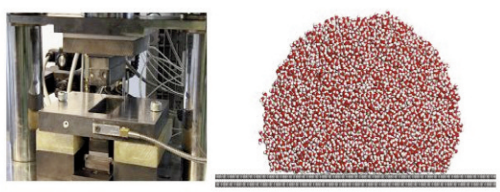


Fig. 3: All atoms (AA) MD simulations of water droplets on a graphite surface

Since 2011 MES is a member of the JTI NEW IndustrialGroup and it is currently involved as partner in two important European demonstration projects inside the Seventh framework programme (JTI-FCH):

The first one is named MobyPost (Mobility with Hydrogen for Postal Delivery http://mobypost-project.eu/).
It was finally approved in February 2011.
Main Partner : La Poste

MobyPost is a European project aimed at developing a sustainable mobility concept by delivering a solar-to-wheel solution.The first core element of this environmentally friendly and novel project is the development of ten electric vehicles which will be powered by hydrogen fuel cells, conceived and designed for post delivery use.
Besides, the development of two hydrogen production and refuelling stations is a second core component of MobyPost. These will be built in the French region Franche-Comté, where photovoltaic (PV) generators will be installed on the roofs of two buildings owned by project partner La Poste and dedicated to postal services. The PV generators allow for the production of hydrogen through electrolysis.
Hydrogen is stored on site in low pressure tanks where it is available for refuelling the canysters of the electric vehicles, the latter being powered by an embedded fuel cell producing electricity that directly feeds the electric motors.
The project develops and tests under real conditions two fleets of five vehicles for postal mail delivery. Consortium partner La Poste will run the field tests in close coordination with the other project partners involved.

The second one is named FCpoweredRBS (Demonstration project for Power Supply in Telecom Stations through FC and H2 technology, http://fcpoweredrbs.eu/).
It was finally approved in January 2012. Main Partner: ERICSSON

The project target is the demonstration of Fuel Cell and Hydrogen market readiness by testing on-field a significant number of powered Radio Base Stations. While Telecom application are widely seen as an early market for FC a wide demonstration of their performances under real operating conditions is fundamental to assess their potential as well as to determine their real strength.
The project creates an integrated approach to the design of high energy efficient Radio Base Stations and will test different FC solutions by European and World Manufacturers. Alternative fuelling solutions as hydrogen, methanol or natural gas will also be tested aiming to address the different range of application of each solution.
While the FCpoweredRBS solution could already improves the energy performance of RBS and reduces their carbon footprint, the proposed set-up also aims to demonstrate a significant advantage in terms of Total Cost of Ownership (TCO). Actually, for specific applications the higher efficiency and the integrated use of local renewable energy sources should also lead to cost savings which could make this application interesting right now.
MES R&D FC department is also focused on various application fields and relative early market in collaboration with industries and research centers. The main are: power supply for remote houses, UPS for telecom,

portable generator, battery charger, APU for bus and UAV.

The closest to the market and to a possible real industrialization is surely the portable and battery charger application, but the most peculiar and strategical one is the UAV (Unmanned Aerial Vehicle) application.
A very close collaboration with Aerospace Department of Politecnico of Turin has been carried out for about two years, and it's still running, for the realization of a Multi-source UAV system platform based on high efficiency power management and MES FC Technology.

The design targets for this special aircraft are:

- long endurance platform (more than 2 hours in operative conditions)
- high payload for on board hardware instrumentations
- UAV or video-control ready
- Multi-source on board power generator (fuel cell, battery, wing photovoltaic liner in the future)
- real time data transmission for telemetry and on board system control

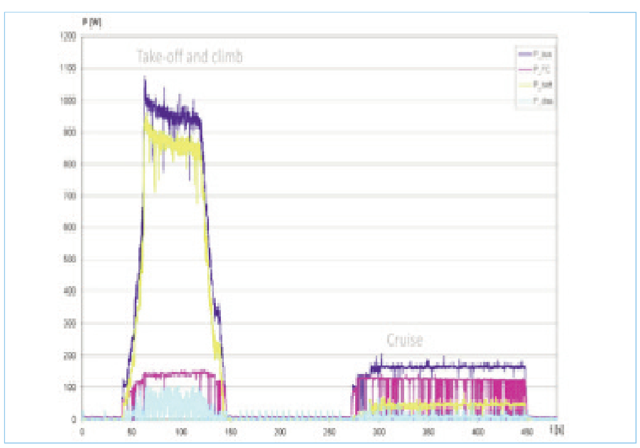


Fig. 4, 5: Multi-source UAV developed by Politecnico of Turin powered by MES 250 W FC system

Contact:

Gianmario Picciotti and Roberto Bianchi
MES R&D Fuel Cells
Via Cantonale, 5
6855 Stabio

Phone: +41 91 641 51 11
Fax: +41 91 641 51 40
e-mail: g.picciotti@mes.ch
e-mail: r.bianchi@mes.ch

PUBLIC TRANSPORT WITH FUEL CELL DRIVE

Nikoletta Seraidou

PostBus is the first company in Switzerland to use fuel cell technology in public transport. Since the end of 2011 five fuel cell buses 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. The ejected emission consists solely of water vapour. PostBus expects to save at least 2,000 tons of CO_2 during the five year trial phase.

PostBus operates a fleet of over 2,100 vehicles with different categories of buses. 39 million litres of diesel are needed to transport over 121 million passengers each year.
Since December 2011 five fuel cell postbuses are operating in the greater Burgg area. It is a ideal testing ground in terms of topography and routes. The aim is to show independence from fossil fuels and the use of fuel cell buses in public transport.

The fuel cell hybrid bus has most of the technology on the roof. The tanks have a 35kg hydrogen capacity providing a 400km range. The lithium ion battery is used as a buffer for the electricity from the fuel cells and the electricity made by recuperation. The two wheel hub motors allow a very quiet and efficient performance.

The fuelling station produces hydrogen from water. The electrolyser (60nm^3/h) splits water into hydrogen and oxygen using certified green energy. The hydrogen is stored in high-pressure tanks. Additionally hydrogen is available in trailers to secure a study supply. This hydrogen is a by-product from the chemical industry.

Fig. 2: Fueling the Postauto with hydrogen

Fig. 1: Project partners in front of the Post-auto in Brugg (AG)

The garage was converted to the hydrogen guidelines. The roof is open and provided with a rain cover. Holes in the gates support the natural ventilation. A hydrogen sensor is installed above each parking spot.
The project is only possible as a result of financial support from public institutions and in cooperation with important partners from industry and research. Contributors to the project include:

Fig. 3: Hydrogen Filling Station

- PostBus Switzerland Ltd
- Swiss Post
- The European Union: Clean Hydrogen In European Cities - Project
- Swisslos Fund of the Canton Aargau
- Swiss Federal Office of Energy
- Empa
- Daimler Buses: EvoBus GmbH Mannheim and EvoBus (Switzerland) Ltd
- Paul Scherrer Institute, Villigen
- IBB Holding Ltd, Brugg
- Carbagas Ltd, Gümligen

Fig. 4: Stefan Oberholzer in front of hydrogen Postauto

Contact:

Nikoletta Seraidou PA-L
PostAuto Schweiz AG
Belpstrasse 37
CH-3030 Bern

Phone: +41 58 338 03 06
e-mail: nikoletta.seraidou@postauto.ch
URL: www.postauto.ch

HYTECH-PECHOUSE2 PROJECT

Paul Dyson

The worldwide growing demand for energy may be satisfied by the utilization of renewable energy sources such as solar and wind energy. A particular challenge associated with renewable energies concerns their storage. This problem is particularly challenging when aiming at replacing fossil fuels used in automotive vehicles. Hydrogen could be the ideal chemical energy storage molecule, if stored at high gravimetric and volumetric densities. Solid-state hydrogen storage has been extensively investigated - but the ultimate solution still awaits discovery.

Abundant renewable hydrogen will also facilitate other aspects of renewable energy, e.g. facilitating CO_2 and biomass transformations. Thus, any realistic and practical solution to develop a sustainable energy economy must be diverse—managing energy conversion, storage and transport at all scales.

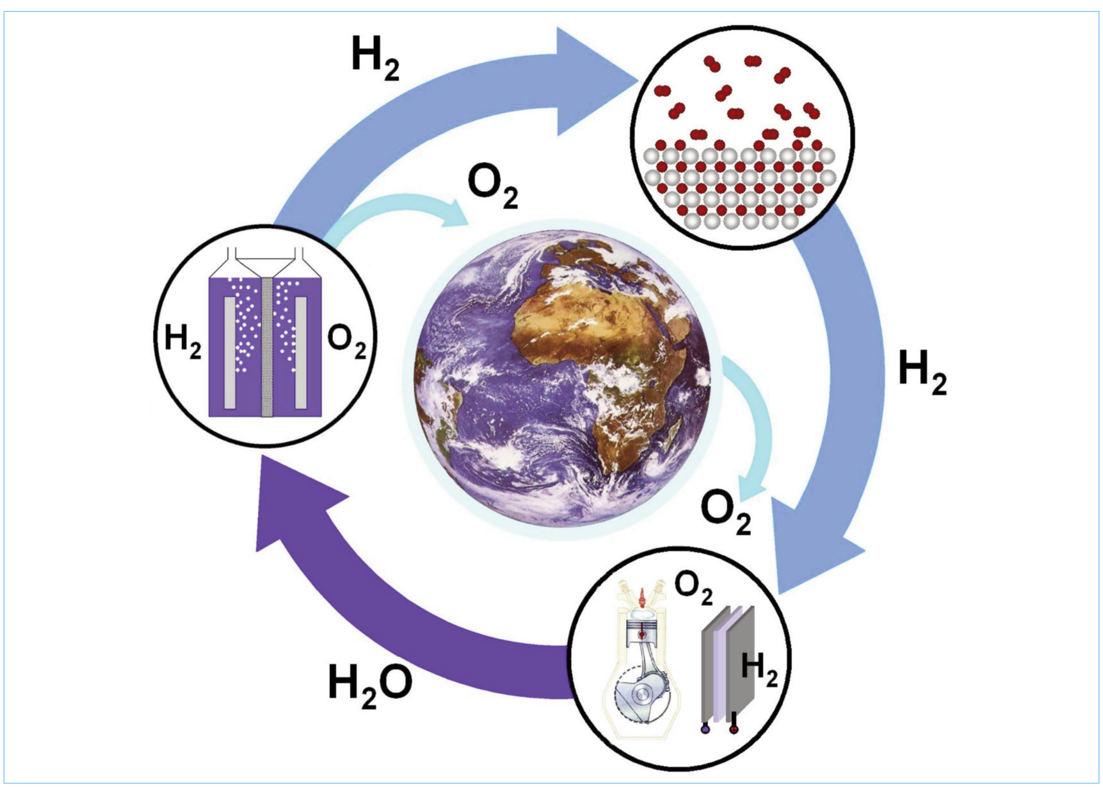
The HyTech-PECHouse2 project is focused on the realization of breakthroughs and advancing innovative technologies in the field of sustainable H_2 utilization. These developments will have a large impact on future H_2 energy systems. To maximize the efficacy of the efforts involved, both the disciplines of solar H_2 production and H_2 storage are engaged and pursued thanks to pioneering approaches.

The safe, energy efficient and high density storage of H_2 will be advanced: encouraging complex metal hydride storage materials are currently investigated both by understanding the thermodynamics of these materials and seeking for formulations liquid at room temperature.

The increase in H_2 production knowledge is also of paramount importance. The goal of investigating the most promising technologies leads to the focus on two complementary routes: photoelectrochemical (PEC) and thermochemical (TC) water splitting. Given the strong connection between H_2 production and storage, a strong Swiss hydrogen consortium should arise from the synergistic alliances between the partners, thus providing the maximum chance for success in convincingly advancing towards a sustainable hydrogen economy.

In addition to advancing on the scientific front, the technologies used in the project will be compared to other possible routes for the production and storage of H_2 at different scales, in order to define the future targets of funding agencies and, more importantly, direct the industrial development of sustainable H_2 technologies.

Fig. 1:
Hydrogen Cycle



The laboratories involved in the project are:

Partner (alphabetical order)	**Partner** (alphabetical order)
EMPA-H_2E Section of Hydrogen and Energy (Prof. Andreas Züttel)	H_2E has a technological expertise ranging from hydrogen sorption in metals, hydrogen in metallic nanoclusters, hydrogen adsorption on carbonous nanostructures, and electro-chemical hydrogen sorption in intermetallic compounds to p-element complex hydrides. H_2E has notably developed instruments for the specific investigation of hydrides and has demonstrated the viability of several solid hydrogen storage systems
EPFL-CEN Energy Center (Prof. Hans Björn Püttgen)	The Energy Center aims at coordinating and promoting state-of-the-art research activities related to energy and mobility at EPFL laboratories, many of which are renowned world-wide both for evolutionary as well as for disruptive R&D.
EPFL-LCOM Laboratory of Organometallic and Medicinal Chemistry (Prof. Paul Dyson, Prof. Gabor Laurenczy)	LCOM has various activities including the design and development of new catalysis and ionic liquids with applications in energy-related research.
EPFL-LPI Laboratory for Photonics and Interfaces (Prof. Michael Grätzel)	LPI pioneered research on energy and electron transfer reactions in mesoscopic materials, as well as on their optoelectronic applications. Prof. Michael Grätzel notably discovered a new type of solar cell based on dye- sensitized mesoscopic oxide particles, pioneered the use of nanomaterials in lithium ion batteries and realized major advances in the use of iron oxide for photoelectrochemical hydrogen production.
EPFL-LSCI Laboratory of Inorganic Synthesis and Catalysis (Prof. Xile Hu)	LSCI develops catalysts made of earth-abundant elements for chemical transformations pertinent to synthesis, energy, and sustainability. Recently LSCI discovers a new class of catalysts for hydrogen production via water reduction.
PSI-LSE Laboratory for Energy and Environment (Prof. Jeroen A. van Bokhoven)	LSE has expertise in synthesis of oxides of controlled size, shape and atom composition as well as in developing characterization methods based on XES and XAS to determine the electronical and geometrical structure of inorganic materials used as heterogeneous catalyst.
PSI-STL Solar Technology Laboratory (Prof. A. Steinfeld, Dr. Anton Meier)	STL develops innovative technology solutions that are required for transforming, at an industrial scale, solar energy into chemical fuels with thermochemical processes. The latter have the potential of achieving higher conversion efficiencies than other solar-to-fuel processes.
ZHAW-ICP Institute of Computational Physics (Dr. Jürgen Schumacher)	ICP develops and applies numerical methods to model the behavior of coupled physical and chemical systems and processes. These simulations have been successfully used in the product development of systems and devices in the fields of sensors and actuators, fuel cells, micro- fluidics, electrochemical and electromagnetic systems, organic electronics and photovoltaics.

Results

The *photoelectrochemical solar hydrogen production & catalysis task* has focused on the development of electrocatalysts for hydrogen production from water.

In addition to the water oxidation catalysts, hydrogen evolution catalysts for PEC water splitting will also be developed. The amorphous molybdenum sulfide (MoS_2) system developed by LSCI will serve as a starting point for further catalyst development. Certain transition metal ions such as Fe(II), Co(II), and Ni(II) were found to promote the catalytic activity of molybdenum sulfide. It was shown that Fe, Co, and Ni ions promote the growth of the MoS_3 films, resulting in a high surface area and a higher catalyst loading.

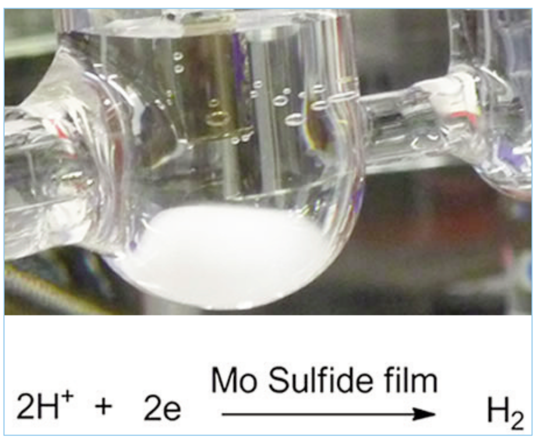


Fig. 2: Mo Sulfide film

The mission of the Solar Technology Laboratory at PSI is to develop the science and technology that is required for transforming, at an industrial scale, solar energy into chemical fuels with a thermochemical process that effects this conversion more competitively than any other solar-to-fuel process. In particular, the thermodynamic fundamentals of energy conversion are applied in the development of novel, efficient and clean technologies for the production of chemical energy carriers (e.g. solar H2, syngas, metals) using concentrated solar power. The first step currently ongoing is the research on heat/mass transfer in porous media. Effective heat/mass transfer properties of complex porous media are needed for engineering design, optimization, and scale-up of thermochemical reactors and processes for solar H_2 production. A PhD thesis is aimed at designing, fabricating, and testing a small-scale solar cavity reactor for effecting the reduction of ZnO under vacuum pressure. A dynamic reactor model shall be formulated based on unsteady mass and energy conservation equations coupled to reaction kinetics. The small-scale solar thermochemical vacuum reactor is currently being fabricated, and will be tested at PSI's High-Flux Solar Simulator.

