Jonathan Lash, President, World Resources Institute, USA, 2003
Hydrogen is, after all, not a source of energy, but a clean and technically attractive means of transporting it.

Cyrus Harding in the novel “The Mysterious Island” by Jules Verne, 1876
Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable.

Duncan Macleod, Vice President Shell Hydrogen, 2006
After all, new energy infrastructures will develop from clusters and hydrogen is particularly efficient in urban areas; and these relatively low infrastructure investments will not only bring clean mobility, but clean energy as well. In fact, in 20 years time, the same amount of primary energy may transport someone over twice the distance, but with a significantly reduced environmental footprint.

Janez Potočnik, EU-Commissioner for Science and Research, 2006
When applied “intelligently”, hydrogen and fuel cells have outstanding environmental and economic potential.

Dieter Zetsche, CEO DaimlerChrysler, 2006
I believe it is realistic to assume that vehicles will be fitted with fuel cells in five to ten years time.

Footnote on British Petroleum's webpage, 2006
Hydrogen has the potential to be used in most applications where other fuels are used today.
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Switzerland is one big hydrogen cluster. Industry and research are spread across the most important industrial regions of the country.
Dear Readers

Hydrogen is a magic word. And rightly so: Hydrogen fuel cells have the ingenious potential to provide intelligent and virtually emission-free energy solutions. The vision of a hydrogen society already exists. It has the capacity to lead us out of our dependence on non-renewable energy carriers such as oil and uranium. The road to attaining that independence, however, is long. How come? While interesting and even successful hydrogen applications already exist – particularly in automotive technology – we have yet to meet one key challenge: How can the efficient, cost-effective, and resourceful production of hydrogen be guaranteed independently of non-renewable energy carriers? This is the challenge facing the next generation of scientists, particularly in Switzerland.

Hydrogen is the perfect match for the Swiss energy research programme. Based on three cornerstones – security, economy, environment – the programme aims at a sustainable 2000-Watt society. Declining fossil fuel reserves, subsequent high energy prices, and the challenges posed by climate change all place renewable energies at the centre of interest. Together with renewable energy carriers and highly efficient technologies, using hydrogen might be our chance to bridge a gap in the energy chain supply in a resourceful and ecological manner. Since road traffic accounts for 35% of current energy consumption in Switzerland, clean mobility has become a priority issue. If we do need road traffic, then we should strive for carbon-free and low-emission fuels. Various Swiss universities and universities of applied sciences are currently developing components, or even overall solutions, for clean vehicles. Several prototypes have already been developed and demonstrated in Switzerland. Among others, these include the SAM (developed at the University of Applied Sciences Bern), the HYDROXY-boats (developed at the University of Applied Sciences Western Switzerland), the PSI’s cooperation projects HY.POWER and Hy-Light, and the PacCars (developed at the Swiss Federal Institute of Technology in Zurich).

Switzerland has even more to offer beyond providing sustainable mobility concepts, solutions, and products. Through successful private-public partnerships, Switzerland has given itself such innovative force that we now also hold the technological key to a sustainable future in other areas of a future hydrogen-based economy.

This report provides an overview of the achievements of the Swiss hydrogen community in terms of key facts and figures as well as its innovations, core research areas, and ongoing initiatives. There are still many lone warriors and pioneers out there toiling away single-handedly. Together, and under the umbrella of this report, they form part of the bedrock to promote Switzerland as a leader and driving force in the field of new energy carriers. We need to make the best possible use of this advantageous position to conduct the research and development still required to build the foundation for cost-effective, ecological, and social sustainability to the point of market maturity, and subsequent market launch!

The Swiss Federal Office of Energy is looking forward to continuing its 30-year pioneering role as Switzerland’s prime coordinator and funding body of hydrogen R&D activities.

Michael Kaufmann, Vice-Director Swiss Federal Office of Energy (SFOE),
Programme Manager SwissEnergy (EnergieSchweiz)
NETWORKS Swiss research and development efforts leading towards realising the vision of the hydrogen economy are very strong. Switzerland is well-poised to undertake the required innovation on account of its first-class research environment and excellent cooperation between universities and industry.

Switzerland's first commercial hydrogen producer started operation in 1898. Although this historic event does not yet make the country an unrivalled place for hydrogen, the continuing efforts of the private sector have led to long-standing sustainable and well-proven experience in dealing with hydrogen. Today, the chemical and petrochemical industry, as well as various other sectors of the Swiss economy, are experts in the hydrogen supply chain. One of the exceptional examples of Switzerland's hydrogen-based industry is Hrand Djehahirdjian SA, the world's leading producer of synthetic crystals. Located in the Valais close to the Lake of Geneva, this company has 90 years experience in the large-scale production, storage, and combustion of hydrogen. Notwithstanding the economic relevance of the traditional uses of hydrogen, the potential of hydrogen in future energy applications is far more decisive. The disrupting potential of commercially competitive hydrogen as an energy vector in future energy markets is beyond dispute. It is also unchallenged that hydrogen is presently still far from being an economically viable competitor. Therefore, the research and development efforts leading towards translating the vision of the hydrogen economy into effect should not be underestimated. On account of its superior research environment, marked by cutting-edge competence in material science, electrical and mechanical engineering, and system integration, Switzerland is an excellent place to achieve the required innovation!

BASIC PREMISES

Committed to sustainable development and currently importing more than 70% of its energy consumption, Switzerland has political, economic, social, and environmental reasons for investigating alternative energy paths. With its world-renowned universities and research institutions, combined with a skilled workforce and many technical colleges and universities of applied sciences, Switzerland invests almost 3% of its GDP to sustain its position as a world leader in R&D. According to an OECD study in 2001, Switzerland ranks first when it comes to innovation and entrepreneurship. This is essentially the merit of a well-developed and competitive private sector. While basic research is funded mainly by the public sector, three quarters of the funding for development comes from the private sector. Such public-private cooperation makes Switzerland a prime location for technology and innovation.

OUTSTANDING SCIENTIFIC REPUTATION

Switzerland is a country with intensive research activities. Switzerland's success in research and development is supported by various cutting-edge industries. The combination of sectors like general machinery, micromechanics, aerospace, biotechnology, medical equipment, pharmaceuticals, chemicals, postal services and telecommunications, finance and insurance, and general business services furnishes an excellent basis to develop or acquire new skills and technologies in order to be well-positioned for future challenges. Swiss academic institutions enjoy an outstanding scientific reputation throughout the world with regard to basic and applied research. This reputation is largely the result of substantial cooperation between universities and industry. Universities and technical colleges are located all over Switzerland and, given geographical topology, define an axis that runs along the line Geneva-Bern-Zurich. The two Federal Institutes of Technology (ETHZ and EPFL) are known worldwide and have brought forth many Nobel Prize laureates. In addition to the federal institutes, Switzerland's cantonal universities also have excellent reputations on account of their high-quality research.
Education has always been an overriding priority in Switzerland, as evidenced by an outstanding level of resources allocated to Swiss schools, universities, and technical institutes. Science and technology are strongly promoted by the federal government and by private industry, encouraging research and development projects in all areas of advanced science. Switzerland’s unique dual education and training system provides a vast range of educational options, from vocational training and apprenticeships to university-level courses, thereby producing a well-qualified workforce at all levels. On account of Switzerland’s high quality education system and its multicultural society, a large part of the population is fluent in several languages. As the workforce is generally highly motivated, Switzerland ranks fifth among the world’s leading national economies with respect to overall productivity.

**WELL-DEVELOPED NETWORKS**

Switzerland also has other advantages. Its size has enabled well-developed networks between the various fields of expertise in research, development, and industry. The Swiss Commission for Technology and Innovation (CTI) is responsible for promoting collaboration between public-funded research and industry. Cooperation and synergies on the cantonal, national, and international levels make Switzerland an almost ideal place to identify solutions designed to develop products to market maturity. Switzerland’s location in the heart of Europe is another advantage. Situated at the nexus of European technologies and cultures, Switzerland is equidistant between America and Asia. Close ties with the EU assure direct links to European science and innovation programmes. Bilateral contracts with the EU provide Swiss-based companies with excellent market access to more than 450 million consumers. And last but not least, Switzerland has an almost ideal size – and spirit – to qualify as a pilot market in which manufacturers can analyse market response to new products.