Concerning the Hydrogen storage technologies (WP2), two promising routes are being researched: the first focuses on liquid complex hydrides (EMPA) while the EPFL-LCOM is working on synthetic fuels.

Liquid hydrides exhibit promising properties required for hydrogen storage, such as high gravimetric density. However, various challenges such as slow kinetics have to be overcome before technical application of complex hydrides. The focus of this project in 2012 was laid on a general study of potential complex hydrides aiming at defining the specific compounds to be further investigated. This includes a review of stability (enthalpy) of formation, melting point and hydrogen content of transition metal alanates and borohydrides, the empirical model describing the hydrogen density, stability, and melting temperature, and the anticipation of promising liquid complex hydrides. An empirical correlation based on vibrational spectroscopy to calculate the stability and melting point of borohydrides was established. In the future, the focus will be translated on the investigation of $Al(BH_4)_3$, $Ti(BH_4)_3$ and $V(BH_4)_3$ as promising liquid borohydrides during the remaining time of the project.

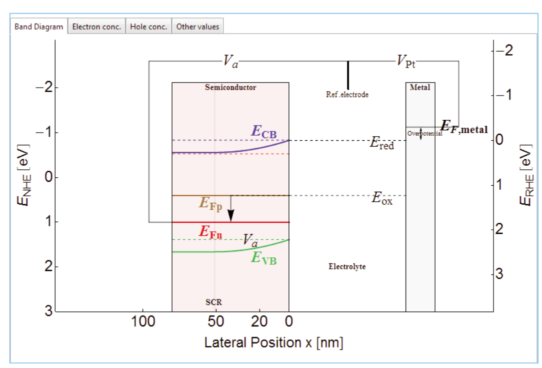


Fig. 3: Energy Band Diagram PEC Watersplittling Demonstration

In response to the needs to develop predictive models of the performance of the materials used in the project and to accurately assess the technological and economic feasibility of the H_2 production and storage systems currently under development, some tasks are dedicated to energy modeling and assessment. Concerning the assessment part, the Energy Center is currently working

on developing methods to evaluate efficiency versus delivery-cost ratio, in order to establish this relation at different production scales and therefore help find the optimum technology for each application.
Additionally, much progress has been made in the energy modeling tasks. This program is dedicated to the fundamental modeling of systems for solar hydrogen production combining both numerical and experimental approaches. The ZHAW-ICP is currently developing a prototype simulator for water splitting PEC cells in collaboration with EPFL-LPI. The mathematical model will combine an analysis of the optics in the cell with a model for the transport of electrons in the mesoporous films and ions in the electrolyte and their recombination.

Main achievements
Some publications have been already been published in leading international journals from the various laboratories involved, and the results obtained during the first part of this project will soon be disseminated in conferences and proceedings. At least one patent is in preparation (details will be disclosed in the next report).

References:

A. Borgschulte, R. Gremaud, O. Friedrichs, A. Remhof, A. Züttel: ***Complex Hydrides*** *in „Hydrogen Energy“ edited by Detlef Stolten, Wiley-VCH, Heidelberg (2010)*

S. Haussener, P. Coray, W. Lipinski, P. Wyss, A. Steinfeld: ***Tomography-based heat and mass transfer characterization of reticulate porous ceramics for high-temperature processing****, ASME J. Heat Transfer* ***132****, 023305-1-9, (2010).*

S. Haussener, W. Lipinski, P. Wyss, A. Steinfeld: ***Tomography-based analysis of radiative transfer in reacting packed beds undergoing a solid-gas thermochemical transformation****, ASME J. Heat Transfer* ***132****, 061201-1-7, (2010).*

H. Vrubel and X.L. Hu: ***Molybdenum boride and carbide catalyze hydrogen evolution in both acidic and basic solutions****. Angewandte Chemie, International Edition, 51, 12703-12706 (2012)*

S. Haussener, A. Steinfeld: ***Effective heat and mass transport properties of anisotropic porous ceria for solar thermochemical fuel generation****, Materials* ***5****, 192-209, (2012).*

S. Haussener, I. Jerjen, P. Wyss, A. Steinfeld: ***Tomography-based determination of effective transport properties for reacting porous media****, J. Solar Energy Eng.* ***134****, 012601-1/, (2012).*

A. Paracchino, N. Mathews, T. Hisatomi, M. Stefik, S. D. Tilley, M. Grätzel, ***Ultrathin Films on Copper(I) Oxide Water Splitting Photocathodes: a Study on Performance and Stability****. Energy & Environmental Science. DOI: 10.1039/C2EE22063F (2012)*

Contact:

Prof. Paul J. DYSON
Ecole polytechnique fédérale de Lausanne
Institut des sciences et ingénierie chimiques
1015 Lausanne

Phone: +41 (0)21 693 98 54
Fax: +41 (0)21 693 97 80
e-mail: paul.dyson@epfl.ch
URL: www.epfl.ch

FUEL CELL RESEARCH AT PSI

Felix N. Büchi

Fuel cell research at PSI, established more than 20 years ago, is based on two pillars. On the one hand fundamentals and materials are investigated and developed, with intense utilization of PSI's large-scale facilities such as the Swiss Light Source (SLS) and the neutron transmission radiography (NEUTRA) station at the at the spallation source SINQ. On the other hand the Electrochemistry Laboratory supports industrial partners in their development of new technologies, e.g., fuel cell systems for mobile applications.

In the past four years PSI and Belenos Clean Power Ltd have collaborated in the development of hydrogen/oxygen fuel cell systems for sustainable mobility. In 2011 an important milestone was reached with the development of the first generation of systems for a vehicle (see Figure 1).

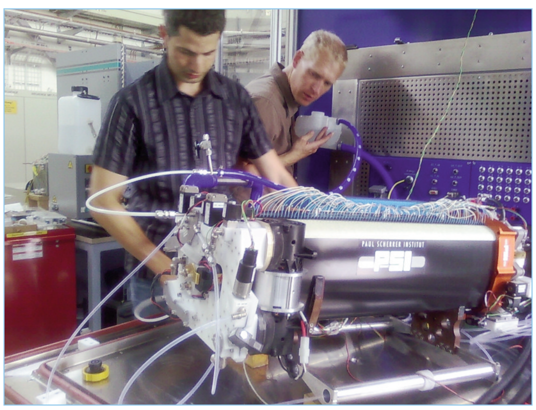


Fig. 1: 25 kW hydrogen/oxygen fuel cell system jointly developed by PSI and BCP

In January 2011 this joint development of BCP and PSI was awarded the "Watt d'Or" award of the Swiss Federal Office of Energy. The 25 kW fuel cell system allows for impressive efficiencies for the conversion of hydrogen to DC power of up to almost 70%. The efficiency (LHV) versus power characteristics of the system are shown for stack and system in Figure 2.

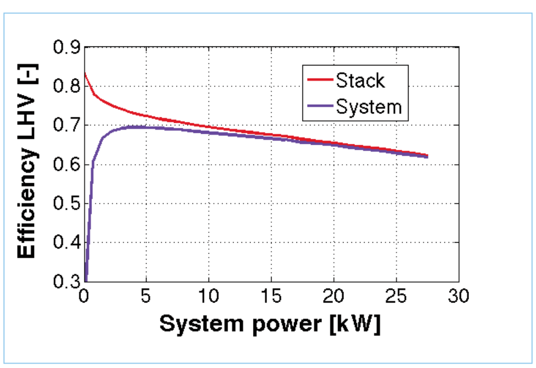


Fig. 2: Stack and System efficiency (LHV) of PSI/Belenos 25 kW system

The reaction product of fuel cells fueled with hydrogen is pure water. At the operating temperatures below 100 °C, this product water is partly liquid and can therefore interfere with the gas transport in the channels and the micro-porous structures of the cell, limiting the performance, in particular at high power densities. Detailed knowledge on the formation and transport of the liquid water is therefore required to optimize the structures and operating conditions for maximum current density and efficiency.

The questions of the interaction of the liquid water in the structures of the cell are therefore also investigated using the imaging techniques available at SLS and NEUTRA. Neutron radiography is a well suited method for imaging water because thermal neutrons are strongly scattered by the hydrogen atoms in water, but are only weakly absorbed or scattered by the structural materials generally used in fuel cells such as metals or carbon. The liquid water in an operating cell can thus be imaged in-situ [1]. Figure 3 shows a neutron radiogram of an operating cell. Liquid water can clearly be seen in the porous structures and the gas channels, impeding the transport of the reactants to the catalyst near the membrane, thus reducing performance and efficiency. Today neutron radiography can image structures with a minimum size of about 15 μm at exposure times of about 10 s.

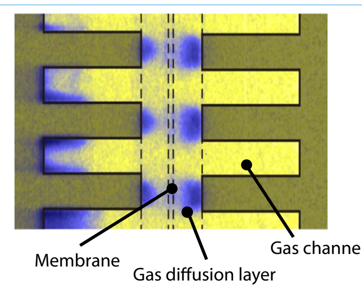


Fig. 3: Visualization of water (blue) in the gas diffusion layer and gas channels of an operating fuel cell using neutron radiography

In order to even better understand the interaction of the water in the porous structures, a technique with higher resolution is required. X-ray tomography at the SLS offers a resolution of about 1 μm with exposure times on the order of milliseconds. X-rays are similarly absorbed by water and carbon. Therefore this technique allows for simultaneous imaging of water and the carbonaceous porous materials.

In addition to taking radiographic pictures (2D images), the short exposure times also allow tomographic imaging (3D images), which requires the acquisition of a series of 1000 to 2000 radiograms, which are then processed by the tomographic algorithm to reconstruct the 3D-stucture. Such an in-situ X-ray tomogram of a fuel cell can be obtained in 10 to 20 s.

However, the high resolution of this technology also imposes severe experimental constraints. The active area of the imaged cell needs to be as small as few tens of square millimeters, therefore special cell developments are necessary [2]. Furthermore, the interaction of the X-rays with the polymeric components of the cell call for careful consideration of the radiation damage induced by the exposure to the high intensity X-ray beam.

Figure 4 shows the tomographic image of the cathode channel of a small cell during operation. The different phases are clearly visible, including the liquid water in the channel and in the porous gas diffusion layer (GDL). Phase segmentation allows for virtual disassembly. After removing the channel and the GDL, the path of the water feeding the droplet can be identified.

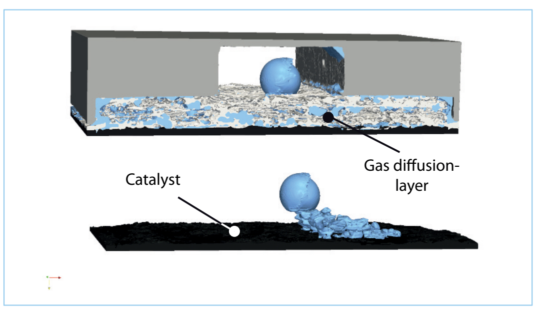


Fig. 4: Visualization of water (blue) in the and gas diffusion layer and gas channels of an operating fuel cell using X-ray tomography

Together with materials research in the area of membranes and catalysts over the past 20 years, fuel cell research at PSI has acquired the competence to successfully perform projects such as the awarded collaboration with Belenos.

References:

*[1] P. Boillat, G. Frei, E. H. Lehmann, G. G. Scherer, and A. Wokaun, Electrochemical and Solid-State Letters, **13,** B25-B27 (2010)*

*[2] J. Eller, T. Rosen, F. Marone, M. Stampanoni, A. Wokaun and F. N. Büchi, J. Electrochem. Soc., **158**, B963 (2011).*

Contact:

Dr. Felix N. Büchi
Electrochemistry Laboratory
Paul Scherrer Institut
CH-5232 Villigen PSI

Phone: +41 56 310 24 11 .
Fax: +41 56 310 44 15
e-mail: felix.buechi@psi.ch
URL:http://ecl.web.psi.ch/index.html

AGENCY FOR PIONEER AND TROOP EQUIPMENT (WTD 51)

Thorsten Reker

Hanjörg Vock

The military engineering agency for pioneer and troop equipment (WTD 51) is part of the division of the federal office for military technology and procurement. It is located in Koblenz and was established in 1958. The WTD 51 is the technology center serving the pioneer and the troop equipment of the German Federal Armed Forces. The center covers technical tasks in the areas of hydraulics, mobile electrical power supply, compressed gases and air condition technology and in particular tests of crossing equipment. Since 2007 the task spectrum of the WTD 51 covers also the energy supply of a field camp powered by alternative energies.

WTD 51 developed an "Energy Camp" within scarcely five years. This camp demonstrates the self-sufficient power supply of a military field camp. The motivation for this energy camp is the large power requirement of the field camps in Afghanistan, in the context of the NATO deployment ISAF. Today's energy supply for the field camps is based on a single-fuel-concept without combined heat and power concept. In order to secure the power supply for the power generation and heating/cooling purposes, at least one tanker truck with fuel is needed per day. This represents a high logistic expenditure and a substantial risk for the truck drivers.

In order to increase the energy efficiency, in 2007 engineers of WTD 51 were given the task to develop an energy-self-sufficient concept, which gets along without fossil fuels. Already in 2010, in a study accomplished for the WTD, the Fraunhofer Society determined together with several institutes 51: „Renewable energies can make a partially significant contribution for the supply of field camps and help thus to lower the operation costs of the camp. […]"

Fig. 1: 10'-Hydrogen storage system

In the meantime, the Energy Camp covers different demonstration type photovoltaic, wind force as well as solar thermal energy plants. All plants are laid out to fit into compact 20' ISO containers, which can be quickly set up at the place of use.

For the storage of the renewably produced energy the hydrogen technology is applied among other solutions. A PEM type "Hogen" electrolyzer as well as different storage systems with storage pressure up to 450 bar have been installed. The re-electrification is based on a PEM fuel cell. An integration project to fit an FC-system including all supply and safety devices into a 20-foot container is ongoing.

In co-operation with different research institutes and supporting companies, numerous system components could already be procured and tested extensively. In addition, safety-relevant investigations have been accomplished, in particular bombardment and fire exposure to tank systems, which go far beyond civilian requirements.

As a practical result of the last years, a 10-foot container was developed, which contained a total of 30 hydrogen containers of the type III, each with a capacity of 260 liters and a pressure of 450 bar. The tank system should be certified soon, which would facilitate shipping of large hydrogen quantities on road and rail. Approval for the air transport is planned also.

Fig. 2: Mustang

Apart from the supply of field camps in Koblenz, other possible operational areas of the hydrogen technology are investigated. An example is the autonomous robotic vehicle "Mustang". In close co-operation with the university Koblenz is was equipped with thermal image camera, laser scanner and ultrasonic sensors. The Mustang can therefore be used for autonomous intelligence operations in unknown terrain. A retrofitted PEM fuel cell system serves as range extender, so that the operation duration could be doubled relative to pure battery operation. The vehicle was presented for the first time during eCarTec 2011 in Munich and equipped with the new hydrogen tank system at CeBit 2012.

Fig. 3: Tactical Generator

A further development is a tactical two kilowatts PEM fuel cell generator (essentially corresponding to the Mustang system). The generator has the same interfaces as a conventional diesel set which served as a guideline. The fuel cell system with a mass < 45 kg can be carried problem-free by two persons. Compared with a diesel generator, the system exhibits additionally substantial advantages regarding noise and thermal radiation – these are two substantial requirements. Investigation of further uses of the hydrogen technology:

Further permissions for the transport of hydrogen reservoirs on road, rail and in air

Standardisation of interfaces, in particular tank connections

Tank systems with higher storage pressure and respective compression stages

Investigation of further uses of the hydrogen technology

„Militarization “of available equipment (e.g. adjustment to extreme climatic conditions, shock loads)

The results of four years basic research by WTD 51 was presented in September 2011 in form of an internal exhibition for German military personnel. Apart from a demonstration of the Energy Camp, the team showed the results of its bombardment tests as well as additional developments in cooperation with a total of 15 partners. Some of the exhibits are the result of the cooperation with civil research institutes.

Fig. 4: Electrolyser Container

References:

Geitmann, Sven:„ Autarkes Energiecamp an der Mosel“, HZwei 04/2012, Oberkrämer, 2012

Contact:

Torsten Reker
Wehrtechnische Dienststelle 51
Universitätsstr. 5
DE-56070 Koblenz
Phone: +49 261 400 1800
Fax: +49 261 400 1745
e-mail: torstenreker@bwb.org

Hans J. Vock
Diamond Lite SA.
Rheineckerstr. 12
CH-9425 Thal
Phone: +41 71 880 0200
Fax: +41 71 880 0201
e-mail: hans.vock@diamondlite.com
URL: www.diamondlite.com

H_2 FUELLING STATION AT THE FRAUNHOFER ISE – RESEARCH PLATFORM AND H_2 INFRASTRUCTURE CORNER STONE

Christopher Vogelstätter

Hansjörg Vock

A hydrogen fuelling station including on-site generation of hydrogen by electrolysis was built by the Fraunhofer Institute for solar energy systems ISE in Freiburg / Breisgau. The filling station features a pem-electrolyser with a net generation of 6 Nm³/h hydrogen, two compressors with gaseous storage at 450 bars and 950 bars as well as fast filling according to SAE J2601 – the standard for filling of hydrogen cars – and was built by Diamond Lite S.A. and sub contactor Air Products. The filling station is used as research platform and as corner stone of the future German H2-infrastructure.

Many experts see a change toward a climate friendly energy supply as central challenge of this generation. Technologies for climate friendly heat and power generation are available on the market and provide an increasing share of the consumed energy. But the mobility sector is still mainly supplied by conventional energy supplies – namely petrol. Battery electric cars for climate friendly mobility are commercially available but suffer from short ranges and long recharge times. Hydrogen powered mobility with hydrogen generated from renewable energies can be a solution, but prior to the roll-out of the cars a fueling infrastructure needs to be provided.

Fig. 1: Hydrogen filling station including a fuel cell electric vehicle

The Fraunhofer Institute for solar energy systems ISE in Freiburg / Breisgau is addressing several technologies concerning regenerative energy production as well as storage and is active in the business segments photovoltaics, energy-efficient building, applied optics and functional surfaces, solar thermal technology, renewable power supply and hydrogen technology (fuel cells, pem-electrolysis, redox flow batteries, reforming, biomass gasification and more).

As part of the business segment hydrogen technology the filling stations was built with partial funding and support by the Ministry for the environment, Climate Protection and the Energy Sector Baden-Württemberg and the national innovation program hydrogen and fuel cell technology. It features a photovoltaic power production, on-site-generation by PEM-electrolysis with a net generation of 6 Nm³/h hydrogen, two compressors with gaseous storage at 450 bars and 950 bars (see fig. 2 for schematic diagram) as well as a fast filling procedure according to SAE J2601 – the standard for filling of hydrogen cars. The filling station was built by Diamond Lite S.A. and sub contactor Air Products. It was opened to the public in March 2012 and has been fuelling since then.

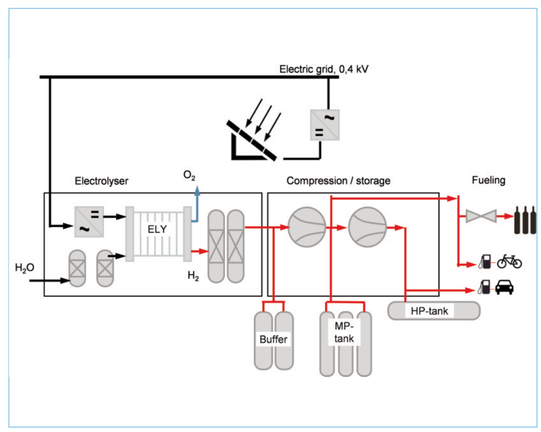


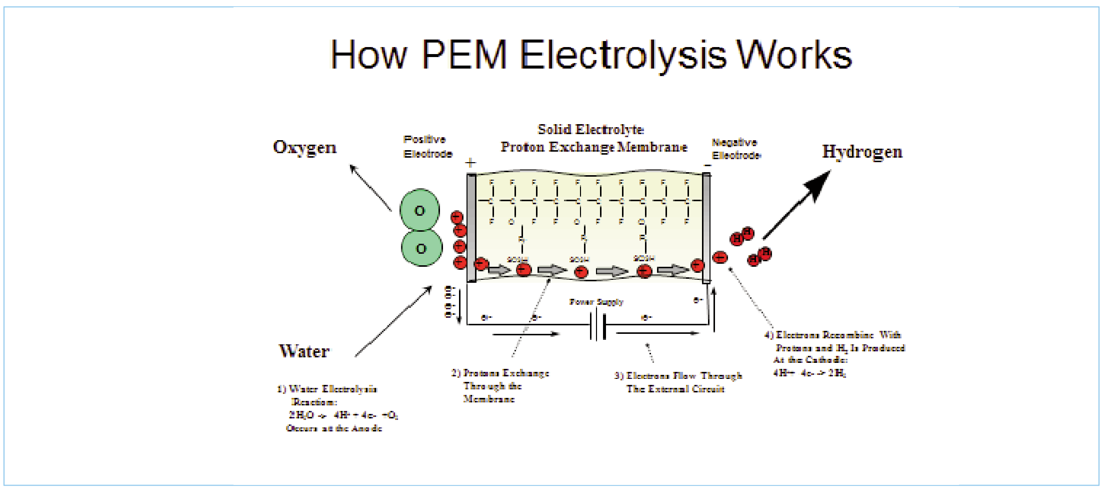
Fig. 2: simplified schematic diagram of the filling station

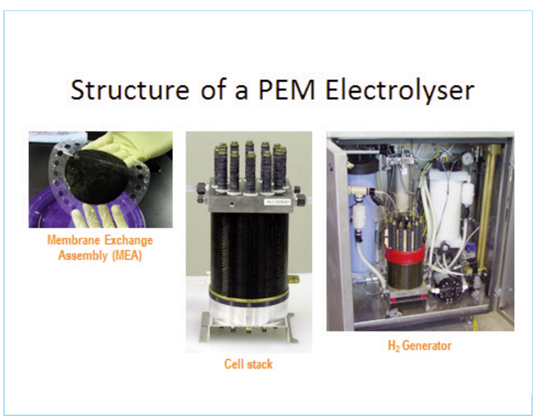
Tried, tested and safe – the technology to generate true green hydrogen in detail

Until now this combination of PEM electrolysis and high-pressure fuelling designed as a public solar driven filling station has not been available in Germany. Both are technologies that are of crucial importance for hydrogen production using renewable energies and everyday practical use. The Hogen® PEM electrolyzer (PEM = Proton Exchange Membrane) used in this station is made by Proton Onsite. Hydrogen is generated using electricity from photovoltaic cells. The Hogen delivers up to 6 cubic meters of high-purity hydrogen per hour. The high purity of the hydrogen of 99.9995% is a crucial prerequisite for its use in automotive fuel cells. Problematic residual components such as CO, sulfur compounds and residual hydrocarbons which are typical in natural gas reformer based hydrogen are not present in electrolysis hydrogen due to the principle of the process.

The PEM process on the other hand does not require elaborate and cost extensive cleanup process steps as needed in alkaline based electrolyzers, where residual oxygen and alkaline has to be removed to reach high purity hydrogen.

Another advantage of PEM technology is the wide load range from 0 to 100%. This allows transforming the very smallest amounts of electricity from the photovoltaic plant into hydrogen. Even with strongly fluctuating renewable power source – for example, during changeable weather – the equipment works extremely effectively and efficiently. The efficiency of the facility is also increased by the fact that a pressure of 30 bar is generated during electrolysis without mechanical compression, which improves the efficiency of the subsequent compression and storage. The Hogen electrolyzer also sets new standards when it comes to safety: The installation works with differential pressure. This means oxygen can never get to the hydrogen side even in the event of electricity loss.





Contact:

Christopher Voglstätter
Division Energy Technology
Fraunhofer-Institut für Solare Energiesysteme ISE
Heidenhofstraße 2, 79110 Freiburg, Germany
Phone: +49 (0) 761/4588-5357
Fax: +49 (0) 761/4588-9357
e-mail: christopher.voglstaetter@ise.fraunhofer.de
URL: www.ise.fraunhofer.de / www.h2move.de

Hans J. Vock
Diamond Lite SA.
Rheineckerstr. 12
CH-9425 Thal
Phone: +41 71 880 0200
Fax: +41 71 880 0201
e-mail: hans.vock@diamondlite.com
URL: www.diamondlite.com

HYDROGEN AS CENTRE PIECE IN POWER-TO-GAS

Michael Bielmann

Hydrogen as a chemical energy carrier is finally gaining momentum: While for a long time, mobility was the main driver for the interest in hydrogen, the increased penetration of renewable energy generation is responsible for increased interest in this pathway. In the future, energy markets converge. Hydrogen couples electricity, gas and fuel markets serving the purposes of active demand, long-term energy storage and renewable fuel. EMPA pursues these transitions with the RENERG2 and FutureMobility Projects.

As Fuel Cells have taken big steps towards maturity in the past 5 years, Hydrogen Generation and Infrastructure become the center of interest in the near future. Massive growth of renewable generation in Germany changes the energy landscape. As generation control is gradually slipping, demand control is gaining importance. Power-to-Gas effectively gives hydrogen generation the necessary boost of interest to resolve the remaining piece of the puzzle.

As political discussion focusses on efficiency, it might seem controversial to propose hydrogen as an efficient solution. But many reputable companies agree: in a future energy system with high renewable energy fraction, hydrogen is the only technology that can offer a fix to the volatility and storage problem [1-3]. Technologists focus on efficiency, economists focus on effectiveness.

Challenge	Opportunity
excess energy with high RE penetration	orders of magnitude higher energy storage capacity than any other technology
stability in electricity grids	active demand capable decoupling of production and use
distribution grid fortification	scalability decentralized, centralized
CO_2 regulation in mobility	artificial, renewable energy carrier
range anxiety in e-mobility	fast fueling and same range

Gradually it is realized, that battery electric vehicles are not the golden bullet solution everybody hoped for: range remains the Achilles heel, vehicle-to-grid has marginal effect for storage of excess energy and while fast charging can reduce the range challenge, it is detrimental from a grid stability point of view. In the industry estimate, fuel cells are now perceived a more attractive solution than pure BEV's[4]. Pure Hydrogen vehicles or H-CNG fueled cars do not suffer those limitations.

Hydrogen therefore is maturing from a fuel to a more holistic solution integrating multiple functionalities. The EMPA project FutureMobility and RENERG^2 – a consortium project of the ETH-domain and ZHAW currently in planning - follow this approach covering all these aspects.

References:

[1] Pieper, C. and H. Rubel, Electricity Storage: Making Large-Scale Adoption of Wind and Solar Energies a Reality, in Focus Report2010, Boston Consulting Group: Boston.

[2] DENA, Analyse der Notwendigkeit des Ausbaus von Pumpspeicherwerken und anderen Stromspeichern zur Integration der erneuerbaren Energien, 2010, Deutsche Energie-Agentur GmbH (dena): Berlin.

[3] Welter, P., Herr Altmaier, so geht's! Photon hat eine Vollversorgung mit Sonne und Wind bis 2030 durchgerechnet - ein Handlungsleitfaden. Photon, 2012. ***October****.*

[4] KPMG, KPMG's Global Automotive Executive Survey 2013 - Managing a multidimensional business model, 2013, KPMG.

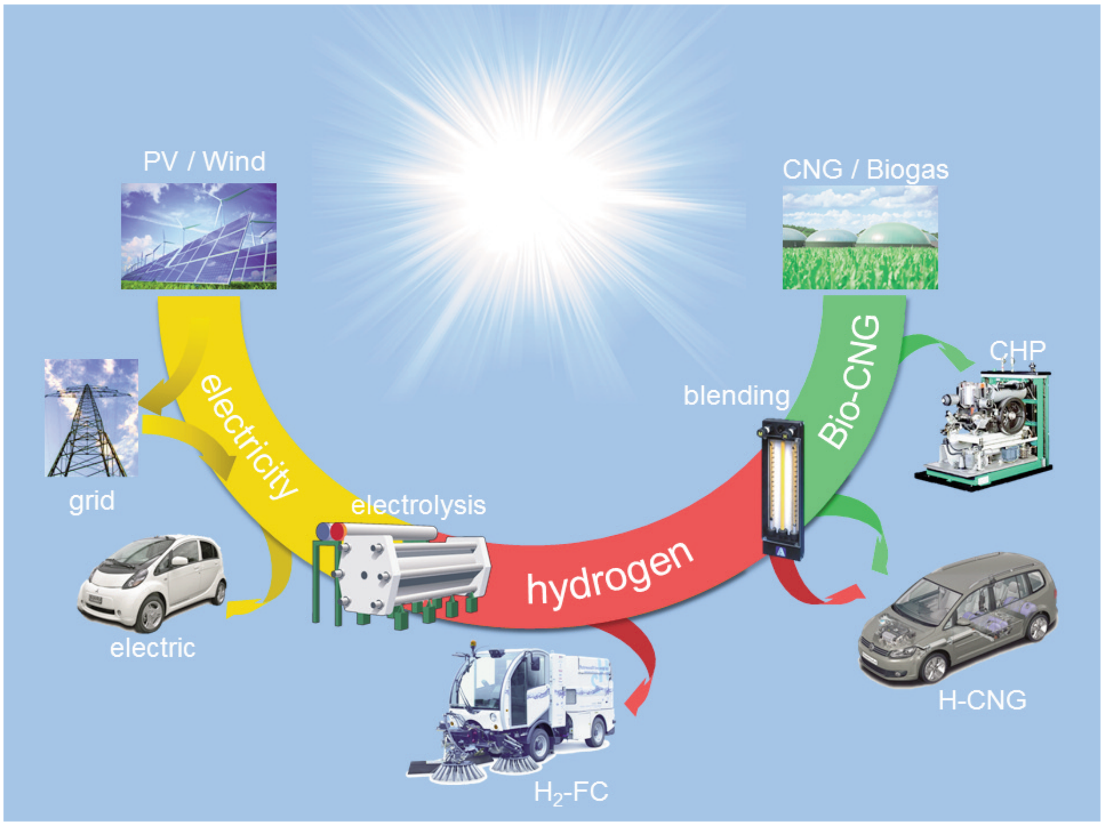


Fig. 1: Schematic representation of the FutureFuel project. The Fuel Hub will serve all novel forms of mobility like battery electric, hydrogen fuel cell, CNG and H-CNG vehicles in one single location.

Contact:

Dr. Michael Bielmann
Hydrogen and Energy
EMPA Materials Science and Technology
Überlandstrasse 129
CH-8600 Dübendorf

Tel. +41 58 765 43 42
Fax +41 58 765 40 20
e-mail: michael.bielmann@empa.ch

HYDROGEN PRODUCTION

ADEL – Advanced Electrolyser for Hydrogen Production with Renewable Energy Sources

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 (www.adel-energy.eu).

Olivier Bucheli
Htceramix, Yverdon
oliver.bucheli@htceramix.ch

ARTIPHYCTION - Fully artificial photo-electrochemical device for low temperature hydrogen

Building on the pioneering work performed in a FET project based on natural enzymes (www.solhydromics.org) and the convergence of the work of the physics, materials scientists, chemical engineers and chemists involved in the project, an artificial device will be developed to convert sun energy into H_2 with close to 10% efficiency by water splitting at ambient temperature (www.artiphyction.org).

Toby Meyer
Solaronix SA, Aubonne
toby.meyer@solaronix.com

Bio-Mimetic Chemistry of [Fe]-Hydrogenase

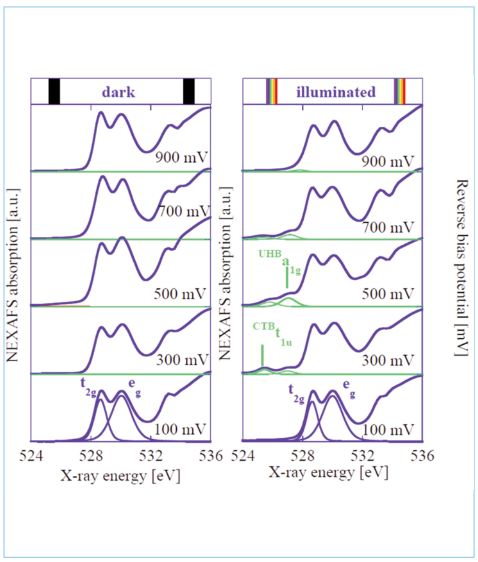
Hydrogenases are enzymes that efficiently catalyze the production and/or utilization of hydrogen (H_2). In light of the central role of H_2 in technologies (fuel cell) and industries (hydrogenation), studies on the structure and function of hydrogenases are of significant current interest. Bio-mimetic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

Xile Hu
EPFL, Lausanne
xile.hu@epfl.ch

Catalysis Under Extreme Conditions: in situ Studies of the Reforming of Organic Key Compounds in Supercritical Water

The project focuses mainly on obtaining insights to the role of the catalytically active metal. Besides on line mass spectrometry (MS) for analyzing the gas-phase species (methane, hydrogen, carbon dioxide, carbon monoxide), in situ investigations of a ruthenium catalyst applying X-ray absorption spectroscopy (XAS) and X-ray emission spectroscopy (XES) are planned.

Jörg Wambach
PSI, Villigen
joerg.wambach@psi.ch

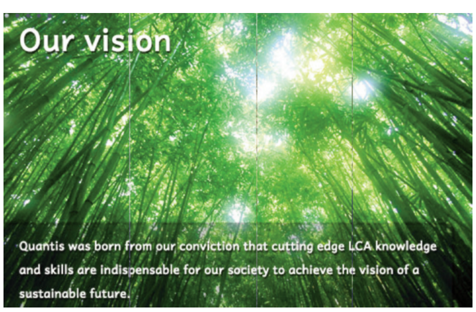


Defects in the bulk and on surfaces and interfaces of metal oxides with photoelectrochemical properties: In-situ photoelectrochemical and resonant x-ray and electron spectroscopy studies

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. This is a joint project of Empa Laboratory for High Performance Ceramics and EPFL LPI, funded by the Swiss National Science foundation.