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**HYDROPOLE IS…**

…the focal point for all hydrogen-related matters in Switzerland. HYDROPOLE is a knowledge and information cluster focused on all aspects of the past, present, and future use of hydrogen. HYDROPOLE serves as a platform for research, development, industry, and other public or private organisations. HYDROPOLE fosters knowledge of hydrogen and its application in the energy sector by providing information to the general public, the educational sector, developing industry as well as for policy needs. The association maintains close links with other hydrogen associations in Europe and worldwide.

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For further information please visit [www.hydropole.ch](http://www.hydropole.ch)
IHT INDUSTRIE HAUTE TECHNOLOGIE SA

Based in Monthey in western Switzerland, IHT designs and manufactures high-pressure electrolyzers, atmospheric electrolyzers, hydrogen and oxygen storage tanks, and all components that build up a complete hydrogen generation plant.

IHT’s engineering group, often in partnership with universities and technical colleges, provides clients with modern global hydrogen solutions based on the electrochemical process of electrolysis, a totally pollution-free hydrogen generation process. IHT realizes this process using two different technologies: the first (in the field of high pressure electrolysis) was licensed in the 1950s by Professor Zdanski on behalf of Lonza; the second (in the field of atmospheric electrolysis) was developed by the German company Bamag. Over the years, the intellectual property of these technologies has changed many times, from Lonza to Lurgi in Germany, which Bamag became affiliated to later.

While the electrolyser market has seen many changes over the last decades, the factory in Monthey, belonging first to Giovanola Freres SA, then to GTec SA, and since 2003 to IHT, has been the only manufacturing place for high-pressure electrolyzers for almost sixty years. Each machine tool has been designed for special fabrication purposes, including mechanical operations as well as chemical and heating treatments.

Recently overhauled, this equipment has been used for the production of more than sixty thousand electrolysis cells shipped to clients all over the world, for the smallest atmospheric electrolyser as well as for the largest high pressure electrolyzer unit producing 760Nm3/hr at 32 bars. With one of the largest ranges of electrolyzers worldwide, IHT is an important partner for anyone requiring hydrogen generators, from small private applications to large industrial consumers. IHT’s traditional clients include large fertilizer producers, food industries, high-technology powder applications, production of high purity crystal, and power plants using hydrogen as a cooling medium. In future, this client base will expand to include petrochemical groups active in the gas business, hydrogen car manufacturers (fuel cell coupling), energy storage systems operators (in particular in the field of renewable energy sources), and general domestic applications. The growing interest of these new potential customers in hydrogen obtained by means of electrolysis is largely motivated by the constant price increase of fossil energies like natural gas and petrol. In addition, environmental protection regulations are becoming more and more restrictive worldwide, and are mainly oriented to non-pollutant sources of hydrogen.

IHT INDUSTRIE HAUTE TECHNOLOGIE SA...

...provides a highly demanding spare parts market with state-of-the-art applications. Pursuant to our HTLC philosophy, we have implemented an ambitious research and development programme to design “High Technology at Low Cost” electrolyzers to meet the infrastructure requirements of the third millennium energy market.
From Research into Practice

NOVATLANTIS Founded by several research institutes, Novatlantis has embarked on a route unparalleled in Switzerland: It takes the latest insights and findings of the research conducted within the domain of the Swiss Federal Institute of Technology (ETH), and applies these to promote sustainable development in Switzerland.

What does a sustainable future look like? Novatlantis attempts to answer this question on the basis of practical examples. Researchers and scientists based at the ETH domain initiate joint transdisciplinary projects to this end. In partnership with government bodies and enterprises, Novatlantis undertakes projects designed to consider the societal and technical aspects of sustainability. Novatlantis projects are forward-looking, cost-effective, and environment-friendly. Novatlantis aims at promoting a life worth living for future generations, a high standard of living and comfort due to the latest technology, material and intellectual development for all through economic prosperity, and an intact environment through the considerate use of resources and closed material cycles.

Novatlantis cooperates closely with the competence centres based at the Swiss Federal Institute of Technology, as illustrated by the following example of CCEM (Competence Centre Energy and Mobility):

Through such close cooperation, Novatlantis promotes the transfer of findings from the competence centres and research institutes located within the ETH domain to assure their socially relevant implementation; it also strives to convey these findings to the general public, particularly to decision-makers in business, government bodies, and politics. Novatlantis allocates so-called seed-money and acquires external funding for select research and implementation projects to enhance and accelerate transfer by way of pilot and demonstration projects. Moreover, Novatlantis assimilates information on evolving market and societal needs, and passes this on to the designated units within the ETH domain.

Contacts with industry are established directly via the competence centres. On the one hand, these provide industry with important know-how and basic research; on the other hand, industry provides research with the required technology. Industry does not as a rule enter into direct contact with Novatlantis, other than to allocate external funding to specific pilot projects or for sponsoring purposes.

For further information please visit www.novatlantis.ch

Distribution of roles between Novatlantis and the ETH-Competence Centres

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For further information please visit www.novatlantis.ch
COMPETENCE CENTRES Over the past 25 years, numerous research groups all over the country have developed competence in hydrogen production, hydrogen storage, hydrogen fuel cells, and hydrogen-based applications.

Hydrogen production by electrolysis from electricity and water has been developed for more than 30 years. The world’s largest electrolysis plant, manufactured by BBC and installed at the Assuan-Barrage, has an installed power of 156 MWel. Djeva S.A. in Monthey (VS) applies two 4 MW electrolysers with renewable energy from a hydropower station for the production of synthetic crystals together with a large pressurized hydrogen and oxygen storage system.

HYDROGEN PRODUCTION

Pressure electrolysers ranging from 30 to 200 bar in a power range spanning a few kW to several MW are developed by two companies: AccaGen manufactures electrolysers based on proton exchange membranes while IHT develops and produces electrolysers based on a diaphragm. Research on the production of hydrogen by photoelectrolysis is carried out at the University of Geneva and at the Swiss Federal Institute of Technology in Lausanne. High temperature water electrolysis for hydrogen production is investigated at Empa by means of an inverted solid oxide fuel cell. At PSI and at the Swiss Federal Institute of Technology in Zurich, indirect hydrogen production from zinc and water is investigated, whereby the zinc oxide is recycled and reduced to metal in a solar concentrator.

HYDROGEN STORAGE

Hydrogen storage is often considered the bottleneck of the hydrogen economy. Conventional hydrogen storage is based on pressurized hydrogen gas or liquid hydrogen in cryogenic tanks. Research focuses mainly on solid hydrogen storage in hydrides, a method which offers a volumetric hydrogen density of up to twice the density of liquid hydrogen. Profound experience on the structures of new hydrides has been gained at the University of Geneva in the last twenty years. The interaction of hydrogen with metallic surfaces, bulk metals, and nanostructures has been investigated at the University of Fribourg since 1989, and has led to the foundation of the new Hydrogen & Energy section at Empa Materials Science and Technology in Dübendorf. Diffusion barriers for high pressure hydrogen vessels are developed and investigated at the University of Applied Sciences in Geneva.

FUEL CELLS

Fuel cell research in Switzerland focuses on proton exchange membranes (PEM) for low temperature reactions of hydrogen with oxygen, and on solid oxide electrolytes (SOFC) for high temperature reactions of methane with oxygen. Research on the electrochemistry of the fuel cell, including membranes, catalysis at the electrodes stack, innovation with bipolar plates and design of complete fuel cell systems, has been conducted at the General Energy Research Unit (ENE) of the Paul Scherrer Institute (PSI) for over ten years. Fluid dynamics and current density distribution of graphite electrodes for PEM fuel cells has been investigated and optimized by the energy systems research group at the University of Applied Sciences in Biel. Research groups at ETHZ and at Empa, together with various industrial partners (for example, HTCeramics and Hexis AG), have developed new high performance solid electrolytes for high temperature solid oxide fuel cells. Furthermore, industrial development of SOFC has already reached small-scale production.