Artur Braun
EMPA Dübendorf
artur.braun@empa.ch

Materials Science & Technology

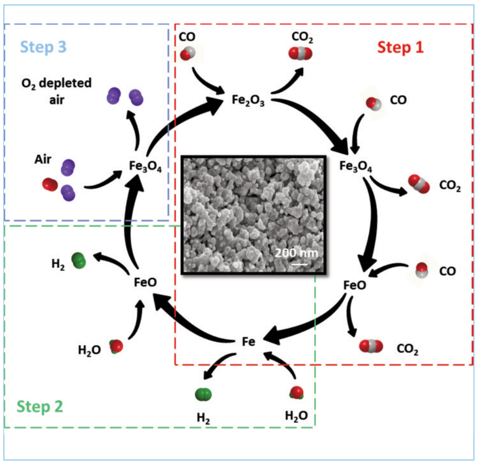


DEMCAMER - Design and Manufacturing of Catalytic Membrane Reactors by developing new nano-architectured catalytic and selective membrane materials

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 (WGS), and Oxidative Coupling of Methane (OCM)) for pure hydrogen, liquid hydrocarbons and ethylene production.

Patricia Girardbille
Quantis Sàrl, Lausanne
info@quantis-intl.com

Quantis
Sustainability counts



Development of novel, synthetic, calcium-based sorbents for CO_2 capture and hydrogen production aided by advanced tomographic techniques on the nano-metre scale

The overall objective of this proposal is the development of novel, synthetic, calcium-based 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.

Christoph Müller
ETHZ, Zürich
muelchri@ethz.ch

ETH
Swiss Federal Institute of Technology Zurich

GENIUS – GEneric diagNosis InstrUment for SOFC SystemsHTceramix / Hexis

The state of health of any SOFC system is currently difficult to evaluate, which makes it difficult to respond to a fault or degradation with the appropriate counter measure, to ensure the required reliability level. Therefore, the GENIUS project aims to develop a GENERIC tool that would only use process values and that would be based on a validateddiagnostic algorithm (https://genius.eifer.uni-karlsruhe.de).

Olivier Bucheli
Htcearmix, Yverdon
oliver.bucheli@htceramix.ch

HTceramix

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

SOLARH$_2$ – European solar-fuel initiative - renewable hydrogen from sun and water

SOLAR-H$_2$ brings together 12 world-leading European laboratories to carry out integrated, basic research aimed at achieving renewable hydrogen (H_2) production from environmentally safe resources. The vision is to develop novel routes for the production of a Solar-fuel, in our case H_2, from the very abundant, effectively inexhaustible resources, solar energy and water.

Jean-David Rochaix
Uni Genève, Genf
Jean-David.Rochaix@unige.ch

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

Hytech (Sustainable Hydrogen Technologies)

The HyTech project is focused on the realization of breakthroughs and advancing innovative technologies in the field of sustainable H_2 utilization. These developments 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.

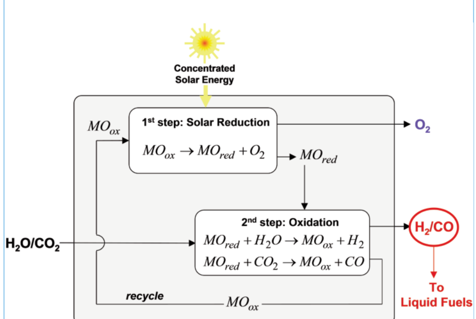
Massimiliano Capezzali
EPFL, Lausanne, Villigen, Dübendorf
PECHouse@epfl.ch

IDEALHY - Integrated design for demonstration of efficient liquefaction of hydrogen

The project (www.idealhy.eu) carries out a detailed investigation of different steps in the liquefaction process, bringing innovations and greater integration in an effort to reduce specific energy consumption by 50% compared to existing plants, and simultaneously to reduce investment cost. IDEALHY will carry out a well-to-end-user analysis to illustrate the role of liquid hydrogen in the energy chain.

Michael Börsch
WEKA AG, Bäretswil
m.boersch@weka-ag.ch

www.weka-ag.ch



IEA Hydrogen Implementing Agreement – Annex High Temperature Hydrogen Production Process

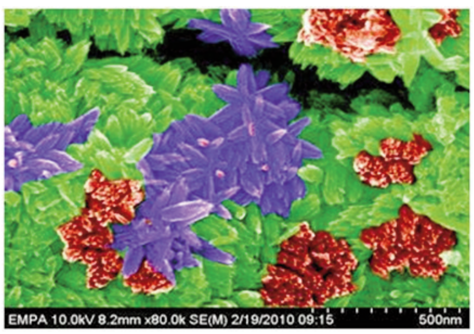
The purpose of Task 25 is to support production of massive quantities of zero-emission H_2 through use of high temperature processes (> 500° C) coupled with nuclear and solar heat sources. The overarching objective is to share existing worldwide knowledge on high temperature processes (HTPs) and further to develop expertise in global assessment of the HTPs that can be integrated in Hydrogen Production Road Mapping.

Anton Meier
PSI, Villigen
anton.meier@psi.ch

IEA Hydrogen Implementing Agreement – Annex Advanced Materials for Hydrogen From Waterphotolysis

The main goal of the new Task 26 is to seamlessly extend the excellent R&D efforts made under previous PEC Tasks 14 and 20 toward practical material and systems solutions for water-photolysis. In this continued research, photon conversion efficiency and durability will be judged as the main measures of success in the development of new PEC materials.

Kevin Sivula
EPFL, Lausanne
PeCHouse@epfl.ch



Metal-oxide nanoparticles and films for solar photo-electrochemical hydrogen fuel production

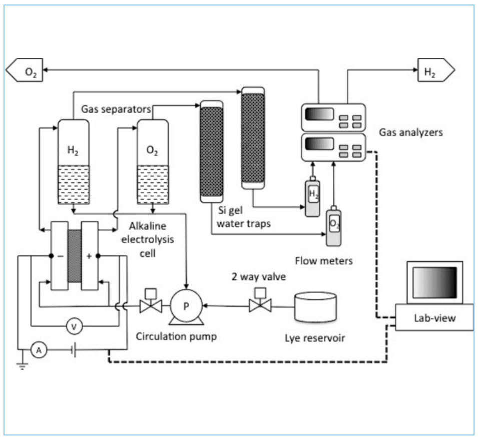
The objective of this project is to develop mixed metal-oxide narrow band-gap semiconduc-tor nanoparticles with optimized redox potentials to produce hydrogen efficiently via photo-catalysis using visible light. Acetylene flame spray synthesis is a new method for nanopar-ticle and nanocomposite production from affordable inorganic precursor solutions with high crystallinity.

Artur Braun
EMPA, Dübendorf
artur.braun@empa.ch

NANOMOF – Nanoporous Metal-Organic Frameworks for production

The discovery of porous hybrid materials constructed from inorganic nodes and organic multifunctional linkers has established a new area of inorganic-organic hybrids (Metal-Organic Frameworks, MOFs) with extraordinary performance as compared to traditional porous solids such as zeolites and activated carbon. NanoMOF will focus beyond discovery and integrate MOFs into products with industrial impact within a strong cooperation of established MOF research institutions and industrial end users.

André Lang
Norafin GmbH, Basel
andre.lang@norafin.com



PALE - Pilot laboratory alkaline electrolysertest bench tor high pressure and temperature

Complementary to the EU-project ELYGRID (www.elygrid.com) in this applied P&D project, a fully automated pilot-laboratory electrolyser with a membrane diameter of 50 mm will be developed and built up. It is possible to test the membrane and total stack concerning efficiency, durability, cell voltage and power consumption under real conditions with electrodes and membranes made of newly developed advanced materials for higher efficiency.

Ulrich Vogt
EMPA, Dübendorf
ulrich.vogt@empa.ch

EMPA
Materials Science & Technology

PHOTO ELECTRO CHEMICAL
PEC HOUSE

PEChouse 2 – Photoelectrochemical water-splitting for solar production of hydrogen

Photoelectrochemical cells (PEC directly split water into H2 and O2 thereby providing a basis for the renewable, clean production of hydrogen from sunlight. They rely on a photoactive material (a semiconductor) capable of harvesting and converting solar energy into stored chemical fuel, i.e. hydrogen. The PECHouse is a collaborative effort with defined goals for the stepwise development of an efficient hydrogen production system (http://pechouse.epfl.ch/)

Kevin Sivula
EPFL, Lausanne
PeCHouse@epfl.ch

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

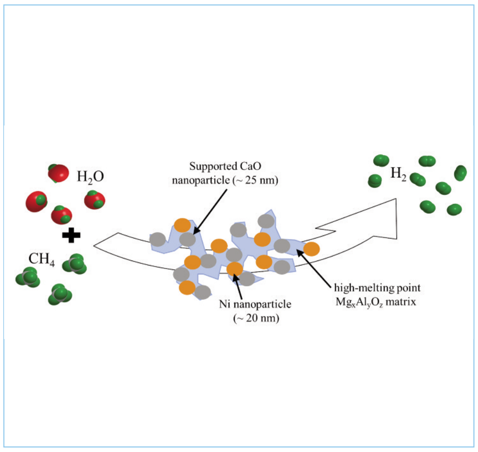
EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

PHOCS - Photogenerated Hydrogen by Organic Catalytic Systems

Aim of the project is the realization of a new-concept, photoelectrochemical system for hydrogen production, based on the hybrid organic/inorganic and organic/liquid interfaces. PHOCS takes the move from the recent demonstration of reduction/oxidation reactions taking place, under visible light and at zero bias, at the interface of an organic semiconductor and an aqueous electrolyte, obtained by the coordinators group.

Michael Graetzel
EPFL, Lausanne
michael.graetzel@epfl.ch

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



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

The proposal 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.

Christoph Müller
ETHZ, Zürich
muelchri@ethz.ch

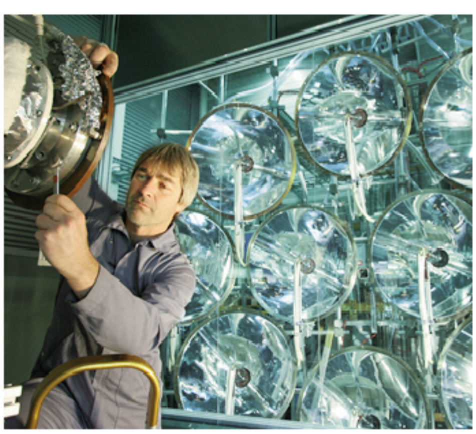
Swiss Federal Institute of Technology Zurich

Splitting H_2O and CO_2 via a solar thermochemical redox cycle

The scope of this project is the solar splitting of H_2O and CO_2 via thermochemical redox cycles, yielding H_2 and CO – syngas: the precursor of liquid hydrocarbon fuels for transportation. The 2-step cycle consists of: 1) the solar endothermic reduction of the metal oxide using concentrated solar energy as the source of high-temperature process heat; and 2) the non-solar exothermic oxidation of the reduced metal oxide with H_2O/CO_2 which yields syngas together with the initial metal oxide; the latter is recycled to the 1st step. The chemical thermodynamics and reaction kinetics are investigated for the zinc-based (Zn/ZnO) and ceria-based ($CeO_2/CeO_{2-\delta}$) redox reactions, and the solar reactor technologies are developed for decentralized (kW) solar parabolic dishes or centralized (MW) solar tower configurations. http://www.pre.ethz.ch/

Aldo Steinfeld
ETHZ, Zürich / PSI, Villigen
aldo.steinfeld@ethz.ch

Swiss Federal Institute of Technology Zurich

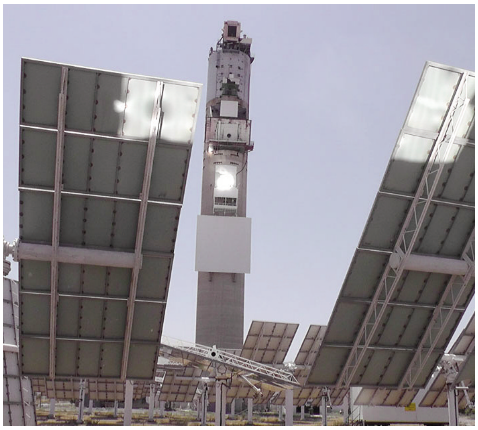


SFERA – Solar facilities for the European research area

The purpose of this project is to integrate, coordinate and further focus scientific collaboration among the leading European research institutions in solar concentrating systems and offer European research and industry access to the best-qualified research and test infrastructures. These are suited for investigating processes for solar electricity generation, for hydrogen and solar fuels production as well as for research in advanced materials and further applications.

Christian Wieckert
PSI, Villigen
christian.wieckert@psi.ch

PAUL SCHERRER INSTITUT



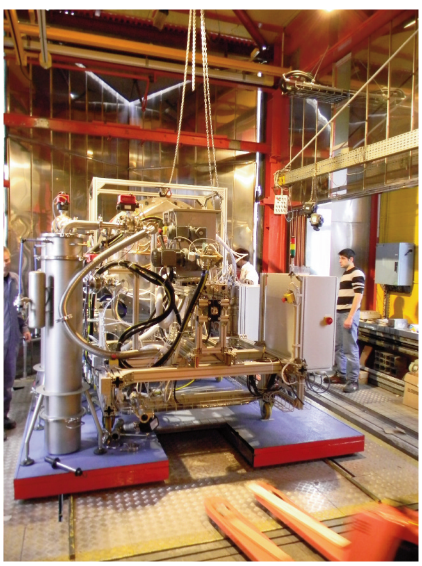
Solar-driven thermochemical gasification of carbonaceous feedstock

The scope of this project is the solar-driven thermochemical conversion of carbonaceous feedstock (e.g. biomass, coal, C-containing wastes) into widely applicable and energy-rich syngas – a fuel mixture of mainly H_2 and CO – which can be used for the production of heat, power, and fuels. The advantages of the solar-driven process vis-à-vis the conventional autothermal processes are four-folded: 1) it delivers higher syngas output per unit of feedstock, as no portion of the feedstock is combusted for process heat; 2) it avoids contamination of syngas with combustion by-products or tars; 3) it produces syngas with higher calorific value and lower CO_2 intensity, as the energy content of the feedstock is upgraded by up to 33% through the solar energy input; and 4) it eliminates the need for an upstream air separation unit. The solar reactor technology is being developed for a large-scale (MW) solar tower configuration.
http://www.pre.ethz.ch/

Aldo Steinfeld
ETHZ, Zürich / PSI, Villigen
aldo.steinfeld@ethz.ch

ETH
Swiss Federal Institute of Technology Zurich

.

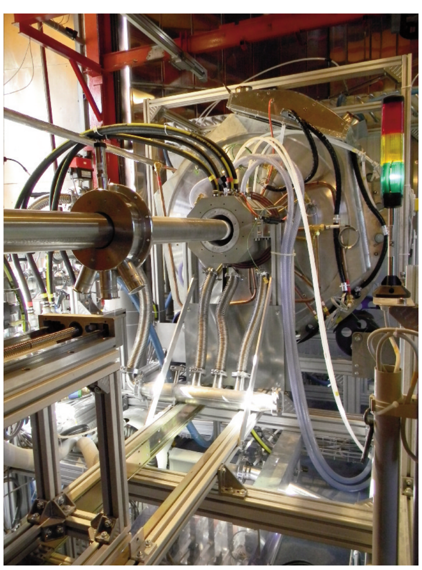


Solar Production of Zinc and Hydrogen Reactor Optimisation for Scale-up

In a two-step cycle based on the ZnO/Zn redox reactions, solar energy provides the process heat for the highly endothermic, high-temperature thermal dissociation of ZnO(s) into storable and transportable Zn metal. Depending on the desired application, the Zn(s) produced in turn can (1) be used as the fuel in a Zn-air battery to generate electricity, or (2) split water in an exothermic Zn hydrolysis reaction and convert the hydrogen to electricity in a H_2-O_2 fuel cell.

Anton Meier
PSI, Villigen
anton.meier@psi.ch

PAUL SCHERRER INSTITUT



Towards Industrial Solar Production of Zinc and Hydrogen – 100 kW Solar Pilot Reactor for ZnO Dissociation

Following the technical demonstration with a 10 kW solar reactor prototype, a 100 kW solar pilot plant for the thermal dissociation of ZnO has been designed, fabricated, and experimentally tested at the large-scale solar concentrating facility of PROMES-CNRS in Odeillo, France. This operational experience has pointed out further R&D needs and is guiding the development of an industrial solar chemical plant for the production of H_2 and syngas – a precursor for liquid hydrocarbon fuels.

Anton Meier
PSI, Villigen
anton.meier@psi.ch

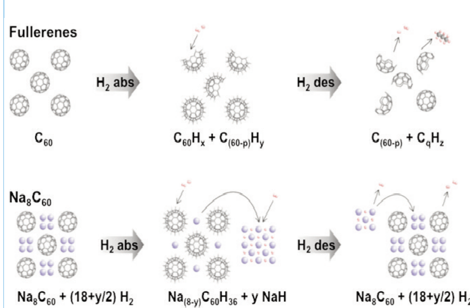
PAUL SCHERRER INSTITUT

SOLARH$_2$ – renewable hydrogen from sun and water

The vision is to develop novel routes for the production of a Solar-fuel, in our case H$_2$, from the very abundant, effectively inexhaustible resources, solar energy and water. Our multidisciplinary expertise spans from molecular biology, biotechnology, via biochemistry and biophysics to organo-metallic and physical chemistry.

Jean-David Rochaix
Uni Genève, Genf
Jean-David.Rochaix@unige.ch

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES



SINERGIA HyCarBo - Smart carbon-based materials for hydrogen storage

In the present project we propose to investigate on the possibility to increase the hydrogen storage capacity of carbon-based materials via chemical activation by means of alkali and alkaline earth metal intercalation. The classes of materials we propose to investigate present two distinct molecular geometry: planar carbon structures and close carbon structures.

Philippe Mauron
EMPA, Dübendorf
philippe.mauron@empa.ch

EMPA
Materials Science & Technology

SOLAROGENIX

SOLAROGENIX – Visible-Light Active Metal Oxide Nano-catalysts for Sustainable Solar Hydrogen Production

The project SOLAROGENIX is a Collaborative Project funded by the Seventh Framework Programme of the European Union. It will investigate novel nanostructured photocatalysts starting from comprehensive theoretical and experimental investigations on visible-light active metal oxides for photoelectrochemical splitting of water to target the environmental hydrogen production from saline water by sun illumination.

Markus Niederberger
ETHZ, Zürich
markus.niederberger@mat.ethz.ch

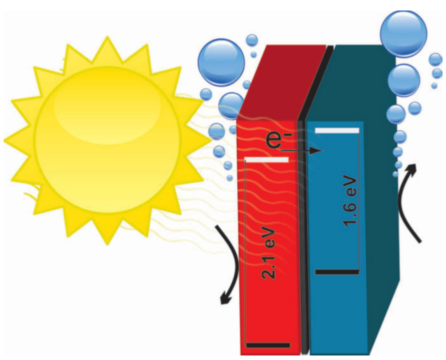
ETH
Swiss Federal Institute of Technology Zurich

SOLHYDROMICS – Nanodesigned electrochemical converter of solar energy into hydrogen hosting natural enzymes or their mimics

An artificial device will be developed to convert sun energy into H_2 with 10% efficiency by water splitting at ambient temperature, including: an electrode exposed to sunlight carrying PSII or a PSII-like chemical mimic deposited upon a suitable electrode; a membrane enabling transport of both electrons and protons via e.g. carbon nanotubes or TiO_2 connecting the two electrodes and ion-exchange resins like e.g. Nafion, respectively.

Toby Meyer
Solaronix SA, Aubonne
toby.meyer@solaronix.com

HYDROGEN STORAGE

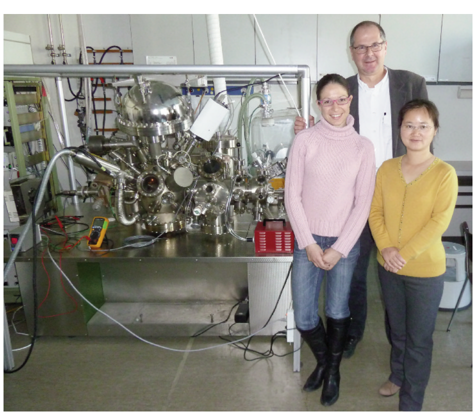


Developing stable and inexpensive p-type photocathodes for the production of solar fuels

The development of promising materials for the direct conversion of solar energy into carbon-based fuels using a photoelectrochemical device is an important goal for renewable energy storage. For this project the performance of promising copper-based p-type photocathodes for the reduction of water is being developed. Overall, we seek to employ inexpensive raw materials and processing techniques while still obtaining high performance devices. Thus, solution based methods for preparing the promising copper oxide materials are being used. The material stoichiometry and doping is being varied to optimize the performance of these devices. Funded by the EOS Holdings SA.

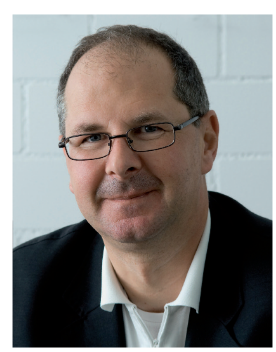
Kevin Sivula
EPFL, Lausanne
PeCHouse@epfl.ch

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



ACH – Advanced Complex Hydrides

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.



Andreas Züttel
EMPA, Dübendorf
andreas.zuettel@empa.ch

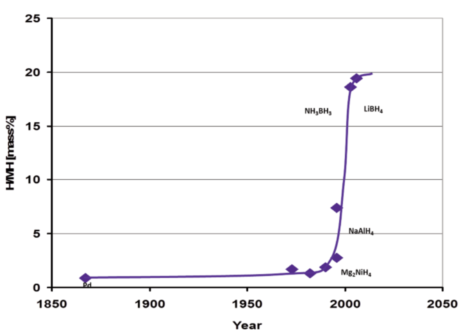
EMPA Materials Science & Technology

BIMETALLIC BOROHYDRIDES: hydrogen storage and superionic conductivity

The aim of the project is the development of new materials - bimetallic borohydrides - as hydrogen storage materials, and as superionic conductors for battery applications. Le projet dans son contexte, son sense et son importance: Hydrogen storage for mobile applications is still an open question.

Radovan Cerny
Uni Genève, Genf
Radovan.Cerny@unige.ch

BOR4STORE - Fast, reliable and cost effective boron hydride based high capacity solid state hydrogen storage materials

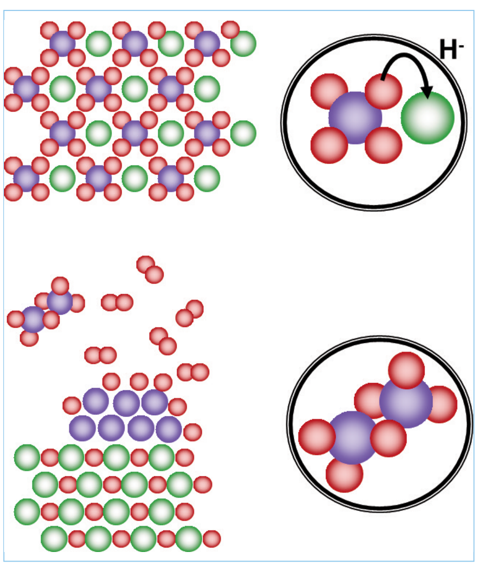


The project proposes an integrated, multidisciplinary approach for the development and testing of novel, optimised and cost-efficient boron hydride based H_2 storage materials with superior performance (capacity more than 8 wt.% and 80 kg H_2/m^3). The most promising material(s), to be indicated by rigorous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

Andreas Borgschulte
EMPA, Dübendorf
andreas.borgschulte@empa.ch

EMPA Materials Science & Technology

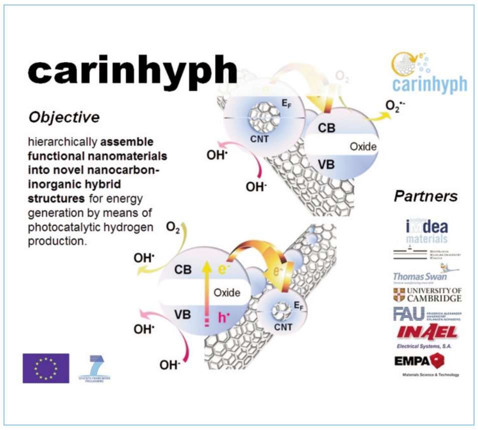
BORANE



In the project the influence of boron-hydrogen compounds on the formation and decomposition of tetrahydroborates is analyzed. The main objective is to understand the related mechanisms based on reactions of hydrogen/borane uptake and release. The understanding of these mechanisms will serve as a basis for optimization of tetrahydroborates to be used for hydrogen storage.

Andreas Züttel
EMPA, Dübendorf
andreas.zuettel@empa.ch

EMPA Materials Science & Technology



CARINHYPH - Bottom-up fabrication of nano carbon-inorganic hybrid materials for photocatalytic hydrogen production

This projects deals with the hierarchical assembly of functional nanomaterials into novel nanocarbon-inorganic hybrid structures for energy generation by photocatalyic hydrogen production, with carbon nanotubes (CNTs) and graphene the choice of nanocarbons. The scientific activities include the development of new functionalisation strategies targeted at improving charge transfer in hybrids and therefore their photocatalytic activity.

Roland Hischier
EMPA, St. Gallen
roland.hischier@empa.ch

EMPA Materials Science & Technology

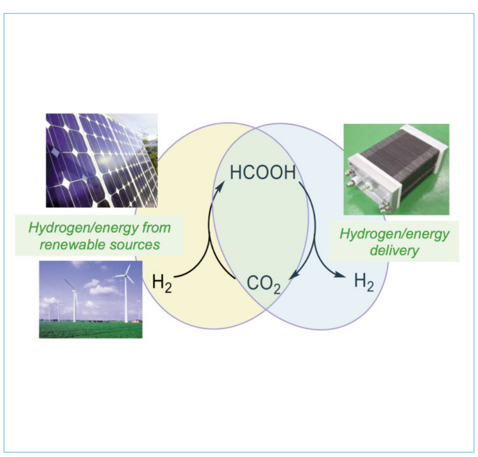
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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

There are two specific aims: (I) bio-inspired sulfur-rich metal complexes as efficient and practical electro-catalysts for hydrogen production and CO_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.

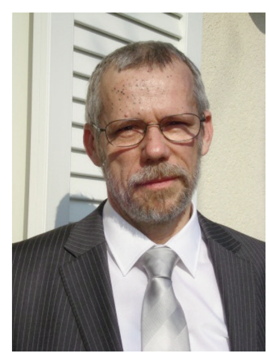
Luciana Vaccaro
EPFL, Lausanne
luciana.vaccaro@epfl.ch

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



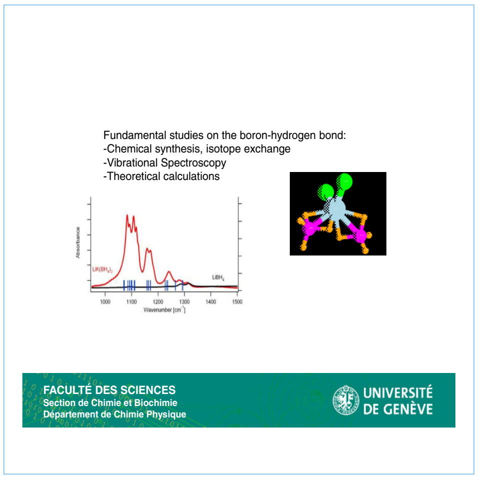
Catalytic activation of small molecules: towards applications in molecular energy storage and delivery

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 H2, CO2, CO and N2, as well as small organic molecules (HCOOH, alkenes, alkynes, methanol, etc.) in aqueous solution and in different reaction media.



Gàbor Laurenczy
EPFL, Lausanne
gabor.laurenczy@epfl.ch

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



Combined experimental and theoretical studies on potential hydrogen storage materials and on new inorganic fluorides

In this project, we aim to contribute to a fundamental understanding of the nature of the boron-hydrogen bond. Vibrational spectroscopy probes directly the strength of chemical bonds. In the first part of our project, we investigate, using a combined theoretical and experimental approach, the effect of geometry changes (bond length and angles) on the vibrational spectra.

Hans Hagemann
Uni Genève, Genf
Hans-Rudolf.Hagemann@unige.ch

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

ETH
Swiss Federal Institute of Technology Zurich

DEMOYS – Dense membranes for efficient oxygen and hydrogen separation

The objective of this project is the development of thin mixed conducting membranes for O_2 and H_2 separation by using a new deposition technique Low Pressure Plasma Spraying Thin Film (LPPS-TF) in combination with nano-porous, highly catalytic layers. TF-LPPS is a technique based on a combination of thermal spray and Physical Vapour Deposition technology (http://demoys.rse-web.it/).

Jennifer Rupp
ETHZ, Zürich
jennifer.rupp@mat.ethz.ch

ETH
Swiss Federal Institute of Technology Zurich

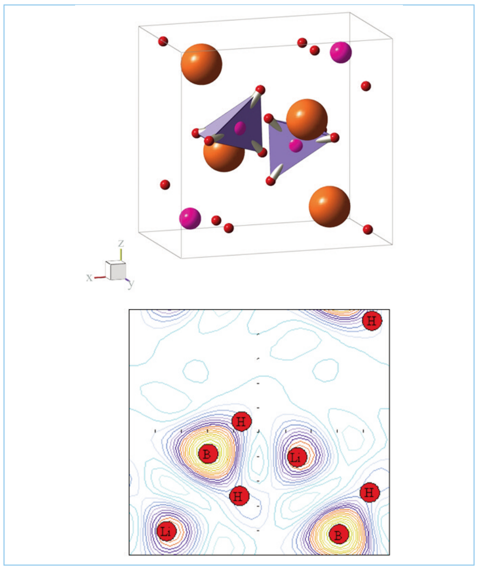
GRANIT TECHNOLOGIES SA

HY-FORM 1: Production et opération d'un nouveau système de génération d'hydrogène décentralisé

In diesem Pilotprojekt geht es allgemein darum, aufzuzeigen, wie ein bestehendes Wasserstofflogistiksystem für industrielle Anwendungen durch ein einfacheres und sicheres, ökonomisch wie ökologisch effizienteres System ersetzt werden könnte. Hierzu wird eine vorindustrielle Pilotanlage zur Vor-Ort- Produktion von Wasserstoff ausgehend von Formylsäure aufgebaut, an der die diversen Aspekte wie energetische, wirtschaftliche und Umwelt-Bilanz einer solchen Anlage für künftige Kunden demonstriert werden sollen.

Maurice Jutz
Granit SA, Orbe
Maurice.jutz@granit.net

GRANIT TECHNOLOGIES SA

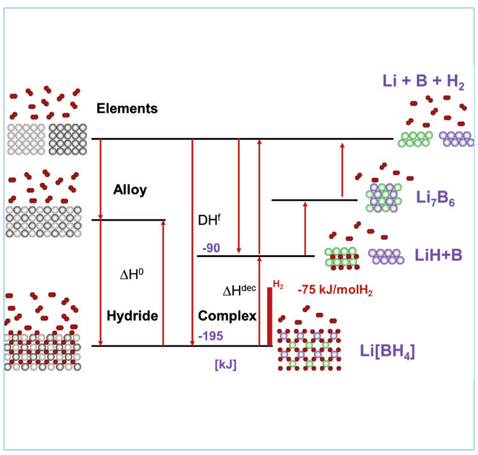


HYDYNA II

In this project we investigate the hydrogen mobility and the hydrogen dynamics of a series of p-element complex hydrides and their influence on the stability and thermodynamic properties of the respective hydrides. In order to achieve the results we will combine neutron difftraction as well as inelastic and quasielastic neutron spectroscopy measurements at SINQ (PSI), at BENSC (Berlin) and at ISIS (Didcot, UK) with nuclear magnetic resonance measurements.

Arndt Remhof
EMPA, Dübendorf
arndt.remhof@empa.ch

Materials Science & Technology

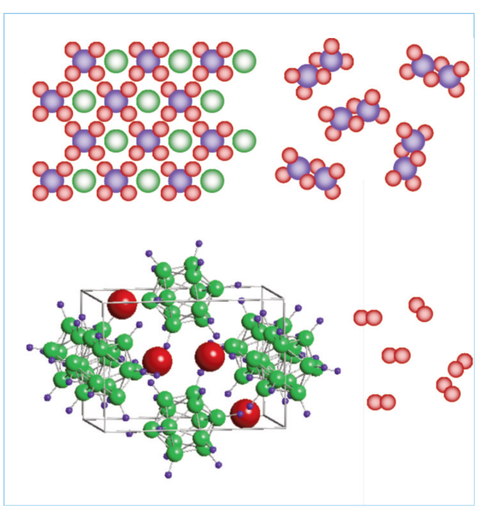


IEA Hydrogen Implementing Agreement – Annex Fundamental and applied hydrogen storage materials development

Task 22 addresses hydrogen storage in solid materials. Hydrogen storage is considered by many to be the greatest technological barrier to widespread introduction and use of hydrogen in global energy systems. Currently, no hydrogen storage system, including pressurized and liquefied hydrogen and hydrogen stored in solid compounds known, satisfies international targets for on-board hydrogen storage in mobile applications.