APPLICATIONS OF HYDROGEN

Applications of hydrogen as an energy carrier and mobility based on fuel cell propulsion have been shown in the past in numerous demonstration projects. In 2002, a joint PSI-Volkswagen project converted a VW Bora into a PEM fuel
cell car equipped with a pressurized hydrogen tank. In 2005, a joint PSI-Michelin project demonstrated the Hy-Light Car, a fuel cell powered lightweight vehicle equipped with hydrogen and oxygen pressure gas tanks. The ETHZ has developed and demonstrated hydrogen powered vehicles called PAC-Car I and II with an energy consumption as low as 15g hydrogen per 100km. A fuel cell powered lightweight 3-wheel car (SAM), fitted with metal hydride hydrogen storage technology from the University of Fribourg, has been developed at the HTI in Biel. The engineering school in Yverdon has constructed and tested a fuel cell powered boat (Hydroxy 3000) on the Lake of Neuchatel. These applications have been based on PSI stacks. The ETH Board is currently establishing a Competence Centre for Energy and Mobility (CEC-M-CH). The new centre pools the research competence of several Swiss technical universities and research institutes, namely PSI, both Swiss Federal Institutes of Technology (ETH Zurich and EPF Lausanne), Empa, and the University of Applied Sciences Aargau, Northwestern Switzerland (FHNW). With the involvement of industrial partners, the centre will provide a nationwide focus for energy research and development.

**SELECTED PROJECTS**

- **Solar hydrogen production**
  Solar thermochemical reactors for the production of hydrogen make use of concentrated solar radiation as the energy source of high-temperature process heat. Considered are watersplitting thermochemical cycles based on Zn/ZnO redox reactions, and reforming/gasification/decomposition processes for the thermal decarbonization of fossil fuels. Contact Prof Dr Aldo Steinfeld, ETH Zurich, aldo.steinfeld@eth.ch, [www.pre.ethz.ch](http://www.pre.ethz.ch)

- **Photoelectrolysis**
  Grätzel’s solar cells produce energy by absorbing light and storing it inside the highly porous organic layers for conversion to energy. Aspects of the technology are being licensed to a growing number of companies throughout the world. Contact Prof Dr Michael Grätzel, EPFL Lausanne, michael.graetzel@epfl.ch, [http://isic2.epfl.ch](http://isic2.epfl.ch)

- **Hydrogen in solids**
  Research activities focus on (1) the interaction of hydrogen with materials, including metals, complexes, and carbon; (2) the synthesis, structure, and properties of nanomaterials; (3) the interaction of gases with metallic and nonmetallic surfaces; (4) hydrogen density and charge density in host metals; (5) hydrogen-induced metal-insulator transition; (6) theoretical modelling of hydrides. Contact Prof Dr Andreas Züttel, Empa Dübendorf, andreas.zuettel@empa.ch, [www.empa.ch/H2E](http://www.empa.ch/H2E)

- **Structure of hydrides**
  Structural and spectroscopic studies of hydrides and transition metal hydrides. Contact Prof Dr Klaus Yvon, University of Geneva, klaus.yvon@cryst.unige.ch, [www.unige.ch](http://www.unige.ch)

- **Proton exchange membrane fuel cells**
  The fuel cells and fuel cell systems groups are a collaborative effort of electrochemists and engineers at the PSI Laboratory for Electrochemistry. Current research focuses on various aspects of Polymer Electrolyte Fuel Cells (PEFC), including components, fuel cell stacks, fuel cell systems, in situ diagnostics, and modelling. Contact Dr Günther G. Scherrer, Dr Felix N. Büchi, PSI Villigen, felix.buechi@psi.ch, guenther.scherrer@psi.ch, [ecl.web.psi.ch](http://ecl.web.psi.ch)

- **Solid oxide fuel cells**
  The “Ceramic Materials for Energy Technology” research group focuses on fuel cells (SOFC), high temperature electrolysis (SOEC), and proton conducting materials and mixed conductors (MIEC). Contact Dr Ulrich Vogt, Empa Dübendorf, ulrich.vogt@empa.ch, [www.empa.ch](http://www.empa.ch)

- **Fuel Cell SAM**
  Development of fuel cell powered car, system integration, and thermal management. Contact Prof Michael Höckel, BFH-HTI Biel, hkm1@bfh.ch, [www.hti.bfh.ch](http://www.hti.bfh.ch)

- **PAC-Car**
  PAC-Car II is a joint project of ETH Zurich with various university and industry partners. The aim was to build a vehicle powered by a fuel cell system that uses as little fuel as possible. PAC Car II set a new world record in fuel efficient driving during the Shell Eco-marathon in Ladoux (France) on 26 June 2005. Contact Prof Lino Guzzella, ETH Zurich, guzzella@imrt.mavt.ethz.ch, [www.paccar.ethz.ch](http://www.paccar.ethz.ch)
PanGas has been involved in hydrogen technology ever since the company was founded. What has changed in all these years? Reiner Schiffbauer: A lot! Back in 1898, PanGas began by operating an electrolysis plant capable of producing less than one cubic metre of hydrogen per hour. By comparison, today’s plants extract several thousand cubic metres per hour. Hydrogen liquefaction has made a significant difference to enhancing transportation efficiency. Liquefaction makes it possible to transport ten times more hydrogen in a 40 ton lorry than in a licensed pressure gas trailer. The development of hydrogen applications also resembles a journey through time: Initially, hydrogen was used chiefly to lift balloons and zeppelins before helium was discovered. In the early twentieth century, hydrogen revolutionized welding technology until it was replaced by acetylene. After the Second World War, hydrogen became increasingly important in the expanding chemical industries. Currently, hydrogen is still a niche product amongst energy carriers, even though we foresee a promising future.

Where does the greatest hydrogen potential lie? Reiner Schiffbauer: Currently, its greatest potential lies in crude oil processing, metallurgy, and in the chemical industries. Other applications are less significant. Even aerospace, where liquid hydrogen is used to power rockets, is negligible on balance. Should hydrogen-powered fuel concepts break through, this could well change.

Is Switzerland equipped to become the leading nation in hydrogen as an alternative energy carrier?
Reiner Schiffbauer: What is certainly true, is that there are too many single-handed efforts to develop full-scale hydrogen-based power concepts. I have the greatest respect for all these endeavours, but a hydrogen-based economy, including vehicles, is an extremely complex matter to say the least. There is a tremendous danger of getting bogged down in resolving the gargantuan number of small-scale problems, to the extent that the final result becomes secondary or unaffordable. It would be more efficient to commit to a division of labour with a view to undertaking the professional and pragmatic development of single, world-class components. If this is recognised in good time and implemented, Switzerland will have all it takes to assume a driving force in promoting hydrogen as an alternative energy carrier.

Robert Trotta, Electric Vehicles, Fuel Cell and Components Sales Manager, MesDea

“Switzerland is very active in the field of hydrogen.”

MesDea was founded in 1999. It specialises in electric vehicles and fuel cells. In 2002, MesDea patented a hydrogen battery technology and constructed a hydrogen generation station powered by solar energy.
Why did MesDea decide to expand its business into the field of hydrogen?

Roberto Trombetta: Because we wanted to study and develop alternative energy technologies conducive to reducing air pollution, especially regarding urban traffic conditions. For this reason, MesDea became the owner of the ZEBRA battery technology patents and since 2002 of the PEM fuel cell technology developed by Novars.

Our interest to enter the field of hydrogen has also led us to develop a hydrogen generation station powered by solar energy. Moreover, MesDea is involved in developing and manufacturing medium power (0.3 up to 6.0 kW) Proton Exchange Membrane (PEM) fuel cells. The main characteristic of MesDea technology is its high power density (W/kg), allowing us to save more space than other technologies.

How do you rate Switzerland as an innovation place in the field of hydrogen?

Roberto Trombetta: In my opinion, Switzerland is very active in this area. There is a lot of interesting technology development and many operators are not only working on, or manufacturing, fuel cells, but they are also exploring system integrators, combining the most effective and most efficient technology for a given hydrogen application.

Compared with other new energy resources, how do you rate hydrogen and its different fields of application?

Roberto Trombetta: A lot of work has to be done to further develop the hydrogen supply chain; furthermore, compared with other alternative energy sources, the main issues are cost and „fuel“ availability. These two issues are directly linked. As a matter of fact, the technology required to produce hydrogen needs further development to increase efficiency, and hence to reduce costs.