Andreas Züttel
EMPA, Dübendorf
andreas.zuettel@empa.ch

Materials Science & Technology

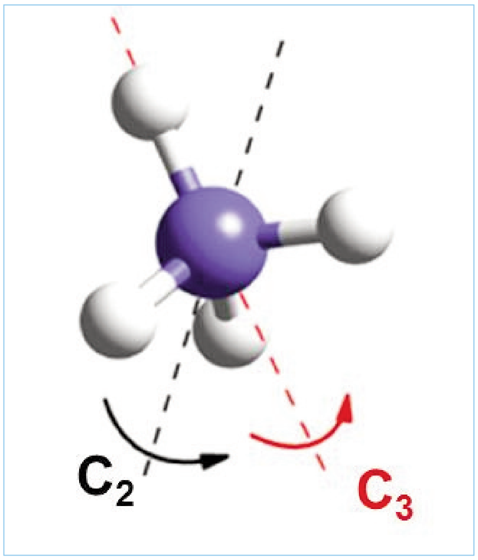


Influence of borane on the sorption of complex hydrides

Apart from being widely applied reagents in organic and inorganic synthesis, complex hydrides are ideal candidates to be used as future energy carriers. They can store high amounts of hydrogen per volume and hence present compounds with very high energy densities. In particular alkaline and alkaline-earth tetrahydroborates with one of the highest volumetric and gravimetric hydrogen capacity are intensively studied as hydrogen storage materials.

Andreas Züttel
EMPA, Dübendorf
andreas.zuettel@empa.ch

Materials Science & Technology



Ion mobility in complex hydrides

In a joint binational project, implemented under the Polish Swiss Research Programme (PSRP) we to investigate the fundamental transport properties in Li based complex hydrides, aiming to understand and to improve them with respect to potential applications as hydrogen storage materials and as solid state electrolytes.

Arndt Remhof
EMPA, Dübendorf
arndt.remhof@empa.ch

Materials Science & Technology

NaNiBo - Nano-confinement of nitrogen and boron based hydrides

The availability of a safe and effective way to store hydrogen reversibly is one of the major issues for its large scale use as an energy carrier. At present, no single material fulfilling all requirements is in sight. Amidoboranes and aluminium borohydride have a high hydrogen content and release hydrogen at rather the low temperatures. The main aim of this project is the development of novel and safe boron respectively nitrogen containing hydrogen storage materials with the help of nano-structures.

Andreas Borgschulte
EMPA, Dübendorf
andreas.borgschulte@empa.ch

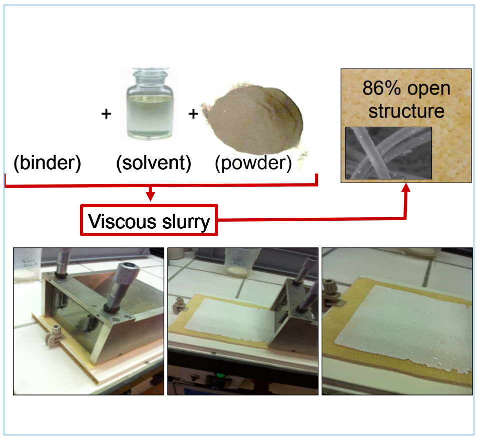
Materials Science & Technology

HYDROGEN END USES

Production de chaleur par le biais d'une chaudière à hydrogène Pictet & Cie

Es soll aufgezeigt werden, wie ein Teil des Sanitärwassers im Administrationsgebäude von Pictet & Cie in Genf erneuerbar bereitgestellt werden kann. Hierzu soll Überschussstrom einer hauseigenen PV-Anlage zur Produktion von Wasserstoff genutzt werden, welcher in einem neuartigen katalytischen Brenner eingesetzt wird. Ziele des Projektes sind das Aufzeigen von Speicheroptionen für dezentrale Produktion mit Erneuerbaren, insbesondere langristige oder saisonale.

Jean-Hugues Hoarau
Pictet & Cie, Genf
jhoarau@pictet.com

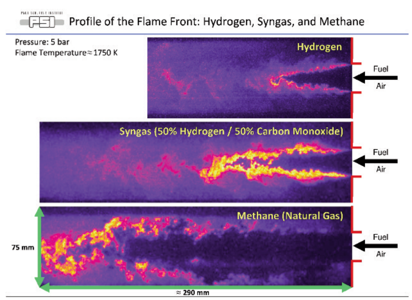


ELYGRID - High Pressure Alkaline Electrolysers for Electricity/H_2 production from Renewable Energies

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 (>0.5 MW) 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 parts: cell improvements, power electronics, and balance of plant (BOP). Two scalable prototype electrolysers will be tested in facilities which allow feeding with renewable energies (photovoltaic and wind).

Ulrich Vogt
EMPA, Dübendorf
ulrich.vogt@empa.ch

EMPA
Materials Science & Technology



H_2-IGCC – Low Emission Gas Turbine Technology for Hydrogen-rich Syngas

The objective of this project is to provide technical solutions which allow the use of state-of-theart highly efficient, reliable gas turbines in thenext generation of IGCC plants, suitable for combusting undiluted hydrogen-rich syngas derivedfrom a pre-combustion CO_2 capture process. The challenge is to operate a gas turbine reliably on hydrogen-rich syngas with emissions and process parameters similar to current state of-the-art natural gas fired turbines.

Peter Jansohn
PSI, Villigen
peter.jansohn@psi.ch

PAUL SCHERRER INSTITUT
PSI

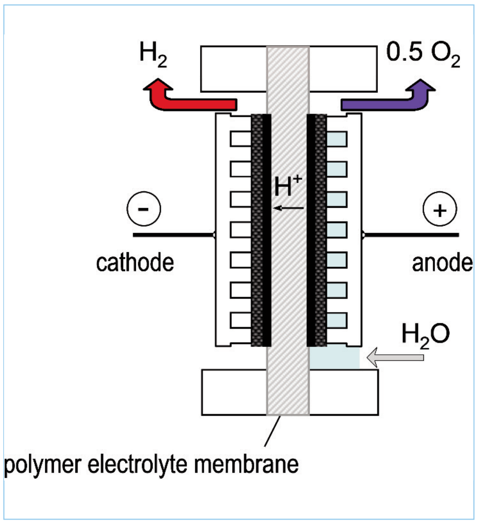
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

Hydrogen detectors and sensors for PEM fuel cell and electrolyser systems

Mass markets of hydrogen powered vehicles and hydrogen production units for residential areas require hydrogen detectors and sensors on a very large scale. The devices must be cheap, sensitive and selective, and allow to detect hydrogen and to monitor hydrogen-oxygen reaction processes. This project aims at developing sensing by using thin films and novel materials undergoing hydrogen-induced metal-insulator transitions.

Klaus Yvon
Uni Genève, Genf
klaus.yvon@unige.ch

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES



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

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).

Lorenz Gubler
PSI, Villigen
lorenz.gubler@psi.ch

PAUL SCHERRER INSTITUT
PSI

FUEL CELLS

TEMONAS
Technology Monitoring + Assessment

Fomenta AG
Fomenting Energy & Technology

TEMONAS - TEchnology MONitoring and Assessment Services

The objective of the project is to provide a functional and integrated TMA methodology and tool specifically tailored for the needs of research project and program progress evaluation. TEMONAS will take the various existing technology monitoring and assessment methodologies a step further in providing a transparent service that allows a targeted comparison and evaluation of project results and technology achievements with objectivity and confidentiality (www.temonas.eu).

Michael Spirig
European Fuel Cell Forum AG
and Fomenta AG
m.spirig@efcf.com /
m.spirig@fomenta.ch

EFCF EUROPEAN FUEL CELL FORUM

STATIONARY APPLICATIONS

EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

T-CELL - Innovative SOFC Architecture based on Triode Operation

In order to provide a proof of concept of the stackability of triode cells, a triode SOFC stack consisting of at least 4 repeating units will be developed and its performance will be evaluated under methane and steam co-feed, in presence of a small concentration of sulphur compound. Success of the overall ambitious objectives of the proposed project will result in major progress beyond the current state-of-the-art.

Jan van Herle
EPFL, Lausanne
jan.vanherle@epfl.ch

EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

ASSENT – Anode Sub-System Development & Optimisation for SOFC systems

The high temperature fuel cell technologies have potential for high electrical efficiency, 45-60%, and total efficiency up to 95%. SOFC has the added benefit of offering commercial applications from 1 kW residential to several MW stationary units with high fuel flexibility. Whilst much effort is devoted to cell and stack issues, less attention has been paid to the components and sub-systems required for an operational system (http://assent.vtt.fi/).

Olivier Bucheli
HTceramix / Hexis, Lausanne
olivier.bucheli@htceramix.ch

ASTERIX3 – ASsessment of SOFC CHP systems build on the TEchnology of htceRamIX 3

The main objectives of this project are: Improving lifetime, reliability and robustness of the overall system; Improve component quality; Increase robustness and tolerance to thermal cycling; Develop and integrate fully automated control of the system; Reduce cost and volume of the system; Increase thermal and electrical efficiency. Achieving these objectives will enable us to demonstrate a residential CHP concept fulfilling market requirements (http://asterix3.eu/).

Olivier Bucheli
HTceramix / Hexis, Lausanne
olivier.bucheli@htceramix.ch

DESIGN - Degradation Signatures identification for stack operation diagnostics

The project proposes to study the influence of slowly-damaging conditions on measures performed on the stack sub-components: the Cells and the Single Repeating Units (SRU) and on small stacks. Identification of characteristic signatures of these degradation phenomena at the lower level will be subsequently transposed at the stack level, to provide a way to diagnose slow degradation phenomena in a commercial SOFC stack (www.design-sofc-diagnosis.com/).

Jan van Herle
EPFL, Lausanne
jan.vanherle@epfl.ch

HITTEC – integration of high temperature thermoelectric converter for electricity generation in a solid oxide fuel cell system

To convert waste heat from solid oxide fuel cells into electricity is the goal of the "HITTEC" project. Researchers from Empa, in a strategic partnership with Hexis AG, are developing a thermoelectric converter to make fuel cell systems more efficient, possibly generating an extra 10 per cent energy output. However, the first step is to develop suitable materials to meet a diverse range of requirements.

Andre Heel
EMPA, Dübendorf
andre.heel@empa.ch

LOTUS – Low temperature Solid Oxide Fuel Cells for micro-CHP applications

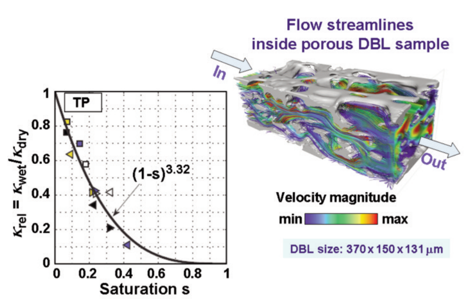
The objective of the LOTUS project is to build and test a Low Temperature SOFC system prototype based on new SOFC technology combined with low cost, mass-produced, proven components. The use of a modular concept and design practices from the heating appliances industry will reduce maintenance and repair downtime and costs of the system.

Olivier Bucheli
HTceramix / SOFCPower, Lausanne
olivier.bucheli@htceramix.ch

MCFC-Fuel Cells – Pilot Plant Grünau. ewz and Erdgas Zürich

The Molten Carbonate Fuel Cell (MCFC), supplied by FuelCell Energy Solutions GmbH, built in the heating centre of the Überbauungsgemeinschaft Grünau (Building Association Grünau) is to demonstrate how it stands the test in a real heat-, electricity-, and natural gas network long term. The pilot plant is also to show how the fuel cell behaves in a permanent operation and what way the operating costs are developing. The annual electric utilisation level is approx. 47% gross and the overall annual utilisation level is approx. 85% gross. The MCFC has an electric gross performance of 230 kW and a thermal performance of 170 kW.

Mevina Feuerstein
EWZ, Zürich
Mevina.Feuerstein@ewz.ch



Through-plane (TP) relative permeability in the diffusion barrier layer (DBL) of a PEFC, as a function of water saturation

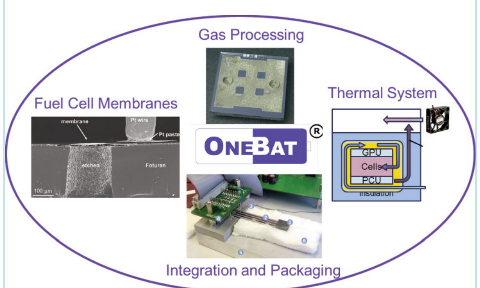
(T. Rosen, J. Eller, J. Kang, N.I. Prasianakis, J. Mantzaras, F.N. Büchi, JES 159: F536, 2012)

Modeling of energy conversion processes at the microscale

The aim of the project is to develop an advanced numerical tool capable of modeling key microscale processes occurring in both thermochemical and electrochemical conversion systems. A particular objective is to apply this model in a Polymer Electolyte Fuel Cell (PEMC) and compare the predictions with measurements of permeabilities and diffusivities inside the gas diffusion layer (GDL).

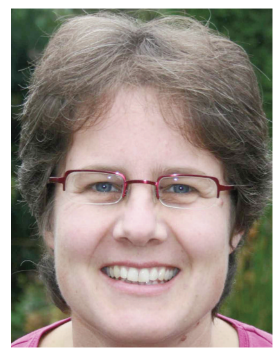
Ioannis Mantzaras
PSI, Villigen
ioannis.mantzaras@psi.ch

PAUL SCHERRER INSTITUT



ONEBAT – Battery Replacement using Miniaturized Solid Oxide Fuel Cell

The idea behind the project proposal is the vision of a micro-SOFC system which can be used as battery replacement for small portable electronic equipment. A factor of two to four higher energy density, geographical independence and immediate charging are expected from a micro-SOFC system compared to state-of-the-art Li-ion batteries. Polymer based fuel cells are not expected to show similar performance improvements over state-of-the-art batteries.



Anja Bieberle
ETHZ, Zürich
anja.bieberle@mat.ethz.ch

ETH
Swiss Federal Institute of Technology Zurich

HTceramix

RAMSES - Robust Advanced Materials for Metal Supported SOFC

The objective is to develop a SOFC cell with an improved lifetime thanks to the low operating temperature (600°C) while achieving high performances by applying advanced low-temperature electrodes and electrolyte materials. The Metal Supported Cell concept (MSC) will in addition reduce statistically based mechanical failures and decrease manufacturing cost by decreasing the amount of expensive ceramic materials to minimum.

Olivier Bucheli
HTceramix, Lausanne
olivier.bucheli@htceramix.ch

HTceramix

ReforCELL - Advanced multi-fuel Reformer for CHP-fuel CELL systems

The main focus of the project is to develop a new multi-fuel membrane reformer for pure hydrogen production (5 Nm^3/h) based on Catalytic Membrane Reactors in order to intensify the process of hydrogen production through the integration of reforming and purification in one single unit. The novel reactor will be more efficient than the state-of-the-art technology due to an optimal design aimed at circumventing mass and heat transfer resistances (http://reforcell.eu/).

Patricia Girardbille
Quantis Sàrl, Lausanne
info@quantis-intl.com

Quantis
Sustainability counts

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

ROBANODE – Understanding and minimizing anode degradation in hydrogen and natural gas fuelled SOFCs

The proposed project offers an effective methodology for a holistic approach of the SOFC anode degradation problem, through detailed investigation of the degradation mechanisms under various operating conditions and the prediction of the anode performance, degradation and lifetime on the basis of a robust mathematical model, which takes into account all underlying phenomena (http://robanode.iceht.forth.gr/).

Jan van Herle
EPFL, Lausanne
jan.vanherle@epfl.ch

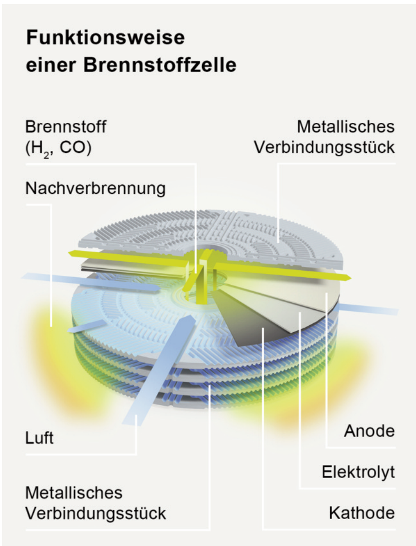
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

SCOTAS – Sulphur, Carbon, and re-Oxidation Tolerant Anodes and Anode Supports for SOFC

The project will demonstrate a new full ceramic SOFC cell with superior robustness as regards to sulphur tolerance, carbon deposition (coking) and re-oxidation (redox resistance). Having a more robust cell will enable the system to be simplified, something of particular importance for combined heat and power (CHP). The new ceramic based cell will be produced by integrating strontium titanates, into existing, proven SOFC cell designs (www.scotas-sofc.eu).

Andreas Mai
Hexis AG, Winterthur
andreas.mai@hexis.com

HEXIS



SOF-CH ASE — Increased efficiency and reliability of SOFC system using Anode-Supported-Electrolyte technology

Solid oxide fuel cells (SOFC), based on ceramics as central components, stand out with the highest potential for electrical efficiency, longevity and manageable cost, owing to thermal process integration, wide fuel flexibility, and absence of corrosive liquids and noble metals. This project addresses the three crucial features of electrical efficiency, durability and reliability of operation.

Andreas Mai
Hexis AG, Winterthur
andreas.mai@hexis.com

SOF-CH ESC — Electrolyt Supported Solid Oxid Fuel Cells for Small Combined Heat and Power Plants

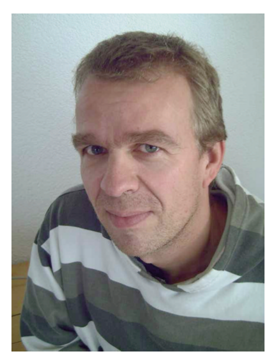
It is the main target of the project to develop new solutions which lead to a significant extension of the stack lifetimes, based on new and established know-how. In addition the planned project will also include characterisation and modelling activities for reliable lifetime predictions.

Olivier Bucheli
HTceramix, Lausanne
olivier.bucheli@htceramix.ch

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

SOFC-Life – Integrating Degradation Effects into Lifetime Prediction Models

Long-term stable operation of Solid Oxide Fuel Cells (SOFC) is a basic requirement for introducing this technology to the stationary power market. Degradation phenomena limiting the lifetime can be divided into continuous (baseline) and incidental (transient) effects.This project is concerned with understanding the details of the major SOFC continuous degradation effects.



Jan van Herle
EMPA, EPFL, Hexis
HTceramix, ZHAW, Lausanne
jan.vanherle@epfl.ch

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

SOFCOM - SOFC CCHP with poly-fuel: operation and management

SOFCOM is an applied research project devoted to demonstrate the technical feasibility, the efficiency and environmental advantages of CCHP plants based on SOFC fed by different typologies of biogenous primary fuels (locally produced), also integrated by a process for the CO2 separation from the anode exhaust gases (http://areeweb.polito.it/ricerca/sofcom/).

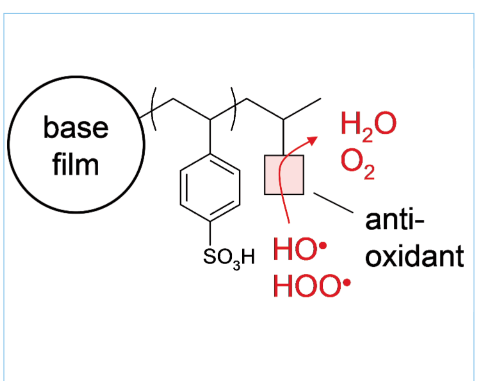
Jan van Herle
EPFL, Lausanne
jan.vanherle@epfl.ch

MOBILE APPLICATIONS

SAFEDRIVE - A Platform Power Management System and Low Voltage Drive Train for Hybrid and Electric Vehicles

The European hybrid, electric and fuel cell vehicle industries commercialise small volumes of low emission vehicles. These vehicles do not meetcustomer performance demands, at a price pointwhich is competitive with IC engines. Large vehicle manufacturers overcome this gap and reductheir development costs by platform sharing component technologies. The Safedrive proposal addresses the technology gap through the development of a new design DC motor, a high efficiency converter and an open platform power management system. This system easilyaccommodates fuel cell power sources.

Susanne Wegmann
Association e'mobile, Bern
swegmann@e-mobile.ch



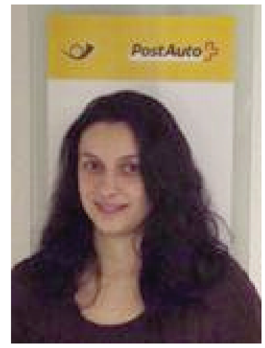
Antioxidant strategies for the stabilization of fuel cell membranes against oxidative stress

The chemical stability of fuel cell membranes represents a major challenge. During fuel cell operation, reactive oxygen species (ROS) are created as intermediates. They can attack the ionomer and cause degradation and aging, eventually leading to the failure of the cell. The aim of this project is to incorporate antioxidant functionalities into the membrane to protect the polymer from oxidative degradation.

Lorenz Gubler
PSI, Villigen
lorenz.gubler@psi.ch

CHIC – Clean Hydrogen in European Cities / Swiss Hydrogen Filling Station Postauto AG

Hydrogen and fuel cells can play an important role in the reduction of local air pollutants, as well as in the decarbonisation of Europe's transport system. Hydrogen powered transport is currently able to meet the normal operational requirements of buses and light passenger and commercial vehicles. The objective of CHIC is to move these demonstration vehicles towards full commercialization by 2015 (http://chic-project.eu).



Nikoletta Seraidou
Postauto AG, Brugg
nikoletta.seraidou@postauto.ch

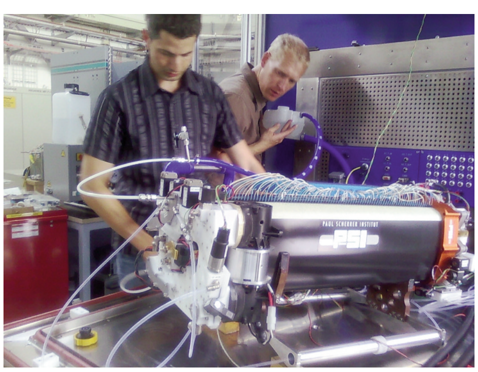
PAUL SCHERRER INSTITUT
PSI

S-Chain Fundamentals (Belenos)

The main project goals are to understand and improve the operation of the polymer electrolyte fuel cells (PEFC) of Belenos by means of numerical simulations and to develop a simulation program tailored to describe the complex S_Chain design and to understand and improve the sub-zero operation by experimental investigation and by modeling of the sub-zero start and operation for H_2/O_2 operation.

Felix Büchi
PSI, Villigen
felix.buechi@psi.ch

PAUL SCHERRER INSTITUT
PSI

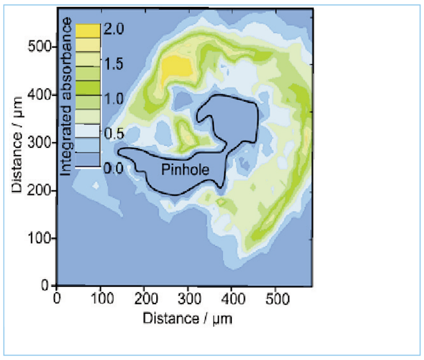


Development of a 25 KW Hydrogen / Oxygen Fuel Cell system

To achieve a competitive component for a fuel cell (FC) driven powertrain for a passenger car the FC-system has to meet several goals, which shall be addressed in the BELENOS CLEAN POWER -Fuel Cell project. The degradation of the FC-system shall be reduced by optimal stack design and a specific operation strategy for a H_2-O_2 FC. The cost issue will be addressed by improving production processes of the components, integration of system components and the development of the concept of an industrial assembly process.

Thomas Schmidt
PSI, Villigen
thomasJustus.schmidt@psi.ch

PAUL SCHERRER INSTITUT
PSI

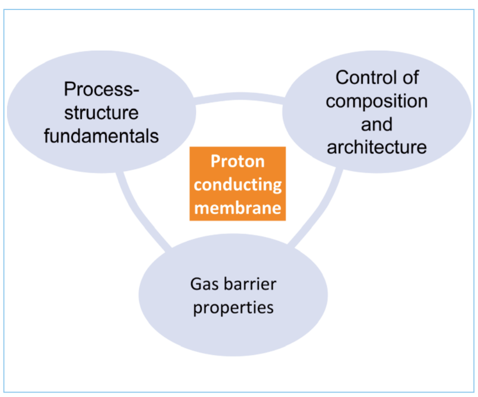


Gas Analysis in PE Fuel Cells

In polymer electrolyte fuel cells reactants are gaseous. Their distribution and permeation through the polymer electrolyte play an important role for the durability and efficiency. In-situ and on-line local gas analysis is an important tool for the understanding of these processes. The method using tracer gases is new and unique.

Felix Büchi
PSI, Villigen
felix.buechi@psi.ch

PAUL SCHERRER INSTITUT



GreenPower: Connecting the renewable energy to green mobility using Hydrogen as energy carrier under the Belenos Clean power Initiative

As part of the developments on-going within Belenos, an issue is the development of adequate membranes for the fuel cells. In this project, the membrane will be based on new materials to enable a cost effective application in an H_2-O_2 fuel cell. These new membranes will be optimized for cost as well as for mechanical and chemical stability. Another issue addressed in this project is the safety related to hydrogen and oxygen storage in a car or at home.

Lorenz Gubler
PSI, EPFL, Villigen
lorenz.gubler@psi.ch

PAUL SCHERRER INSTITUT

PAUL SCHERRER INSTITUT

H_2FC European Infrastructure Project

European Infrastructure addresses the topic INFRA-2011-1.1.16 Research Infrastructures for H_2FC Facilities and the related energy-chains, by bringing together, for the first time in Europe, the leading European R&D institutions of the H_2 community together with those of the fuel cell community, covering the entire life-cycle of H_2FC, i.e. hydrogen production, storage, distribution, and final use in fuel cells (http://www.h2fc.eu/).

Pierre Boillat
PSI, Villigen
pierre.boillat@psi.ch

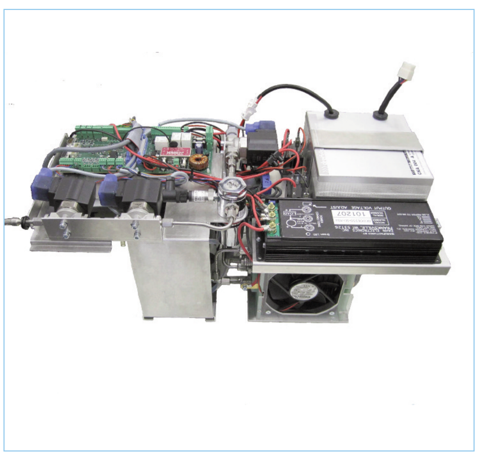
PAUL SCHERRER INSTITUT

Hy.muve – hydrogen driven municipal vehicle

Suitable niche market applications play an important role for the development of the hydrogen based mobility. Within the hy.muve-project, a fuel cell hybrid electric driven road sweeper with 50% energy consumption reduction compared to the diesel hydraulic driven basis vehicle and significant lower noise emissions was developed. The project vehicle is actually operated in a 1.5 year field testing from city cleaning services in 3-4 Swiss cities. (www.empa.ch/hy.muve).

Christian Bach
EMPA, Dübendorf
christian.bach@empa.ch

EMPA
Materials Science & Technology



IHPoS - Independent-Hydrogen-Power-System advanced fuel cell system

The focus of this project is the development of a PEM- fuel cell system with an optimal output power in the range of 250 – 1000 W. The systems are being commercialized by the company CEKAtec AG for niche market applications. The cost-efficient production of the components of the fuel cell stack and a lean system architecture contribute to the development of a competitive product.

Michael Höckel
BFH, Biel
hkm1@bfh.ch

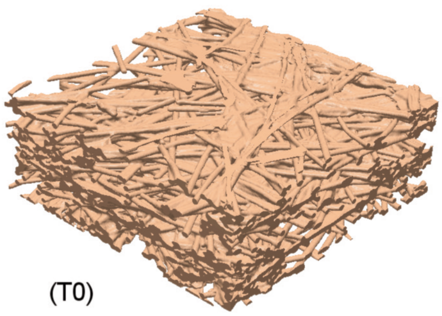
Berner Fachhochschule
Hochschule für Architektur, Bau und Holz

IHPoS-E – Fuel-cell-Minibar

Providing hot and cold food and drinks on trains is a valuable revenue stream for train operating companies. However, the choice of electrical appliances and hence, goods, is limited by today's conventional power sources: batteries. Batteries provide a limited amount of energy and are prone to needing replacing. CEKA's IHPoS-E 500W fuel cell system has already been successfully integrated into a minibar for Swiss trains, providing freshly made coffee and onboard refrigeration.

Marco Santis
CEKAtec, Wattwil
Marco.Santis@ceka.ch

CEKA
CEKAtec AG

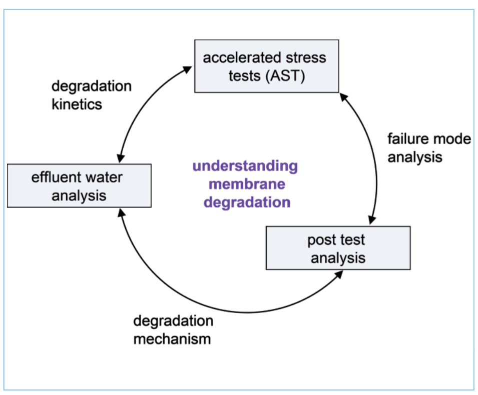


IMPALA - IMprove PEMFC with Advanced water management and gas diffusion Layers for Automotive application

The purpose of the IMPALA project is to manufacture improved GDL to increase performance (up to 1 W/cm²) and durability of PEMFC for automotive applications. Two approaches will be followed: i) Homogeneous GDL will be modified to ensure a better water management on anode and on cathode side. ii) More innovative non uniform GDL will be manufactured to adjust their local properties to the non uniform local operating conditions of a PEMFC.

Felix Büchi
PSI, Villigen
felix.buechi@psi.ch

PAUL SCHERRER INSTITUT

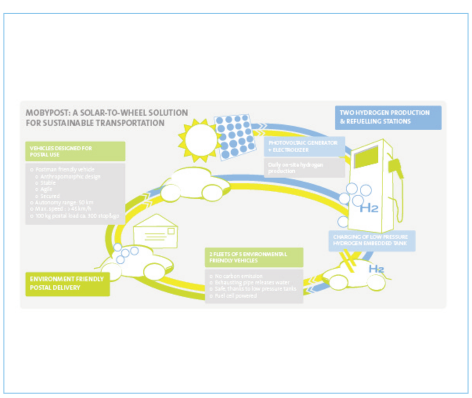


MemDeg

Understanding degradation mechanisms of radiation grafted proton conducting membranes under fuel cell operating conditions.

Lorenz Gubler
PSI, Villigen
lorenz.gubler@psi.ch

PAUL SCHERRER INSTITUT



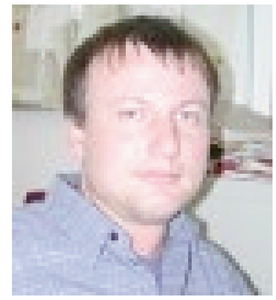
MOBYPOST – Mobility with Hydrogen for Postal Delivery

MobyPost proposes to develop the concept of electric vehicles powered by fuel cells for delivery application and a local hydrogen production and associated refuelling apparatus from a renewable primary energy source, using industrial buildings to produce hydrogen by electrolysis, roofs of the buildings being covered of photovoltaic solar cells able to supply electrolysis. (http://mobypost-project.eu/).

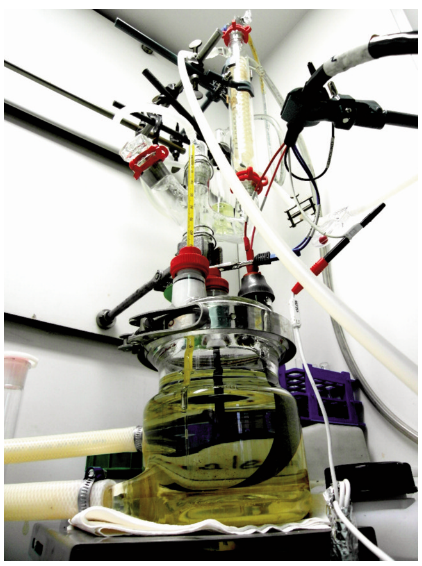
Roberto Bianchi
MES SA, Stabio
r.bianchi@mes.ch

Morphological studies of polymer electrolytes for fuel cell application

Despite the increasing interest in ion-conducting polymer electrolytes, the influence of the molecular composition on the morphology, and the influence of the morphology on the functional properties are far from being understood. Small-angle neutron scattering (SANS) and small-angle X-ray scattering (SAXS) are used to probe the morphology of the fuel cell membranes on the nanometer scale.

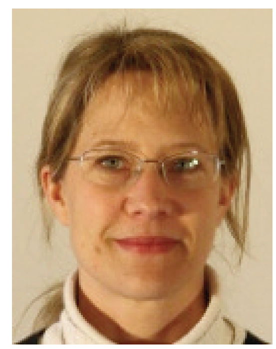


Joachim Kohlbrecher
PSI, Villigen
joachim.kohlbrecher@psi.ch

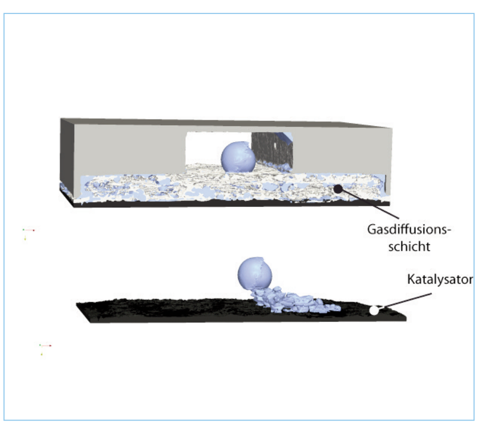


PEMICAN - PEM with Innovative low cost Core for Automotive application

PEMICAN proposes to reduce the Pt loading for automotive application down to 0.15 gram of Pt per kW, by a twofold approach: 1. to increase Pt utilization and power density by improving effective transport properties of ALs by tuning properties of the electrolyte and by adding special carbon blacks in order to improve catalyst, electrolyte distribution and water management; 2. to reduce Pt loading by controlling its distribution.