HANS BIERI,
CEO BIERI ENGINEERING GMBH

H. Bieri Engineering designs, calculates, and produces components and plants for very different applications. Based on thirty years experience, it has been developing innovative solutions for hydrogen applications since 2002.

What exactly does your company do and why are you active in the field of hydrogen?

Hans Bieri: We have been concerned with hydrogen for thirty years because it will be the most important form of energy in the future alongside natural gas. We focus on building extreme-temperature containers and heat exchange vessels to contend with extreme pressure and to meet the highest impermeability, safety, and precision requirements. We develop both small and large-size containers for gas-like and liquid hydrogen. We also specialize in hydrogen reactors, heat exchange systems for lowest to highest pressures and temperatures, level measurement probes, liquid gas pumps, Stirling refrigerating machines (80K), or other special, bespoke plants.

How do you as a start-up rate Switzerland?

Hans Bieri: We are based in Winterthur where we can draw on substantial technical know-how, well-trained and well-qualified staff, and on an advanced manufacturing pool. Our location in Switzerland grants us good access to the international markets.

Where do you procure your ideas for innovations?

Hans Bieri: Since my days in farming, I have endorsed the belief that I need to produce what society needs, both tomorrow and long-term. We as engineers are challenged to find new solutions. If we commit ourselves to these tasks and can identify solutions, we will be able to motivate the younger generation to help shape the future. We can thus promote our greatest potential.
UNIVERSITIES OF APPLIED SCIENCES This article gives an overview of research and development activities in the fuel cell stacks and systems of the Swiss Universities of Applied Sciences.

The fuel cell group at the Bern University of Applied Sciences in Biel (HTI) is specialized in developing new fuel cell designs for water and air-cooled PEM-fuel cell stacks. While writing this article, the HTI is developing an air-cooled fuel cell stack designed for cheap production together with its industrial partner CEKA (see box page 15) Further projects are being conducted in the field of integrating PEM-fuel cell systems in portable or mobile applications. In 2005, the HTI’s three-wheel fuel cell car SAM was road tested. The results were very satisfying: Low consumption (about 450 g H2 / 100 km) and a range of 130 km, which seems very interesting for a lightweight electric vehicle. A further typical project with an industrial partner is the fuel cell trailer. This trailer is fitted with a fuel cell power supply, providing an electrical ac power of maximal 1000 W for a duration of 8 hours.

The Centre for Computational Physics (CCP) located at the Zurich University of Applied Sciences in Winterthur (ZHW) has been working on the modelling and simulation of different types of fuel cells for almost ten years. In the field of high temperature fuel cells (SOFC), it collaborates closely with Hexis AG (formerly Sulzer Hexis AG), Winterthur, to develop a stationary 1 kW cogeneration system for single households. Based on the inhouse multiphysics finite element (FE) code NM Seses (see http://ccp.zhwin.ch/seses/ for details), scientists have been applying a variety of FE-models to different optimization tasks in the field of 2D and 3D thermal flow modelling. In the field of low temperature fuel cells, a computationally efficient PEM fuel cell model is currently being developed together with the Paul Scherrer Institute (PSI) in Villigen. The model describes the most important transport processes that are present in PEM fuel cells. Both the cathode and anode domains are described by two-dimensional submodels. These submodels are coupled by a one-dimensional model describing the gas diffusion layers, the electrodes, and the proton conducting membrane. Furthermore, the ZHW is associated with a German research network working on the mathematical description of scale transitions in the field of proton exchange membrane fuel cells.

The University of Applied Sciences of Central Switzerland (HTA Lucerne School of Engineering and Architecture) is specialised in fuel cell systems. One realised project is a “PEM Fuel Cell Back-Up System”. In this project, the lead-batteries of an Uninterruptible Power Supply System (UPS) for a telecommunication installation are replaced by a PEM fuel cell system. Following the design and construction phase, the products are now undergoing field tests with monthly grid failure simulations. To date, researchers have made very good experiences with the reliability and performance of the system. Two industrial partners – producers and users of UPS-Systems – are involved in the project. The HTA Lucerne is engaged in further projects exploring the concrete application and system integration of fuel cells.

The University of Applied Sciences of Western Switzerland in Yverdon (HEIG-VD) focuses on the development, integration, and adaptation of FC systems for mobility and cogeneration. Through numerous FC projects conducted since 1997, the Institute of Energy and Electrical Systems (IESE) has acquired expertise in the field, and has developed particular skills in navigation applications. Following the early development of a one-seated boat propelled by a 100 W PEMFC (Hydroxy100) in 1998, a two-seater trimaran, designed for a 300 W PEMFC, was realised in 1999. The crew crossed the Atlantic with a 300 W PEMFC as APU on a racing sailboat in the “Course du Rhum 02”. Developers are currently testing the third generation boat, the “Hydroxy3000” (see http://iese.heig-vd.ch), prefiguring the motorized boat of the future for family leisure on lakes and canals. This boat, propelled by a 3 kW PEMFC, is intended for 7 passengers and a speed of 12
km/h. The institute owns several FC, from 50 to 3000 W, of different technologies. An electrolyser, fed by PV panels, is also used as a prototype for future projects.

Within its fuel cell research activities, the University of Applied Sciences Valais (HEVS Sion) is currently examining the integration of a converter that is especially adapted to the specifications of several PEMFC-type and methanol fuel cells. This 3 kW triphasic converter with an additional monophasic phase to feed the accessories is currently being tested in an industrial cogeneration plant.

The school's test benches allow us to characterise every new cell type under real conditions, in particular according to climatic conditions, and to integrate them optimally into any new type of application. Every application is managed by an automaton that ensures the complete integration of every examined system.
WEKA AG Based near Zurich, Weka is the leading manufacturer in the field of valves and components servicing cryogenic processes. With about 60 employees, it is able to respond very fast and flexibly to changing customer needs.

Weka’s products are mainly used with gaseous or liquefied fluids like helium, hydrogen, nitrogen, argon, or oxygen\(^*1\)). Temperatures down to nearly the absolute zero point\(^*2\)) are common. Cryogenics is basically a thermo-physical process with a warm and cold side. The cryogenic fluid will undergo compression, heat exchange, and expansion to either cool down or warm up. Due to the extreme physical properties of both temperature and pressure, highly specific technical requirements are imperative. Weka Cryogenic Components are used in the whole cryogenic cycle process on the cold and warm side.

Weka’s customers are located worldwide. The main users are active in high energy physics, plasma physics, aerospace research, and fusion power research. Typical applications include the cooling of superconducting magnets, cables or acceleration cavities to attain higher research performance. Helium is mostly used as cryogen. Liquefied argon is used in particle detectors for high energy physics. Nitrogen will also be used as a cryogenic fluid for so-called new high-temperature superconductors. Demonstration projects with real applications for high load power cables are in service.

Since the beginning of Weka’s cryogenic activities in the 1970s, its components have also been used in hydrogen and oxygen liquefaction plants. At the time, typical applications could be found in the aerospace industry, such as in fuel for high-performance rocket engines. Furthermore, cryogenic distillation processes were used to separate tritium and deuterium (the radiation emitting isotopes of hydrogen) to clean the fission cycle in nuclear power plants. The semiconductor industry also requires the purest hydrogen, which only can be produced by cryogenic technology. Nowadays, more and more hydrogen is used as a fuel cell propellant. Fuel cells have a large potential for future power supply and demonstration cars using this new technology are already on the road. Power cells may also become more and more important as a power supply in stationary applications. In the wake of these developments, hydrogen is now considered the ideal energy storage and energy conversion fluid.

The Weka Cryogenic Components product range meets all the different requirements for producing, storing, and dispatching hydrogen in the whole supply chain. This includes the cryogenic as well as the high pressure path.

\(^*1\) Normal boiling points for helium (He) -269 °C/4.2K, hydrogen (H\(_2\)) -253 °C/20.4K, argon (Ar) -186 °C/87.3K, oxygen (O\(_2\)) -183 °C/90.2K, and nitrogen(N\(_2\)) -196 °C/77.3K, \(^*2\) Absolute Zero Point -273.15 °C/0K

Some like it cold

WEKA IS...

...a leading manufacturer of instruments for the level measurement of liquids, cryogenic components, and special valves. Its key strengths are developing, producing, and testing tailor-made solutions for the level measurement of liquids based on the float principle, as well as for cryogenic components and special valves.

For further information please visit www.weka-ag.ch
HYDROGEN PATENTS The following review presents a compilation of patent information that provides insight into recent developments in the field of hydrogen technology with special consideration of the situation in Switzerland.

Dr Peter Bruns

The field of hydrogen technology is vast. It comprises the production of hydrogen, storage, transport, and distribution as well as the use of hydrogen in the chemical industry and in fuel cells for electric energy or heat production, just to list a few. Although different aspects interact, individual technologies may not be related; for example, the use of hydrogen for refining fossil fuels is unrelated to the technology of fuel cell design. The amount and complexity of information available makes it necessary for the present study to limit itself to only a few hydrogen related technologies.

The specific hydrogen technologies selected herein are fuel cells, reversible hydrogen storage, electrolytic hydrogen production, and a subaspect of fuel cells, those cells used to generate both electricity and heat. They all have in common that they may prove useful in environment friendly and sustainable use of hydrogen as a multi-purpose energy carrier.

PATENT DATA BASICS

All statistics in the present study use patent application data. Applications result only in part in patents. This means that the technological information contained in patent applications is more complete than in delivered patents. The more so, since the whole process to obtain a patent can be lengthy and costly, which makes data derived from patent applications less biased by economic and strategic considerations than technical data derived from patents. To get an estimate for the importance of the aforementioned fields of technology according patent application data are shown in Table 1 (page 20). The fields of technology have been defined using patent classifications, key word searches, reference hunting, and random sampling. The uncertainty of the numbers produced cannot be precisely determined. This would require the analysis of the roughly 50 Mio. patent documents published so far – an impossible task within the scope of limited studies. However, random sampling and the sighting of documents may allow for estimating the uncertainty resulting from the problems associated with defining fields of technology. In the present case, sighting randomly sampled documents produced about one out of ten documents unrelated to the fields of technology in question. This means that possibly one aspect of the technology was present but not essential to the invention, or that key words overlapping with other topics generated unrelated hits. Considering that classifications are incomplete, and that misplaced documents occasionally occur, the overall uncertainty of the absolute figures produced should lie between 10 and 20%. The uncertainty of the absolute numbers regarding fuel cells for electricity and heat production

INCIDENTAL PATENT EVIDENCE

On 20 March 2006, the news reported (http://www.chemie.de/news) that European Patent EP08688760, attributed to Celanese Ventures GmbH (related to PEMEAS GmbH) and contested by Ballard Power Systems Inc., was held up in the opposition procedure at the European Patent Office. It was also contested in the US and held up as well.

This specific case offers indications which might well be of interest to the hydrogen community. First, the patent focuses on a technology to increase the efficiency of fuel cell production – not the fuel cell itself. This may indicate that industry is shifting its focus from research to production, hence a sign of maturing. Second, the patent being contested in both the US and Europe also underlines the emerging global importance of fuel cells. Third, it shows that patents are very important, and that they also allow small companies to successfully defend their hard earned technological developments.
appears to be somewhat higher, perhaps between 20 and 30%.

Note that errors seem large, but the trends observed should be well supported. This is because the scale of the numbers has analytic value, and, because in trend analysis relative variation is significantly less affected than are absolute numbers. Note also that since most patent applications are published about 18 months after filing, the very latest developments cannot be seen. The 18 month publication delay is not a sharply defined window because classification and electronic loading of documents sometimes give rise to further data accession losses for newer documents. This study was carried out in March 2006. Therefore, the most recent completely accessible year is 2002. This is illustrated by the drop in applications shown in Figures 1 to 3 after 2002 or 2003 despite increasing application numbers to the present day, numbers which are available as such without further technical information.

**US, JAPAN AND EUROPE**

This section considers the triadic patents related to fuel cells by year and region of origin (see fig. 1 on page 20). All three regions have about the same amount of applications up to the year 2000. Most remarkable is that the US, Japan, and Europe evolve differently. US applications show a constant increase from 1997 to 2002, the last year with reliable data. Japanese patent applications evolve likewise, although on a slightly lower level. European applications increased from 1997, peaked in 2000, and reach a plateau or decline thereafter. Japanese patent applications continued to climb until 2003. Most likely, this represents a tendency to use a different filing strategy resulting in quicker data accessibility and, thus, has for the time being no particular analytic relevance.

Fig. 1a (page 20) includes a line showing all triadic patent applications. In order to fit the line into Fig. 1a, the numbers for that line have been scaled down by factor 100. The line is primarily of heuristic interest to see how fuel cell patent applications compare to the overall picture and to help distinguish technological from administrative, legal, and strategic effects. The line is not suitable for detailed analysis because many non-technological developments like the US introduction of publication of patent applications, the increasing number of business patents which can only be obtained in some countries, and the increasing number of non-Japanese Asian patents need to be filtered out.

Fig. 1b (page 20) is a complementary graph to Fig. 1a. Fig. 1b shows a marked increase for US and Japanese patent applications for fuel cells up to 2003, the last year for reasonably complete processing of non-triadic application data. European applications also increased from about 1994 onwards and seem to have reached a plateau in 2000 that still persists. Combining Figs. 1a and b may indicate that US and Japanese patent filing activities are still increasing whereas European filing activities remain on a lower, steady level. Although the diverging trend of European triadic versus non-triadic patent applications, which is much weaker in the Japanese data, may indicate that European and less so Japanese patent appli-
cants tend to envision a strategy of locally more restricted patenting, complementary data would be needed to confirm this reasoning.

**SUSTAINABLE USE OF HYDROGEN**

Patent applications related to reversible hydrogen storage and electrolytic hydrogen production vary at about the same level with a slight increase from 1997 onwards (see fig. 2 on page 20). Fuel cell related applications increased sharply after 1997 and even more so fuel cells for cogeneration of heat and electricity. Combining Figs. 1a, 1b, and 2 provides an even broader picture. Fuel cell technology emerges as the key field with the largest overall application numbers investigated here and with the sharpest and most persisting increase to present. Fuel cells for the cogeneration of heat and electricity seem to be of particular recent interest. Reversible hydrogen storage and electrolytic hydrogen production seem to follow the fuel cell developments slowly and somewhat reluctantly.

**THE SITUATION IN SWITZERLAND**

In order to gain insight into the situation in Switzerland, the apparent key hydrogen technology, the field of fuel cell development, has been considered in some detail. The seven most active applicants have been put into perspective together with the total number of Swiss patent applications in the field of fuel cells (see Fig. 3). This restriction to the most actively patenting companies is necessary to reduce the small numbers induced statistical artefacts related to the low total number of Swiss patent applications, which hardly exceeds 20 per year. Relative to the population, however the Swiss numbers on an European scale are not so low.

Dr Peter Bruns is an expert in patents and technology at the Swiss Federal Institute of Intellectual Property.

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**THE SWISS FEDERAL INSTITUTE OF INTELLECTUAL PROPERTY**

...is the federal competence centre for all matters dealing with patents, trademarks, designs, and copyrights. The broad range of services offered by the institute can be divided into three areas: Property rights, information products, and training. The issuance and administration of property rights is the institute’s core business. Information products such as research into technological developments (novelty searches) and trademark searches are important market-oriented services for our clients. In addition to these services, we offer training courses in all areas of intellectual property rights.
**INTERNATIONALLY PURSUED PATENTS**

**Fig. 1a** Triadic patent families by year and region of origin (= region of first patent application) for patent applications related to fuel cells, reversible hydrogen storage, electrolytic hydrogen production, and fuel cells used to generate both electricity and heat (listed under international/European patent classification H01M8 and US patent classification 429/12). Triadic patent families are patent applications that derive from a common priority (=initial application) and further applications including at least the three major economic regions United States, Japan, and Europe. Using triadic patent families instead of individual documents compensates for unwanted statistical effects due to different patent laws, patent filing strategies, and the like. Triadic patent families because of the resources they require may indicate the seriousness as well as the economic and research capabilities behind a patent application.

**Fig. 1b**: Non triadic patent applications. (strictly national Japanese documents omitted, explanation see Fig.2). Fig. 1b refers to the same fields of technology as Fig. 1a, but because the more complex and thus more time consuming processing of triadic patent applications has been omitted, it offers better insight into the latest trends and in combination with the triadic patent application statistics, provides insight into strategic changes pursued by applicants.

**OTHER PATENTS**

**Table 1**: Total number of patent applications by field of technology as of March 2006 rounded to the next thousand or hundred

<table>
<thead>
<tr>
<th>Technology</th>
<th>Number of Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cells</td>
<td>80 000</td>
</tr>
<tr>
<td>Fuel cells strictly Japan national</td>
<td>20 000</td>
</tr>
<tr>
<td>Reversible hydrogen storage</td>
<td>4 500</td>
</tr>
<tr>
<td>Electrolytic hydrogen production</td>
<td>6 000</td>
</tr>
<tr>
<td>Fuel cells for electricity and heat</td>
<td>700</td>
</tr>
</tbody>
</table>

*See explanation Fig.2

**RELATIVE PATENT APPLICATIONS ACTIVITIES**

**Fig. 2** Relative patent application activities by technology field. All values in the graph for each technology field add up to 100%. Purely national Japanese patent applications, hence only those documents not used to claim a priority in another country have been omitted. Omission of Japanese patent applications is necessary because these tend to use several filings to cover an invention, which in other countries would most likely result in only a single document.
Because valve technology for high pressure applications (up to 350 bar) is well-established in the CNG (Compressed Natural Gas) industry, it could have been assumed that further developments involving the use of hydrogen for similar pressure ranges as well as up to 870 bar would be rather easy to manage. Past and more recent experience has shown that this is not the case. Two of the main reasons are:

- Being the smallest gas molecule, hydrogen has the ability to escape through materials. This permeation must be managed when designing a high pressure hydrogen valve.
- Pressures up to 870 bar result in much higher forces at valve as well as in solenoid, hence requiring stronger power as well as improvements on seals.

All these special requirements call for enhanced surface and material quality as well as for special sealing- and 0-rings material for the different temperature ranges. In the automotive industry, the temperature requirement is – 40°C up to +85°C. High temperatures require very special solenoid design and power. For low temperatures, special sealing material needs to be sourced. Another challenge for the process of developing hydrogen valves are the special testing, laboratory, and technical requirements. A prototype and serial valve testing infrastructure needs to be installed. Eugen Seitz AG has been cooperating closely with Swiss TS as well as Powertech/Canada in this area. Substantial investments have been necessary to test high quantities of valves for function, burst pressures, etc. The assembly line is now installed in a “clean room” to avoid any dirt or dust particles which might cause leakages. Another important experience has been the close cooperation with various “partners,” such as universities, laboratories, or companies. For a medium-size company, it is important to communicate and work openly with close allies. Eugen Seitz AG has established close cooperation with Dynetek/Canada. Unfortunately, no common rules and regulations exist to date (for example, for burst pressures, etc.); currently, the technology is available for stationary application (such as hydrogen stations) as well as mobile application (automotive). Substantial efforts are being made in Europe as well as in the US to bundle existing knowledge into a set of standard regulations or norms. Today, Seitz hydrogen valves are used in 350–450 bar applications, both in hydrogen stations as well as hydrogen-/fuel cell-powered vehicles. The solenoid valves for hydrogen are mainly used in hydrogen stations such as dispensers. These valves control the high pressure flow of hydrogen from the compressor to the dispenser and further into the storage cylinder (350 bar or 700 bar tank) of the automobile or truck. Hydrogen valves are also used in mobile applications, such as cylinder valves.
HYDROGEN ENERGY

A hydrogen industry and infrastructure exist today, with more than 50 million tonnes of hydrogen produced and consumed worldwide every year. In future, however, hydrogen could also be used directly in energy activities. Worldwide, many initiatives are under way.

David Hart

Hydrogen is a well-understood industrial chemical, and its market is growing steadily. However, it could be used directly in energy activities, in addition to many of the industries where it is already common. It could be used as a transport fuel, in storing renewable electricity, and in power generation. Because no greenhouse gas emissions result from its use (though emissions may result from its production, which must always be carefully considered), it is seen as one of the possible ways to help combat climate change. It can also benefit air quality, as it is clean-burning, and help secure energy supply, as it can be produced from many different resources.

SIGNIFICANT INVESTMENTS

This flexibility has led to significant investments in the development of hydrogen energy over the past decade. Major initiatives are underway worldwide, aimed at exploiting the potential of hydrogen to alleviate concerns over greenhouse gas emissions, air quality, and energy security. Energy companies and automotive manufacturers are investing heavily in hydrogen energy technology development and demonstration activities, not for altruistic reasons but as a means to secure market share and generate returns for shareholders.

The Japanese government was one of the first to consider the potential of hydrogen energy in a national sense. The WE-NET project, started in 1993, examined fundamental hydrogen technologies with a view to introducing hydrogen into the Japanese energy system, to alleviate pressure caused by imported energy dependence. Government support was matched by investments from major Japanese corporations, with the automotive manufacturers perhaps the most visible. Japanese government investment in hydrogen energy technologies is equivalent to several hundred million dollars per year.

During this timeframe, however, other regions were beginning to actively consider hydrogen technologies. In Canada, fuel cells were seen as a strategic opportunity to provide new industrial growth, and funding was allocated to small research and development teams. Together with subsequent investments, this has resulted in major pre-industrial clusters of fuel cell and hydrogen technology companies in Vancouver and around Toronto, amongst others.

Hydrogen and fuel cells have had a longstanding history in the United States, particularly in aerospace programmes. More recently, however, pressure has mounted on the US energy system by becoming a net importer of oil, and by upheavals in the Californian electricity market. Domestic energy supply that still meets principal environmental goals, such as clean air and low greenhouse gases, is a key issue; large investments are being made in fundamental research as well as in the development and commercialisation of hydrogen technologies. Some investment comes from the government, while a significant amount is provided by both the financial sector, where venture capitalists and banks are funding entrepreneurs, and by corporations promoting inhouse development and demonstration. Publicly traded hydrogen and fuel cell companies have a market capitalisation of several billion dollars.

HYDROGEN IN EUROPE

In Europe, too, the different possible benefits of hydrogen have generated interest from commissioners in different jurisdictions. The Transport
and Environment, Energy and Research Directorates all supported the formation of a High Level Group on Hydrogen and Fuel Cells, which culminated in the publication of a report and the subsequent establishment of a Hydrogen and Fuel Cell Technology Platform. This non-government body provides guidance and direction on research and the deployment of hydrogen technologies, and has membership from major European corporations and research organisations.

The following example will help illustrate the strategic value of hydrogen energy in a specific context. While the UK has historically not invested in hydrogen technologies, it does have a strong environmental agenda and some relevant major industrial organisations, such as BP and BOC. Committed to trying to reduce its greenhouse gas emissions by 20% from 1990 levels, and seeing transport emissions in particular grow inexorably, the UK government has evaluated the potential of hydrogen energy to help resolve this issue. E4tech (with partners Element Energy and Eoin Lees Energy) was commissioned by the Department of Trade and Industry to analyse a Hydrogen Strategy for the UK. Following E4tech’s report, the UK government has put in place demonstration funding for hydrogen energy systems, and pledged its commitment to a more structured organisation of hydrogen energy issues.

In France, Norway, Germany, and many other parts of Europe, specific hydrogen programmes aimed at supporting the development of an industrial and service sector are underway. These generally take the form of loose public-private partnerships, with government investment being used to seed corresponding or greater investments from companies. However, the direction of growth is common to both. Germany has a particularly long history in hydrogen energy development, typically related closely to initiatives on behalf of its federal states (Bundesländer).

In addition to the multiple government approaches, interest from the corporate sector is strong and varied. Shell set up a dedicated division, Shell Hydrogen, several years ago to deal with developments in this area. BP specifically includes hydrogen amongst its internal business units, and companies in the automotive sector, such as BMW and DaimlerChrysler, are aggressively pursuing hydrogen as a possible major future fuel. Various major industrial gas companies – Air Liquide, Air Products and Chemicals, BOC, Linde – clearly see hydrogen as a key part of their future growth. And, excitingly, the developing hydrogen sector offers opportunities to small, specialized, or start-up organisations looking for a niche. Key technical problems still need to be resolved, and small organisations are often more nimble in achieving this than larger companies. In support, financiers are involved too – for example, Conduit Ventures in London only invests in companies in the hydrogen energy and fuel cells sector, and several companies in the sector have moved through venture financing to public listings on London’s Alternative Investment Market (AIM) during 2004 - 2006.

Hydrogen is an energy carrier that could play a key, cutting-edge role in future energy strategy. It is quite clear that the future shows a mix of energy carriers, just as today. Electricity, gas, oil, and biofuels will play a part, though their proportions will change. Companies see both a threat and an opportunity – they are being challenged to reduce their impact on the environment while trying to enter large new energy markets worldwide, such as China. From both a corporate and country perspective, hydrogen offers Switzerland an interesting strategic opportunity. Engineering and environmental standards in Switzerland are high, and Swiss companies compete worldwide in providing high technology solutions to clients. Swiss finance is also world-class, with the sector becoming more flexible. A strategic vision of the possibilities of hydrogen energy, both for its use within Switzerland and for exploitation further afield, can help Swiss organisations realise their full potential in this complex and rapidly developing arena.

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For further information please visit www.e4tech.com
Alternative energy technologies are becoming increasingly attractive for investors. Dieter Küffer, Senior Portfolio Manager at SAM Group, explains what should be borne in mind.

Which investment opportunities does hydrogen provide?
Dieter Küffer: It is important for investors to diversify investment risks. From our point of view, no single technology will ever assert itself over all others. Rather, it is a matter of different energy management. We must assume that fossil energy resources, like coal and gas, will remain important sources of energy for a considerable time. Both for fossil and alternative energies, it is key that energy is used efficiently. It is a question of enhancing the efficiency factor. Alternative technologies, like wind power, solar power, natural gas, natural ethanol, and hydrogen are already being used in certain segments. Investors need to focus on trends, not on a single technology. Which is what our SAM Smart Energy Fund does, for example.

Which investment criteria apply to companies in the hydrogen business?
Dieter Küffer: The same criteria as to any other company. It should be well-managed, have reasonable key figures, and have a good strategy. Investing in hydrogen is like any other normal investment, but with a very long-term investment horizon and considerable technology risks. We are very interested in these technologies and are monitoring developments in this area with the greatest possible attention.

Where would you identify the greatest potential for hydrogen as an energy carrier?
Dieter Küffer: In our assessment, the greatest potential lies in powering vehicle fleets, such as buses or taxis. Daimler Chrysler is far-advanced with these technologies. It is important to bear in mind that hydrogen is not an energy source itself but an energy carrier. Today, natural gas is usually used to produce hydrogen.

What kind of investment horizon do you recommend for investing in the hydrogen business?
Dieter Küffer: Anyone considering an investment in hydrogen technologies should adopt a long-term investment perspective.

Which companies are the rising stars in the hydrogen business?
Dieter Küffer: Fuel cells are an important element of the future market. We are very cautious about issuing investment recommendations. Masterflex, for instance, is one of a small number of investment opportunities. Masterflex has developed a hydrogen-based fuel cell for mobility purposes.

Headquartered in Zurich, SAM Group was founded in 1995 as an independent asset management company specialising in sustainability investments. Today, SAM is one of the world's leading financial services companies in this sector. Its clients include banks, insurance companies, pension funds, foundations, and private clients.
MOBILITY In partnership with the Paul Scherrer Institute (PSI), the Michelin Group research centre in Givisiez has designed the so-called Hy-Light, a prototype of what a clean car could be like in 15 to 20 years time.

In 2030, the global population will consist of between 7.5 to 10 billion human beings compared to 6 billion today. The number of cars on the road is expected to rise from 700 million today to 1.6 billion, resulting in more global warming and greater pressure on the price of oil (oil reserves are estimated to last another 30 to 40 years).

Under these circumstances, Hy-Light represents an ideal fusion between the travel needs of society and environment-related constraints. Hy stands for “hydrogen” as this is an electric car which does not use batteries but rather a fuel cell; Light refers to its weight, a mere 850 kg. Built using technology which will be available in a decade or so, it is non-polluting, consuming only renewable energy and capable of carrying four persons at 130 km/h.

The fuel cell was developed by the PSI while Michelin designed the electric engines and the transmission chain, as well as the chassis management based on an active electric suspension (which stabilizes the vehicle in bends and during braking).

WATER AND SUN AS THE ONLY ENERGY SOURCES

The principle of the fuel cell is to directly convert the chemical energy resulting from the combination of oxygen and hydrogen into electricity. Hy-Light’s fuel cell is specific as it is fed by in-car hydrogen and oxygen. Hydrogen is stored in the chassis and oxygen in cylinders. Ordinarily, in fuel cells, oxygen is taken directly from the atmosphere, which requires a compressor to draw it in, thus increasing consumption and also leading to lower performance than with pure oxygen because air may be polluted. Hy-Light avoids this limitation and can travel 400 km (250 miles) at a constant speed of 80 km/h (50 mph).

For further information please visit www.psi.ch www.michelin.co.uk

LICENSING TEST VEHICLES

Roland Klaus

Only roadworthy cars can be licensed for road traffic use. Promoting forward-looking and environment-friendly technologies involves keeping down entry thresholds. Cooperation between industry and government bodies can deliver generally satisfying solutions, as the example of Michelin and the road traffic licensing department (OCN) of the Canton of Fribourg proves. Off-road trials involving test vehicles require no licensing or official approval. As development reaches more advanced stages, however, road tests under normal traffic conditions become indispensable, requiring official approval, that is to say, license plates. Depending on the circumstances, the first step can be made via test drives. Under official legislation (SVG Art. 53), cantonal bodies may issue permits for vehicles either failing to meet all or some of the necessary regulations to access a clearly defined area. Significant restrictions apply, however, thus severely limiting vehicle developers’ scope of action. Ensuring the operational reliability of prototypes in the early stages of development is hence essential. Road traffic licensing departments can issue licenses to such vehicles provided these are roadworthy and comply with noise emission as well as measurement and weight regulations. Components failing to meet regulations initially must constitute a real prospect for later approval of the type of vehicle in question. In the case of hydrogen-based vehicles, particular attention must be paid to storage. High pressure tanks in particular must comply fully with what are exacting regulations. The two prototypes licensed in Fribourg were not only new as regards energy storage and fuel cell propulsion, but the entire vehicle was full of innovation. Preference was thus given to integrating this vehicle into road traffic step-by-step to a point where individual licensing could be considered.

Roland Klaus, Head of the Road Traffic Licensing Department (OCN), Fribourg
OVERVIEW

Hydrogen and fuel cells are promising technologies offering economical opportunities that are environmentally sound provided that they are based on renewable energy sources. It is often proposed to make the transition to a hydrogen based economy in evolutionary steps. The use of carbon-based primary energies in the near and mid-term presents itself as the most probable first step to large-scale hydrogen production. However, the use of fossil fuel frees carbon dioxide and the transformation losses in this production cycle would be simply prohibitive. As a matter of fact, it would be more efficient to use fossil fuel directly.

Nevertheless, Hydropole agrees with bodies such as the Commission of the European Communities that we must begin to explore the avenue of hydrogen-based energy systems in order to attain more sustainable living. The awareness that fossil fuels not only facilitate everyday life but also impact the environment adversely has risen throughout the last 30 years. Many governments are worried about the dependency on energy imports. With hydrogen being, overall, one of the most promising alternatives to conventional transport fuels, it is no surprise that these governments have developed and organised ways to probe or even develop the use of hydrogen in tomorrow’s energy market.

The following reflections are meant to provide a starting point for further information on some of the measures taken around the world.

WHAT’S UP IN SWITZERLAND

Switzerland’s energy research is primarily aimed at the 3Es, i.e. energy security, economy, and environment. The Swiss Federal Institute of Technology (ETH) has translated this concept into a vision of a “2000-Watt society”; this vision has been adopted by the government as a long-term policy building block. Although there is no specific hydrogen policy on the federal level, the hydrogen path is one of the various issues evaluated by the Swiss Federal Energy Research Commission (CORE). In a roadmapping exercise, CORE concluded that a major step towards reaching a “2000-Watt society” by 2050 includes – as one of four key elements – the realisation of stringent energy efficiency standards equal to an average vehicle fleet fuel consumption of 3 liters per 100 km.

To achieve this goal, various efficiency measures and new CO2 neutral or carbon free fuels like hydrogen must be explored, developed, and introduced to the market. Every four years, this consultative body develops a mid-term master plan for federal energy research. This includes basically all of the publicly funded energy research in Switzerland. In order to surmount obstacles between basic research and market penetration, the Swiss Innovation Promotion Agency (CTI) backs innovative projects by various means of support, such as management consulting, networking, or funding.

Through the greater use of resources by universities and increased contributions from the private sector, efforts are being made to strengthen energy research in Switzerland.

www.bfe.admin.ch
www.bbt.admin.ch/kti/profil/e/
WHAT'S UP IN THE EUROPEAN UNION

The European Commission (EU) has implemented an energy and research policy with the goal of implementing hydrogen as a future energy vector. The recently published white paper on the EU’s future energy policy clearly indicates that the EU intends to decouple European energy needs from imports, to develop environmentally sound energy paths, and to ensure that European know-how is transformed into business opportunities for European industry. Within the Framework Programmes for Research and Technological Development (RTD), basic research as well as demonstration and pilot projects are addressed. These initiatives have led to the European Hydrogen and Fuel Cell Technology Platform (HFTP), an industry-driven cluster where public and private agents are co-developing the concepts and technologies needed to implement tomorrow’s energy markets associated with hydrogen as an important new energy carrier. The European Hydrogen Association (EHA) operates as an industry-supported portal for hydrogen activities in the EU.

INTERNATIONAL INITIATIVES

Two major groupings in the international arena are currently pursuing collaborative efforts related to hydrogen as a future energy carrier. These are the Hydrogen Implementing Agreement (HIA) of the International Energy Agency (IEA), which was established back in 1977, and the International Partnership for the Hydrogen Economy (IPHE), established only recently in 2003. While the HIA continues to focus on the initiation, coordination, and conduct of a specific portfolio of internationally collaborative, pre-commercial research and development efforts, the IPHE – organised as an interest group with ministerial direction – aims to accelerate the transition to a hydrogen economy through a more applied approach with deployment plans. Both groups also maintain coordinated efforts relating to information dissemination and key safety matters relating to codes and standards. In addition, the IPHE also educates and informs stakeholders as well as the general public on the benefits of establishing a hydrogen economy, and the challenges associated with doing so.

Similarly to Europe, the US and Canada have been exploring the hydrogen path since the 1970s oil crisis. With successive programmes in place since the early 1990s, both governments have focused on investigating several aspects of a future hydrogen economy, such as various production methods, means of distribution and, most prominently, the application of hydrogen in fuel cells for mobility uses. In the US, major efforts are being undertaken to develop technologies for the production of hydrogen from clean coal as well as nuclear power options.

Japan is undertaking various policy measures with the aim to attain cost and performance comparable to conventional energy sources shortly after 2010. The most important instruments are technological development and demonstration projects involving fuel cells. Organized by the Ministry of Economy, Trade and Industry (MITI), the Japan Hydrogen and Fuel Cell Demonstration Project (JHFC) comprises a wide range of activities related to the use of fuel cell vehicles. Besides these activities, governmental bodies are probing current legislation in respect of its compatibility with hydrogen use, therefore creating a legislative framework encouraging the innovation and development processes needed in this sector.
MILESTONES

1766 Cavendish reports hydrogen to be 7 to 11 times lighter than air
1783 Balloon made of paper and filled with 25 m³ hydrogen gas ascends to nearly 914 meters
1800 Nicholson and Carlisle separate water into oxygen and hydrogen by passing an electric current through it
1820 Cecil carries out experiments using hydrogen as an engine fuel
1839 Sir William Grove constructs a "gas voltaic battery" as the forerunner of modern fuel cells
1861 Kirchhoff and Bunsen analyze the emitted spectrum of the sun and find hydrogen to be the major constituent of the sun
1866 First dynamoelectric generator demonstrated, ends temporally the development of fuel cells as electricity generators
1874 Jules Verne writes his novel "The Mysterious Island" in which water delivers energy
1898 James Dewar uses regenerative cooling to become the first to statically liquefy hydrogen
1898 Gmüür starts the first industrial hydrogen production in Switzerland
1909 Fritz Haber discovers a process allowing the synthesis of ammonia (NH₃) from the elements hydrogen and nitrogen
1911 Carl Bosch upscales Haber's synthesis to industrial production scale
1937 The Hindenburg disaster in Lakehurst ends the air applications of hydrogen after 150 years
1955 Justi describes the utilization of hydrogen as an energy carrier
1959 First fuel cell vehicle equipped with alkaline fuel cells delivering a power of 15 kW demonstrated
1959 Zdansky, on behalf of LONZA, files a patent on a pressured electrolysis system
1963 Rockets are launched using liquid hydrogen and oxygen as propellant
1967 Saturn V rocket lifts off with 12'000 m³ of liquid hydrogen
1967 GM's Electrovian is the first operational fuel cell powered electric vehicle
1969 A hydrogen energy concept using properties of hydrogen including non-conventional energy systems developed
1970 Kordesch builds an alkaline fuel cell/battery hybrid electric car based on an A-40 Austin sedan and drives it for three years
1974 The first hydrogen vehicle in Japan is a small pick-up Musashi 1 equipped with an internal combustion engine
1984 Daimler-Benz together with Aral, Dornier, Mannesmann, Thyssen Engineering demonstrates the Mercedes 280 TE hybrid vehicle equipped with a gasoline and hydrogen internal combustion engine
1988 A triple-jet powered Tupolev Tu-154 flies with a liquid hydrogen fueled engine
1988 The 10 Daimler-Benz vehicles in operation since 1984 ran more than 250'000 km
1993 Uni Geneva presents a hydrogen powered Lawn Mower
1994 Based on a Mercedes-Benz transporter MB-180, NeCar 1 demonstrates 50 kW fuel cell combined with a 30 kW electric drive
1998 The EU launches CUTE, Clean Urban Transport for Europe
1998 First Hydroxy demo project with 100 W fuel cell for transportation on water
2000 Total hydrogen production worldwide amounts to 500 bn m³ (STP) or approximately 45 mio tonnes annually
2001 BMW demonstrates a small fleet of 15 vehicles with hydrogen-powered internal combustion engines
2002 A small series of Daimler Chrysler A-class cars called F-Cell is produced. A 85 kW Mark 902 fuel cell and a compressed hydrogen tank at 350 bar allows range of 150 km
2002 PSI and VW present a prototype vehicle based on the VW Bora, equipped with a 28 kW fuel cell, electrochemical double layer capacitors for acceleration and break energy recovery
2002 Auxiliary Power Unit of 300 Watt is installed on sailboat participating in the "Course du Rhum"
2003 PowerPac, a hydrogen driven portable power-unit developed by ETH/PSI receives the Swiss Technology Award
2003 On request of ETH, Shell Eco-Marathon accepts hydrogen as fuel. PAC-Car I is the first fuel-cell car in this competition
2003 Boat Hydroxy3000, equipped with a 3 kW fuel cell, is successfully tested on the Lake of Neuchâtel
2004 Michelin and Paul Scherrer Institute (PSI) demonstrate a new developed lightweight passenger vehicle equipped with a PEM fuel cell with 30 kW, supercapacitors increase power output to 75 kW and 2 x 30 kW motors
2004 Electric powered FUEL Cell SAM uses 300-400 g hydrogen per 100 km (1-1.5 l gasoline)
2005 PAC-Car II developed by ETH Zurich sets a new world record in fuel economy at the Shell Eco-marathon in Ladoux/F

Swiss R&D projects are marked in blue
## WHO IS WHO IN SWITZERLAND’S HYDROGEN INDUSTRY

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The distribution of energy end use varies drastically from country to country. Switzerland has a rather high energy consumption in the household sector.

WORLDWIDE PRIMARY ENERGY SOURCES (2000)

Together, coal, oil, and gas account for 80% of primary energy. New renewable sources like solar, wind, and geothermal energy make up 0.5%.

DISTRIBUTION OF ENERGY END USE IN SWITZERLAND (2004)

The distribution of energy end use varies drastically from country to country. Switzerland has a rather high energy consumption in the household sector.
Impressum

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