Marlene Rodlert
Timcal SA, Bodio
m.rodlert@ch.timcal.com



X-Ray Tomographic Microscopy of PE Fuel Cells

Transport processes are of high importance for the optimization of efficiency and durability of polymer electrolyte fuel cells. The understanding of the role of condensed water in the porous gas diffusion layers on the gas transport is therefore of importance. X-ray tomographic microscopy is a powerful tool to investigate and characterize the behavior of liquid water.

Felix Büchi
PSI, Villigen
felix.buechi@psi.ch

OTHER APPLICATIONS

FCPOWEREDRBS - Demonstration Project for Power Supply to Telecom Stations through FC technology

FC and H2 may represent an enabling technology for a wider diffusion of Radio Base Station energized by renewable energy sources. While the expected higher energy efficiency already has an attractive potential for these applications, the energy storage potential of H2 is even more interesting as it could extend significantly the number of hours of unattended operation which very much determines the overall energy cost for these installation.

Gianmario Picciotti
MES SA, Bodio
g.picciotti@mes.ch

MES

FITUP – Fuel cell field test demonstration for portable generators, backup and UPS power system applications

A total of 19 market-ready fuel cell systems from 2 suppliers (ElectroPS, FutureE) will be installed as UPS/ backup power sources in selected sites across the EU. Real-world customers from the telecommunications and hotel industry will utilize these fuel cell-based systems, with power levels in the 1-10kW range, in their sites. These units will demonstrate a level of technical performance that qualifies them for market entry (www.fitup-project.eu).

Ulrike Trachte
Hochschule Luzern /
Swisscom AG / BKPNW
ulrike.trachte@hslu.ch

Lucerne University of Applied Sciences and Arts
HOCHSCHULE LUZERN
FH Zentralschweiz

u b
UNIVERSITÄT BERN

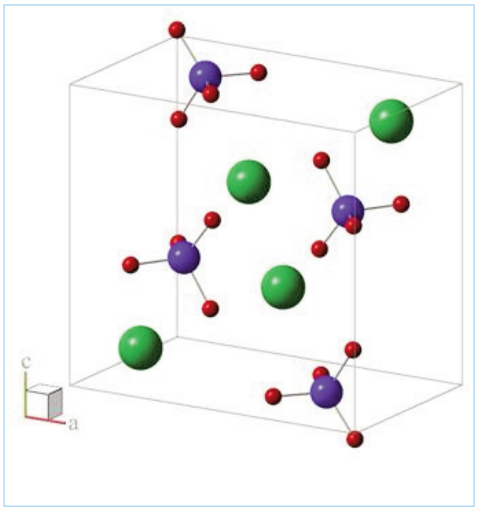
BACWIRE – Bacterial wiring for energy conversion and remediation

The aim of the project is to develop a new paradigm for the simultaneous cogeneration of energy and bioremediation using electro-active bacteria. A new nano-structured transducer that efficiently connects to these bacteria will be developed, aiming to the production of devices with superior performance across a range of applications including microbial fuel cells, whole cell biosensors and bioreactors.

Thomas Wandlowski
Uni Bern, Bern
thomas.wandlowski@dcb.unibe.ch

u b
UNIVERSITÄT BERN

HYDROGEN

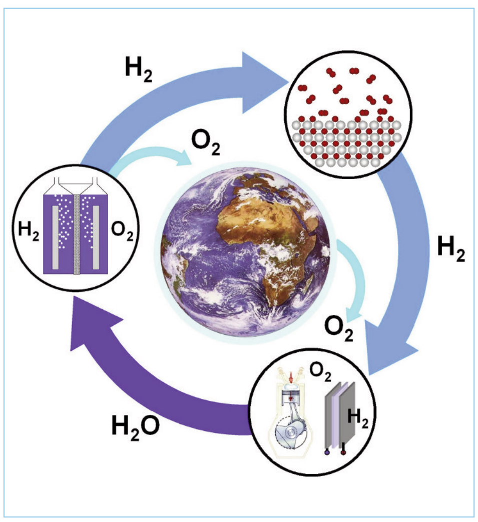


IEA Hydrogen Implementing Agreement – Annex Hydrogen Safety

In recent years, a significant international effort has been initiated to development codes and standards required for the introduction of these new systems. Such codes and standards are usually developed through operating experience in actual use that is accumulated over time. Without such long term experience, there is a tendency for early codes and standards to be more restrictive to ensure that an acceptable level of safety is maintained. One possible effect is to hinder the introduction of hydrogen systems.

Michael Bielmann
EMPA, Dübendorf
michael.bielmann@empa.ch

EMPA
Materials Science & Technology



IEA Hydrogen Implementing Agreement (IEA-HIA)

The International Energy Agency(IEA) Hydrogen Implementing Agreement(HIA) was established in 1977 to pursue collaborative hydrogen research and development and information exchange among its member countries. Through the creation and conduct of some thirty annexes or tasks, the HIA has facilitated and managed a comprehensive range of hydrogen R&D and analysis activities.The HIA is an IEA Implementing Agreement.

Stefan Oberholzer
BFE, Bern
stefan.oberholzer@bfe.admin.ch

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

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

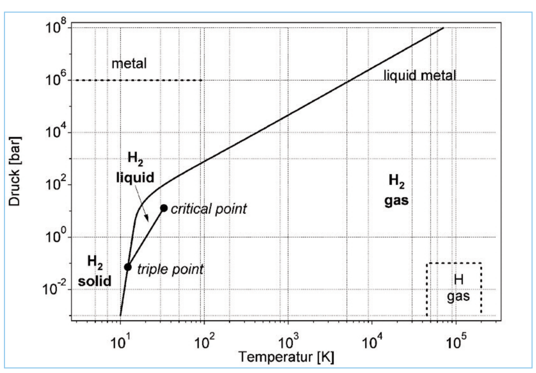


Fig. 1: Primitive phase diagram for hydrogen

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

Temp. [K]	Vapor pressure [kPa]	Density [kg/m^3]		
		ρ_S	ρ_L	ρ_G
1	$11 \cdot 10^{-37}$	89.024		
5	$4.76 \cdot 10^{-3}$	88.965		
10	255.6	88.136		0.006
12	1837	87.532		0.037
13.803[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	822.5		53.930	10.887
32.976[c]	1293			31.43

Tab. 1: Vapor pressure and density of p-hydrogen at low temperatures, [a] Triple point, [b]101.3 kPa, [c]Critical point.

Production of hydrogen worldwide now amounts to about $5 \cdot 10^{10}$ 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 Euro/Ci; deuterium gas is readily available, without permit, at about 10'000 Euro/kg. Heavy water, deuterium oxide (D_2O), which is used as a moderator to slow down neutrons, is available without permit at a cost of 500 Euro/kg, depending on quantity and purity. The price of hydrogen is directly bound to the price of electricity (0.05 €/kWh) and therefore around 2.5 Euro/kg.

Quite apart from isotopes, it has been shown that hydrogen gas under ordinary conditions is a mixture of two kinds of molecules, known as ortho- and para-hydrogen, which differ from one another by the spins of their electrons and nuclei. Normal hydrogen at room temperature contains 25% of the para form and 75% of the ortho form. Consideration is being given to an entire economy based on solar- and nuclear-generated hydrogen. Located in remote regions, power plants would electrolyze sea water: the hydrogen produced would travel to distant cities by pipelines. Pollution-free hydrogen could replace natural gas, gasoline, etc., and could serve as a reducing agent in metallurgy, chemical processing, refining, etc. It could also be used to convert organic waste into methane and ethylene.

	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}]	0.1237	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	1-7.6
Detonability limits in air [vol%]	18.3-59	6.3-13.5		1.1-3.3
Limiting oxygen index [vol%]	5	12.1		11.6^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

Tab. 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 C_1-C_4 and higher hydrocarbons including benzene. ^{c}Based on the properties of n-pentane and benzene. ^{d} Theoretical explosive yields.

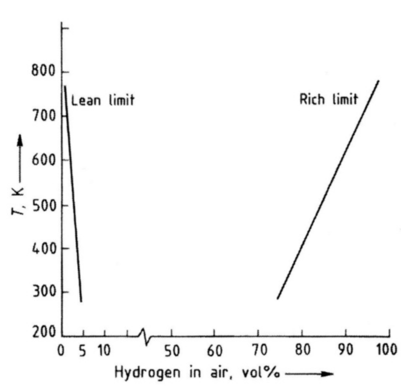


Fig. 2: Effect of temperature on flammability limits of hydrogen in air (pressure 100 kPa).

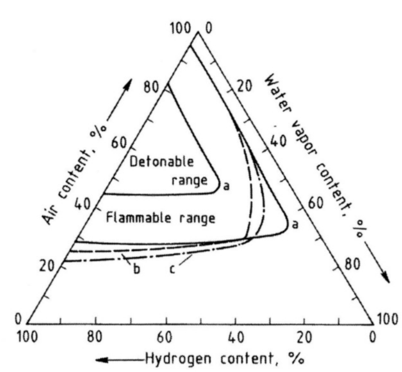
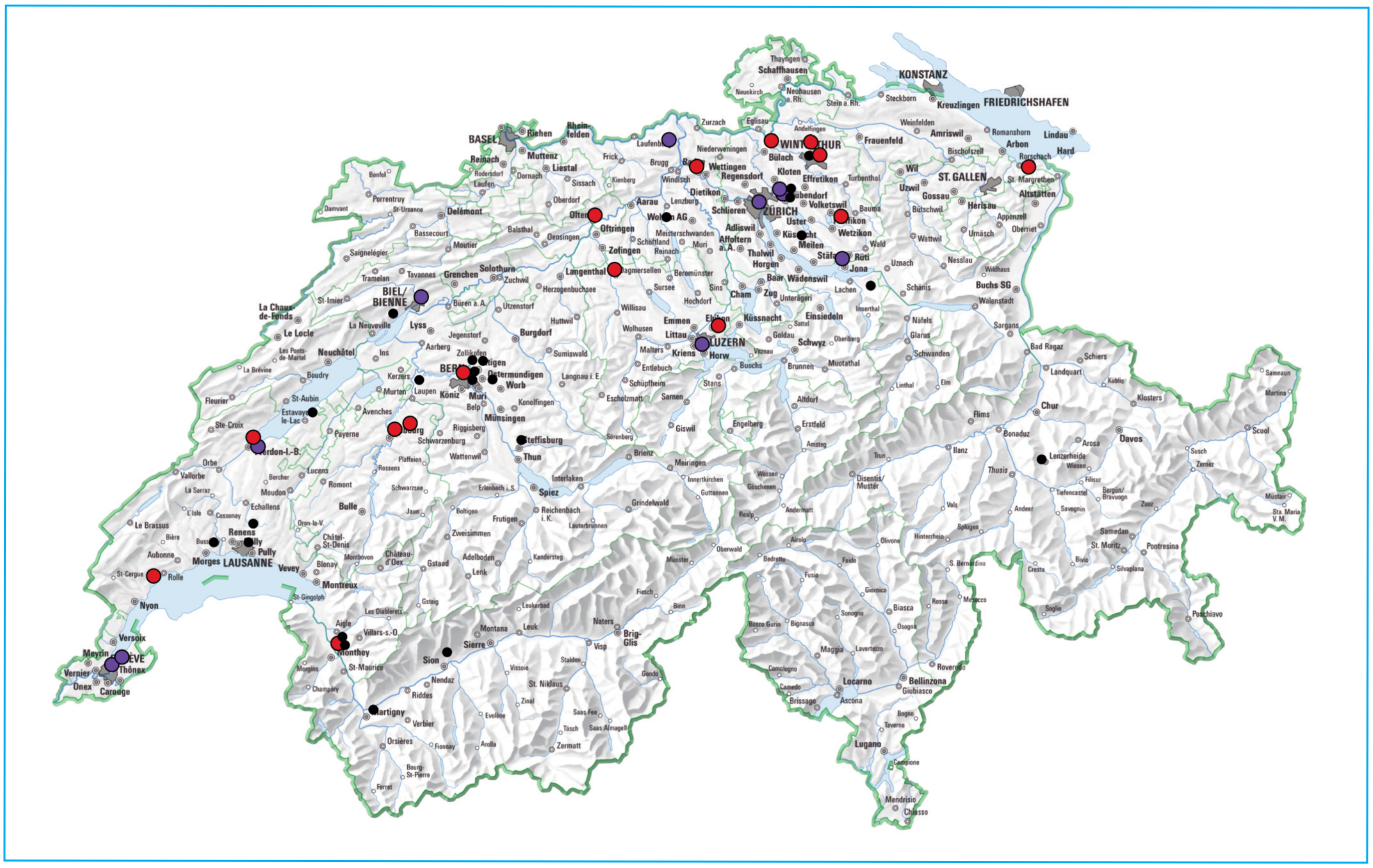


Fig. 3: Flammability and detonability limits of the three component system hydrogen-air-water a) 42°C, 100 kPa; b) 167°C, 100 kPa, c) 167°C, 800 kPa

HYDROPOLE NETWORK



- Industry
- Research and Education
- Individual Members

Industry

CEKA Elektrowerkzeuge AG + CO. KG, Bereich B	Wattwil	www.ceka.ch
Commune de Monthey, Service Industrielle	Monthey 1	www.monthey.ch
Diamond Lite S.A.	Thal	www.diamondlite.com
DJEVAHIRDJIAN H. S.A.	Monthey	www.djeva.ch
European Fuel cell Forum A	Adligenswil	www.efcf.com
H. Bieri Engineering GmbH	Winterthur	www.bieri-ing.ch
Htceramix-SOFCpower	Yverdon-les-B.	www.htceramix.ch
H2 Nitidor	IT-Codogno	www.h2nitidor.it
Industrie Haute Technologie SA	Monthey	www.iht.ch
Linde Kryotechnik AG	Pfungen	www.linde-kryotechnik.ch
Michelin Recherche et Technique SA	Givisiez	www.michelin.ch
NEL Hydrogen AS	NL-Notodden	www.nel-hydrogen.com
Nova Werke AG, Hochdrucktechnik	Effretikon	www.novaswiss.ch
Office de la circulation et de la navigation de FR (OCN)	Fribourg	www.ocn.ch
PostAuto Schweiz AG	Bern	www.postauto.ch
S-ce Simon consulting experts	Zürich	www.s-ce.ch
Science Solutions	Baden	www.sciencesolutions.ch
Swiss Federal Office of Energy (SFOE)	Bern	www.bfe.admin.ch
WEKA AG	Bäretswil	www.weka-ag.ch

Research and Education

Empa, Hydrogen & Energy	Dübendorf	www.empa.ch/h2e
EPFL, Institut des sciences et ingénierie chimiques	Lausanne	www.epfl.ch
Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud (heig-vd)	Yverdon	www.heig-vd.ch
HES-SO/Valais-Wallis	Sion	www.hevs.ch
Hochschule für Technik und Informatik HTI	Biel	www.ti.bfh.ch
Hochschule für Technik+Architektur HTA Luzern	Horw	www.hslu.ch/technik-architektur
novatlantis c/o Competence Center Energy and Mobility CCEM	Villigen	www.novatlantis.ch
Paul Scherrer Institut (PSI)	Villigen	www.psi.ch

Anmeldeformular als Mitglied des Vereins HYDROPOLE

Fax: 058 765 69 22

Mail: info@hydropole.ch

www.hydropole.ch

Verein HYDROPOLE
c/o EMPA Dübendorf
Frau Sara Rebsamen
Überlandstrasse 129
CH-8600 Dübendorf

Zweck des Vereins ist die Förderung der Nutzung von Wasserstoff als Energieträger und Prozesschemikalie sowie die Förderung seiner Gewinnung aus regenerativen Energiequellen, um einen Beitrag zur nachhaltigen Sicherung der natürlichen Lebensgrundlagen und zur Lösung von Energie- und Stoffproblemen zu leisten.

Mitgliederbeiträge:
Einzelmitglieder (nur Privatpersonen): CHF 100.-
Kleinfirmen mit bis zu 5 Mitarbeitern: CHF 200.-
Abteilungen/Gruppen und Firmen mit bis 50 Mitarbeitern: CHF 500.-
Abteilungen/Gruppen und Firmen mit mehr als 50 Mitarbeitern: CHF 1’000.-

Organisation/Abteilung	
Anzahl Mitarbeiter	
Anrede	
Titel	
Vorname	
Name	
Strasse	
PLZ	
Ort	
Land	
Tel.	
Fax	
E-Mail	
Bemerkung	

Datum: Unterschrift:

Wasserstoff Hydrogène Idrogeno Hydrogen
H_2YDROPOLE

Impressum

Layout:	Empa, Sara Rebsamen
Print:	Empa, Swiss Federal Laboratories for Materials Science and Technology
Photos & Figures	Provided by the authors
Printed:	15. 5. 2013

CHF 16.00 / € 10.00 / Yen 1600

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE