H2FC e-newsletter

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Progress in Hydrogen and Fuel Cell Technologies

INTRODUCTION

EDITORIAL

Dr. Olaf Jedicke

Dear Reader,

The increasing amount of available e-newsletters and journals in concern of hydrogen and fuel cell technology constrains not only the importance and attractiveness of the theme; also it mirrors the overlapping with neighbored sciences and technologies, which becomes more and more necessary to achieve technological impact. Several years ago we came to the compliance that a future major challenge must be to team the different scientific communities, which appeared at that time fragmented around the broad topic of hydrogen technology and fuel cell science. That was the nativity of the H2FC e-newsletter. Because each newsletter has its own reason and purpose, also this e-newsletter likes to stand out from the crowd. H2FC e-newsletter has not the pretension to present scientific papers, but likes to inform the reader in clearly and brief represented small articles about ongoing scientific work and networking activities within the respective scientific communities.

This first edition is one further milestone emanated from the coalescence of the communities pillared by the European Research Infrastructure project "H2FC European Infrastructure". H2FC e-newsletter likes to comprise articles quarterly arising from the successful work originated by its three project pillars: joint research on the development and improvement of research infrastructures, coordination to team and cross-link the different and fragmented communities and especially transnational access to unique research infrastructures to foster and support scientific ideas and technical development.

H2FC e-newsletter is structured in categories: research highlights, transnational access summaries, update on infrastructures and communication on networking. This first edition starts with an introduction to the H2FC European Infrastructure project. Research highlights focuses mainly on selected joint research activities regarding hydrogen production, hydrogen storage, fuel cells and safety aspects of hydro-gen technologies. Articles positioned under transnational access summaries reflect an impression about H2FC access activities followed by a monograph about EMPA research facilities available under H2FC European Infrastructure. Communication on the networking completes the e-newsletter and likes to inform about technical schools and workshops focusing on hydrogen technology and fuel cells as well as symposia and conferences.

I don´t like to end at that point without commenting on the development of content to the H2FC e-newsletter. Brief information about research highlights will illustrate the core continuously. The peak of transnational access summaries will be achieved not before end 2015. We can anticipate a couple of research results generated through H2FC research facilities. Communication on networking will remain suspenseful, since the work on collecting information on scientific bottlenecks is ongoing as well as the development of digital information- and research tools on simulation and modelling.

I like to acknowledge the European Commission for funding H2FC European Infrastructure, the authors which supported the origination of this e-newsletter by constructive critics but also existing articles, the reviewers, the design team and last but not least the H2FC consortium.

Please enjoy our H2FC e-newsletter, Olaf Jedicke

H2FC European Infrastructure is a European infrastructure project funded by the European Commission under FP7 Capacities program. It combines European's leading R&D institutions and organisations which possesses unique research infrastructures and technical installations applicable to a broad spectrum of research activities on hydrogen technologies and fuel cells. The project consortium is coordinated by Karlsruher Institute of Technology (KIT) and consists of 19 European partners. Three main pillars govern the project work, networking activities, joint research activities and transnational access activities, further subdivided in 23 work packages, whereat each work package has its own objectives [fig.1.0]. The total budget of € 10.147.583 H2FC European Infrastructure forebodes the importance of the specific theme and challenges associated. Main challenge of the project is to originate a coordinated and integrated alliance based on complementary, state-of-the-art, or even beyond state-of-the-art unique infrastructures, to serve the necessities of the scientific hydrogen and fuel cells community and to facilitate world class research. The key research topics identified are described by the work package headings and focus basically on the integration, enhancement and improvement of existing technical research infrastructures:

1. Facility improvements for investigation of basic hydrogen properties and material behaviour
2. Facility improvements for investigation of components and systems of the hydrogen energy chain
3. Methods, protocols and benchmarking on fire resistance, solid storage materials, fuel cell degradation and fuel quality
4. Development of a cyber-laboratory and central database to practice simulation and modelling on fuel cells and hydrogen safety aspects

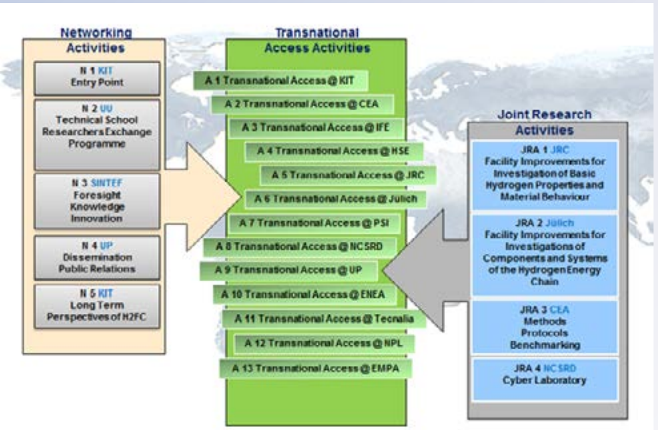

Fig. 1.0 Structure of H2FC European Infrastructure project

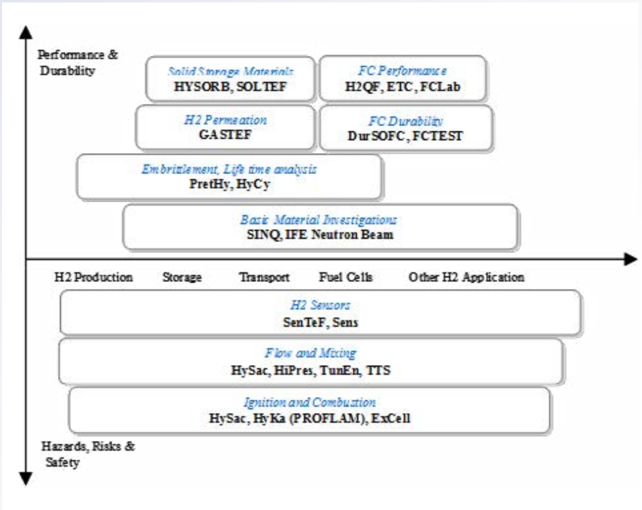

Fig.2.0 Experimental and technical portfolio of H2FC European Infrastructure

The networking activities are heading the R&D communities in concerns of:

1. Relevant education and training actions
2. Foresight, knowledge and innovation on hydrogen technologies and especially to investigate existing scientific bottlenecks but also to inform and discuss with national and international authorities about necessities and demands
3. Dissemination and public relations to inform communities and strengthen collaboration and transfer of knowledge to generate impact in industrial aspects
4. Long term perspectives to develop and install instruments for sustaining communication and collaboration

Transnational access for the H2FC R&D communities to member state infrastructures

Main support to European's hydrogen and fuel cell communities will be given through the transnational access activities, by offering very different technical and experimental facilities to external users. Approximately 52 different technical installations are offered by the consortium free of charge to the fuel cell and hydrogen communities to support scientific ideas, technical development and generation of knowledge [fig.2.0]. Access activities are divided into 7 calls and announced each separately; no exclusion of submitted proposals is effected by. Access activities in the special concern "free of charge" ends with the project in October 2015.

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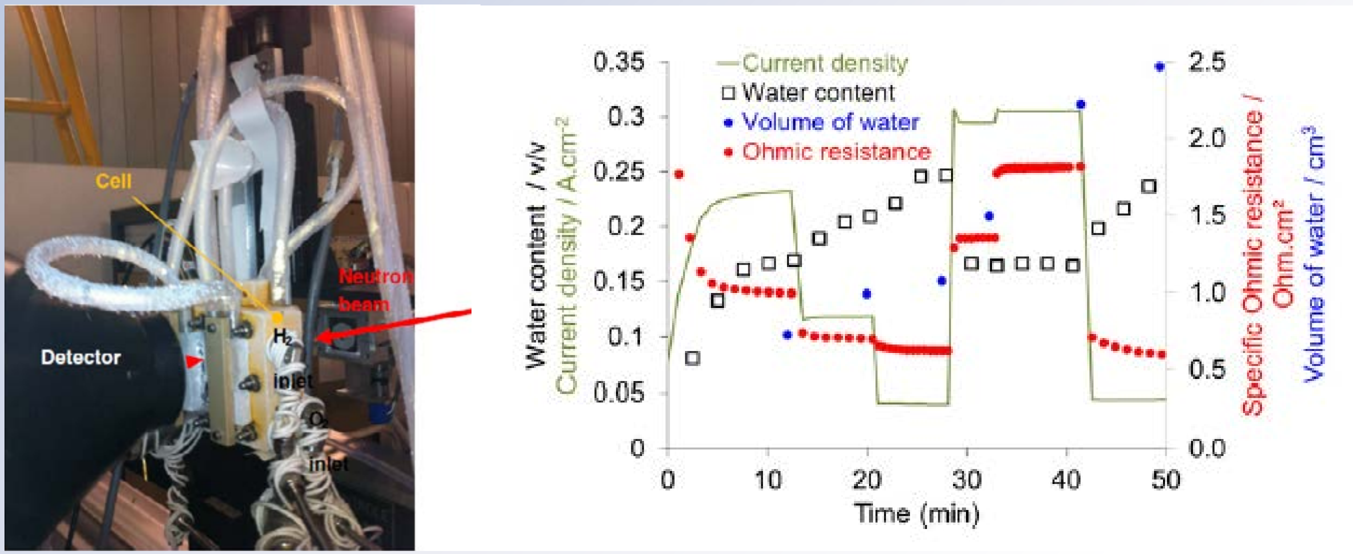
Water management in proton exchange membrane fuel cell at sub-zero temperatures: An in operando SANS-EIS coupled study

The water management is a key issue for optimizing both the performance and durability of proton exchange membrane fuel cells (PEMFCs). In the H2FC Infrastructure project, the CEA-LITEN has improved an approach based on the use of small-angle neutron scattering (SANS) experiments to study operando the distribution of water inside the membrane. Among the main developments, the SANS measurements have been coupled to electrochemical impedance measurements (EIS) and the temperature range has been significantly enlarged from 40 °C–80 °C to -20 °C–105 °C. The interest of studying the water management at low temperatures is to better understand the behavior of fuel cells in winter times and especially to develop new procedures for cold starts.

It was commonly believed that the main difficulty in starting a PEMFC at sub-zero temperatures was related to the production of water at the cathode that crystalize within the porous cathode limiting the access of the reactant gas to the catalyst sites. The present experiment combining SANS and EIS has evidenced that the chocking effect is also aggravated by a degraded water management. A PEMFC fixture specially designed to be transparent to neutrons and at the state-of-art of the PEMFC performance was operated on a neutron beamline at low temperatures (Figure). The data analysis revealed that increasing the current (and so forth the quantity of water produced by the cell) induces a membrane dehydration (Figure). This phenomenon was understood in terms of the competition between electro-osmosis (water transported by the protons moving from anode to cathode) and back-diffusion (water diffusion from cathode to anode due to the concentration gradient). The diffusion process is strongly temperature dependent while the electro-osmosis is not. In other words, back-diffusion cannot compensate anymore the electro-osmosis process at low temperature, water accumulates at the cathode and the membrane dehydrates as confirmed by an increase of the ohmic resistance measured by EIS.



PEMFC operating at sub-zero temperature on a neutron beamline (left); Evolution of the current density, the ohmic resistance, the average water content in the membrane and the volume of water produced (right).

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Fragile and yet firm – glass capillaries as pressure vessels

For the transport of hydrogen or for its use as fuel for road and other vehicles it is necessary to compress as much energy as possible into a given tank volume. Unfortunately hydrogen has a comparatively low density, both in terms of mass as well as of energy density.
One way which has been tried to solve this problem is liquefaction of the gas. While the cryogenic liquid has indeed a satisfactory density a lot of energy is necessary for the liquefaction and storing and handling of the cryogen is complicated due to the enormous temperature difference between the liquid and the environment. Another way is to compress the gas at ambient temperature to higher levels than they are common. Almost all car makers who intend to sell fuel cell cars in the foreseeable future will store the hydrogen in tanks with a maximum operating pressure of 70 MPa, twice the value which is common for natural gas tanks in cars. Of course these tanks are not made from metal because of the prohibitive weight they would have, but from composite polymeric material.

Few people would readily come up with glass as a suitable material for pressure vessels, mainly due to its proverbial fragility. Little known is the fact that certain kinds of glass have a tensile strength higher than that of steel, at least in the right form. Borosilicate glass fibers, for example, have a tensile strength of 6,000 MPa, while the value for AISI 1060 steel with 6 % carbon is only 2,200-2,500 MPa. At the same time the density of glass is lower than that of steel by a factor of about three.

The shape of the glass matters. Capillaries are of special interest because they can be produced easily and because of the stress they can withstand before they burst increases the smaller they are. Burst pressures of the order of 100 MPa can easily be achieved with capillaries of the right size in the micrometer range; the maximum value observed in BAM was 151 MPa.

Of course a single capillary does not hold much gas, but many of them can be bundled. So it is in principle possible to create pressure vessels with a very high maximum operating pressure and a very low dead weight producable from raw materials which are readily available all over the world. Advantageously, they can also readily be recycled. The system could be scaled freely to obtain the desired size and volume, and it can be refilled. Storage capacities for the system as a whole of 10 % are aimed at. It means the DoE targets for storage density are in reach; partly, they have already been exceeded with isolated capillary bundles.

But is it also safe? BAM investigates several questions related to this in a research project funded by the German Research Foundation (DFG) and the Swiss company C.En Ltd. which attempts to develop a commercial pressure vessel on this basis. The first question was how much pressure a single capillary can hold. As mentioned above burst pressures of the order of 100 MPa were found regularly, with a maximum of more than 150 MPa. The values and the ratio of outer diameter and wall thickness are the most important parameter, while humidity of the gas and pre-treatment of the capillaries do not play a significant role. Another important factor is which glass is selected. There are quite different kinds of glass, and not all of them are suitable. Certain kinds of borosilicate glasses have been found to be the best for this purpose.

A pressure vessel should be tight. Unfortunately, there is no material in nature which is indeed absolutely gas tight. Something as small as a hydrogen molecule will always find a way between the atoms or molecules of the matter supposed to contain it. Users of composite tanks for hydrogen made from polymeric material are acquainted with permeation: over long periods of time the hydrogen will diffuse through the tank wall, without damaging it (which is a great difference to hydrogen embrittlement to which certain metals are susceptible). Permeation is found in glass capillaries as well. But how much exactly will be lost per unit time is very different and depends again on the glass selected. The values of permeability easily span seven or more orders of magnitude. Recent investigations at BAM have shown that BABS (Barium-Alumo-Boro-Silicate-glass) which contains additional barium ions shows a very low permeability; thus, it is very well suited under permeability aspects.

But for the design of a pressure vessel permeability is not the only factor which has to be taken into account. The determining factor is the kind of application the vessel is to be used for. At this time it is not yet quite clear which field of application would be the best for such a device. But it appears that glass may very well have a future as material for pressure vessels.

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Fire resistance rating of on-board storage: recent findings at Ulster

Fire resistance rating (FRR) of on-board storage is a time before catastrophic failure on a tank in the bonfire test in conditions when thermally activated pressure relief device (TPRD) is not activated. TPRD can potentially fail to be activated in fire by different reasons, e.g. it can be blocked by other car parts during road accident, etc. Probability of such failure is not known for real conditions and thus deterministic studies to be carried out any way to increase FRR to protect public and first responders at the accident scene. FRR is important to compare different design of thermal protection of storage tanks.

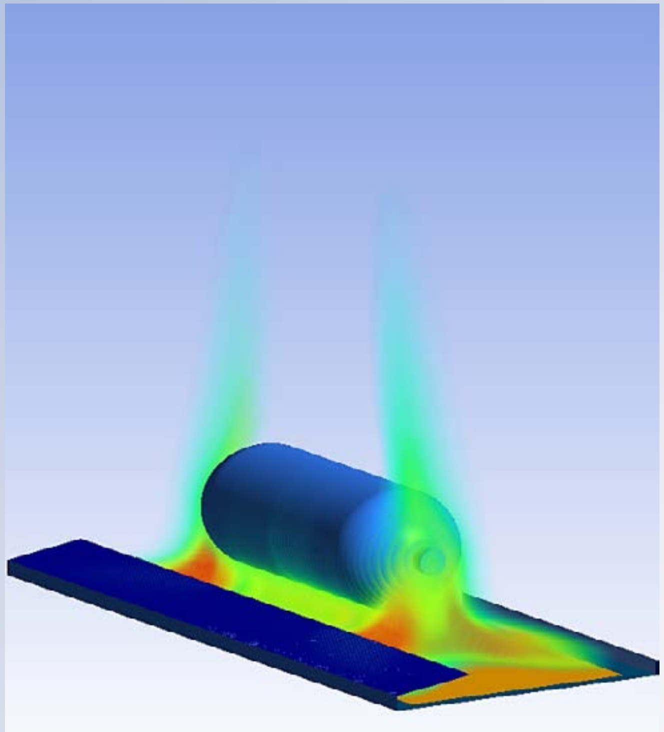

Fig. 1

Why we should increase fire resistance rating of high pressure hydrogen storage tanks? Currently FRR reported in the literature is 6–12 minutes only. This is close to the average time of arrival of firemen to the fire scene, e.g. in London it is about 11 minutes. Strong blast wave from 700 bar storage vessel and fireball of diameter several tens of meters after tank rupture are of high danger for people and building around. To decrease probability of catastrophic tank failure a diameter of TPRD that is currently used is 4–5 mm. Flame length from such TPRD could be as long as 15 m and deterministic separation distance up to 50 m. All these hazardous factors could be overcome if we could increase FRR to 1–2 hours. Indeed, during this comparatively long time any fire could be controlled or extinguished. Due to high FRR the TPRD diameter could be drastically reduced below 1 mm with flame only about 1–2 m! In confined facility such as garage such flame even could be considered as "extinguisher" to primary fire as combusting hydrogen jet will produce the only one product water!

Glass transition temperature of resin	Fire resistance rating
95 °C	2.6 min
170 °C	6 min
225 °C	10 min

Table 1. Dependence of FRR for bare tank on glass transition temperature.

How to increase fire resistance rating? HySAFER Centre at the University of Ulster is carrying research on different ways of thermal protection of high-pressure hydrogen storage tanks. The results of this study will be reported in due course, but here we would like to briefly share preliminary results of our numerical study. A snapshot of simulation of the bonfire test following test burner design by KIT (premixed methane-air sintered burner) is shown in Figure 1.

Table 1 shows the dependence of FRR for bare tank on glass transition temperature (GTT) of resin used in carbon fiber-resin composite for bare storage tank in bonfire test with heat release rate of HRR=350 kW.
It is clear that the use of a resin with higher glass transition temperature in the composite increases FRR. For example, the increase of GTT from 95 °C to 225 °C increases FRR by 4 times! This result yet to be confirmed by tests but we are quite confident that all tank manufacturers should apply this new knowledge to their products.

Another "unexpected" result of our numerical study is demonstrated in Table 2. Fire resistance rating is clearly a →

→ function of heat release rate in bonfire test. The high heat release rate, the lower is FRR. For example, an increase of HRR in bonfire from 78 kW to 350 kW (4.5 times) leads to "un-expected" decrease of FRR from 37 to 6 minutes (6.2 times).

Heat Release Rate	Fire resistance rating
78 kW	37 min
167 kW	9.7 min
350 kW	6 min

Table 2. Dependence of FRR for bare tank on HRR.

This result raises a fundamental question about the modification of the bonfire protocol in current regulations and standards. Indeed, only requirements for temperature in three points under the tank are regulated. However, our research demonstrated that this requirement is not sufficient. Bonfire protocol has to fix HRR too to make bonfire tests in different laboratories around the globe compatible.

Finally, we have to underline that the bonfire test will give only an indication of time to the tank failure in real fire (in conditions when TPRD is not activated). Indeed, the heat release rate in a real vehicle fire could be as high as 15 MW (even for a short period of time). Bonfire test in our opinion should be used first of all for comparison of different thermal protection designs for on-board storage and only as an indication of time of the catastrophic failure of the tank.

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Hydrogen Sensor Application of Palladium based Catalyst Systems

Tests on a novel hydrogen sensor from Hoppecke were carried out at the SenTeF testing facility at the JRC in Petten in the Netherlands. Measurements at different environmental conditions (varying temperature, relative humidity and pressure) were complemented with performance tests such as determining response and recovery time and cross sensitivity to different deleterious gases.

Hoppecke is focusing on applications in specific areas such as battery room monitoring and fuel cell or battery powered material handling vehicles. For this purpose they have developed and tested different electronic sensing devices and sensing configurations.
The sensing component of the Hoppecke hydrogen sensing device relies on the catalyst material used in their well-known catalyst plugs for lead acids batteries. These devices, mounted at the top of each cell, reconstitute the electrolyzed water to the cell by means of a catalytic recombination of hydrogen and oxygen, thus avoiding or significantly extending water replenishing and cell inspection intervals. In the sensor application of this palladium based catalyst system, the exothermic reaction which takes place during the recombination of hydrogen and oxygen can be used to determine the hydrogen concentration. The temperature difference against a reference set (without catalyst) is measured by a couple of thermistors balanced with a standard Wheatstone bridge circuit, which provides a proportional output signal to the hydrogen/oxygen mix. This catalytic sensing device works at room temperature. A particular feature compared to similar devices is the addition of an absorbing material around the catalyst ceramic rod to protect it from poisonous gases like H_2S and SO_2.

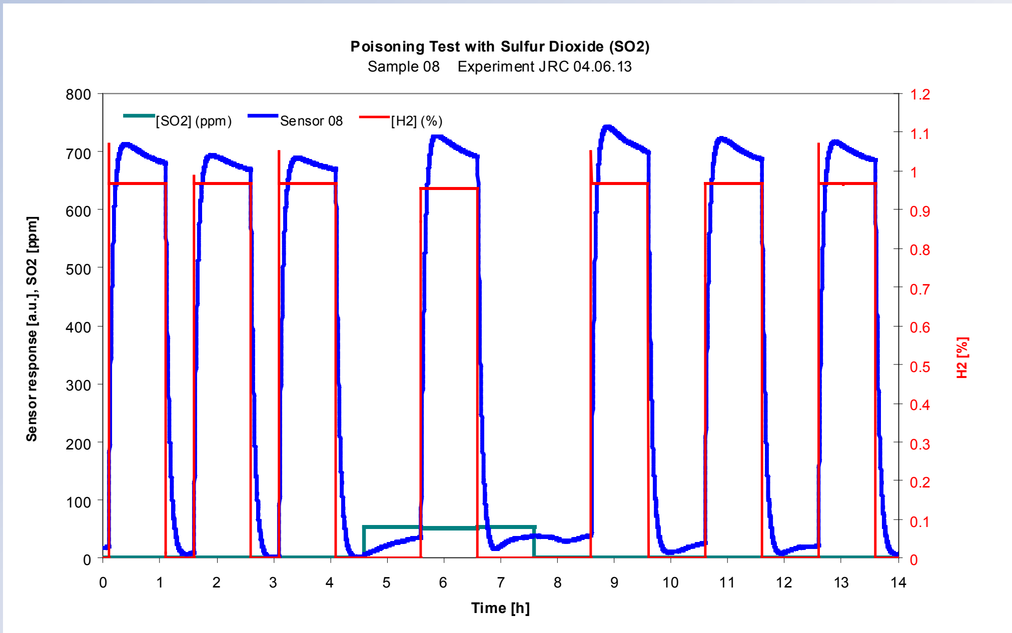

Figure 1 Poisoning test with sulfur dioxide.
As presented at Fall 2013 EMRS meeting, Warsaw, Poland.

The tests carried out at the SenTeF facility, in the frame of the Transnational Access program of the project H2FC, show that this protection mechanism works well. Only a minor effect of SO_2 (shown in Fig. 1) and H_2S (not shown) on the sensor's response was observed.

This collaboration provided valuable input to Hoppecke for further development of their hydrogen sensor.

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In situ diagnostics for PEM fuel cells

The UK's National Physical Laboratory (NPL) has world-leading expertise in the development of in situ measurement and modelling tools and improved test methods for polymer electrolyte membrane fuel cells (PEMFCs). A range of in situ diagnostic techniques has been established to support research into mitigation strategies for critical PEMFC degradation mechanisms and to provide experimental validation of fuel cell models. Here we describe two recent NPL innovations developed as part of research activities in the H2FC Infrastructure project. The first is a novel reference electrode configuration that allows for the first time mapping of electrode potential across the active area of an operating PEMFC and has already been successfully applied to the study of carbon corrosion during start-up/shut-down. The second is a world first in situ measurement of corrosion potential and pH at the surface of a stainless steel bipolar plate during fuel cell operation, which has challenged conventional wisdom on corrosion testing of candidate materials and coatings.

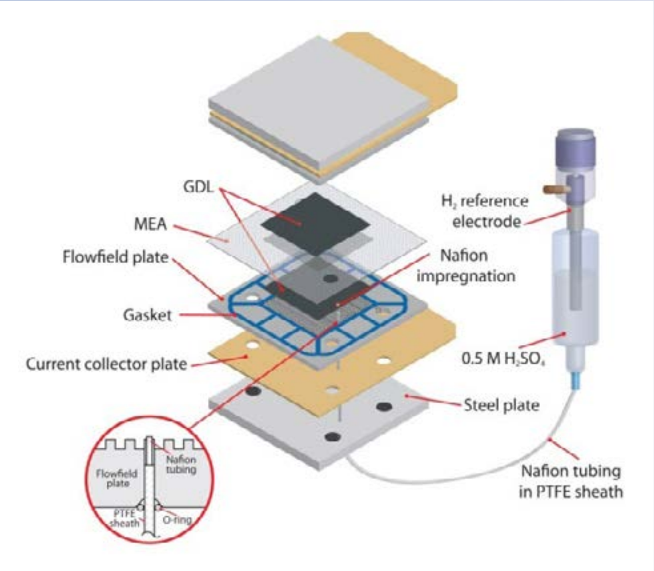

Figure 1: Schematic diagram of NPL reference electrode

Improving PEMFC durability under real-world operating conditions is a key focus for industry in the drive towards widespread commercialisation of the technology. In the most demanding applications, realistic operating conditions include contaminants in both fuel and air, repetitive start-up/shut-down, freeze/thaw cycling and humidity/load variations that result in stresses on the chemical and mechanical stability of PEMFC materials, components and interfaces. The US Department of Energy 2020 performance and lifetime targets for automotive, portable and stationary power applications are widely accepted as a key benchmark for significant market penetration. The major challenge is to achieve cost reductions of the order of 40 % (normalised to mass production) while extending lifetime under automotive drive cycling to 5000 hours. Lifetime extension through the development of damage mitigation strategies is hampered by limited fundamental understanding of critical degradation mechanisms. NPL is addressing this through the development of novel in situ measurement and modelling tools and standardised test methods, in close collaboration with industry and other research organisations.

Figure 2: 316L stainless steel flowfield plate with hole for in situ probe.

Reference electrodes are routinely used in electrochemistry to distinguish between processes occurring at the anode and the cathode. A reference electrode is a stand-alone electrode that provides a stable constant potential against which the potential of the electrode of interest can be measured. Conventional fuel cell reference electrodes are typically connected at the sides of the cell, meaning that they can only really measure what's going on around the edges and yielding limited information about the majority of the active area of the cell. The innovative NPL reference electrode configuration (Figure 1) connects through holes drilled into the end plates of the cell, allowing a point measurement of potential that is unaffected by potential drop in the membrane and electrode edge →

effects. The use of an array of these electrodes allows accurate mapping of electrode potential across the entire active area of an operating PEMFC for the first time.

NPL has used this new technique to study corrosion of the carbon-based cathode catalyst support during start-up and shut-down of a PEMFC. The reference electrode array pinpoints exactly where and for how long the corrosion occurs, and can be used to evaluate mitigation strategies and improvements to hardware design. This unique test facility has been made available to transnational access users under the H2FC project – further details may be found at this link. Furthermore, several UK companies have already adopted the reference electrode technique in their commercial R&D, with many other fuel cell and component manufacturers around the world expected to follow suit.

Metallic bipolar plates are of increasing interest to automotive PEMFC manufacturers due to their low cost, high power density, ease of manufacture, high conductivity and good mechanical properties but minimising the undesirable effects of corrosion remains a key challenge. Unfortunately, reliable assessment of the applicability of stainless steels with a range of coatings and surface treatments has been hampered by a lack of representative ex situ test methods. To address this, ground-breaking work at NPL has characterised the local environment experienced by a bipolar plate during fuel cell operation via in situ measurement of pH and corrosion potential for an uncoated 316L stainless steel flowfield plate (Figure 2) in a single cell PEMFC .

This work has demonstrated conclusively that the degradation mode is more akin to corrosion in relatively dilute thin liquid layers, rather than the fully immersed conditions employed in conventional ex situ screening tests. A key observation is that the corrosion potential of the bipolar plate is largely independent of the potential of the nearest Pt electrode due to the low ionic conductivity of the discontinuous aqueous phase in the gas diffusion layer (GDL). However, localised polarisation of the steel can occur in the presence of oxygen as a result of galvanic coupling with the carbon GDL at wetted interfaces, a process which may be enhanced by the creviced geometry. As a result of these measurements, NPL has made recommendations for significant changes to the way corrosion testing is carried out on candidate materials, coatings and surface treatments. Standardisation of these new ex situ test methods will lead to more reliable and cost effective materials qualification testing, reducing supply chain and manufacturing costs.

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Examples of hydrogen and fuel cell activities at SINTEF

The SINTEF foundation is a broadly based, multidisciplinary research organisation that possesses international top-level expertise in technology, medicine and the social sciences. Hydrogen and fuel cell technology is one of many research areas where SINTEF is actively involved in the full range from fundamental research on materials and processes up to systems demonstration and validation. The present paper aims to give a brief introduction to some of the ongoing activities within the Sustainable Energy sector of SINTEF Materials and Chemistry.

PEM fuel cells and electrolysers

Within this sector SINTEF has specialized in materials for and processes in electrochemical energy conversion technologies. The main focus is on research related to PEM fuel cells, electrolysers and batteries, other activity areas include alkaline fuel cells and electrodes, as well as ion-selective electrodes. The vast experience and high competence on materials development and characterization as well as various electrochemical characterisation techniques is central in all these activities.

SINTEF is coordinating a significant portfolio of national and international projects related to several aspects of the development of PEM fuel cells and electrolysers. Over the last ten years the research activities have spanned from fundamental research on structure-activity relationships in electrocatalysis, characterisation of novel materials and components in fuel cells and electrolysers, evaluation of fuel cell systems and technology demonstration. In this period, the research groups involved have participated in a total of 12 FP7 projects in the field of low temperature fuel cells and electrolysers of which SINTEF has been/is the coordinator of 5.

The development of new catalysts with higher catalytic activity and durability are addressed in several ongoing projects and methods for production of a range of catalysts with high performances for fuel cells and electrolysers have been established. The advantages of using these catalysts are currently being demonstrated in fuel cell and electrolyser single cells and there is a significant need to increase the capacity and capability to perform such tests. It is also an increased interest from external users to validate their pre-commercial materials in fuel cells and electrolysers, further increasing the need for infrastructure for single cell testing.

SINTEF is also developing and testing low cost and durable coatings for metallic bipolar plates (BPP) for both PEM fuel cells and electrolysers. Research activities comprise of coating of metallic bipolar plates with a range of different coating methods, ex situ corrosion and contact resistance measurements and in situ accelerated lifetime testing with online spacial resolved contact resistance monitoring.

The study of degradation and lifetime limitations of PEM fuel cells have been a strategic focus for SINTEF during the last ten years and we have developed both in situ and ex situ methods to determine degradation processes of PEM fuel cell components and to propose mitigation strategies. The projects have varied from fundamental research on →

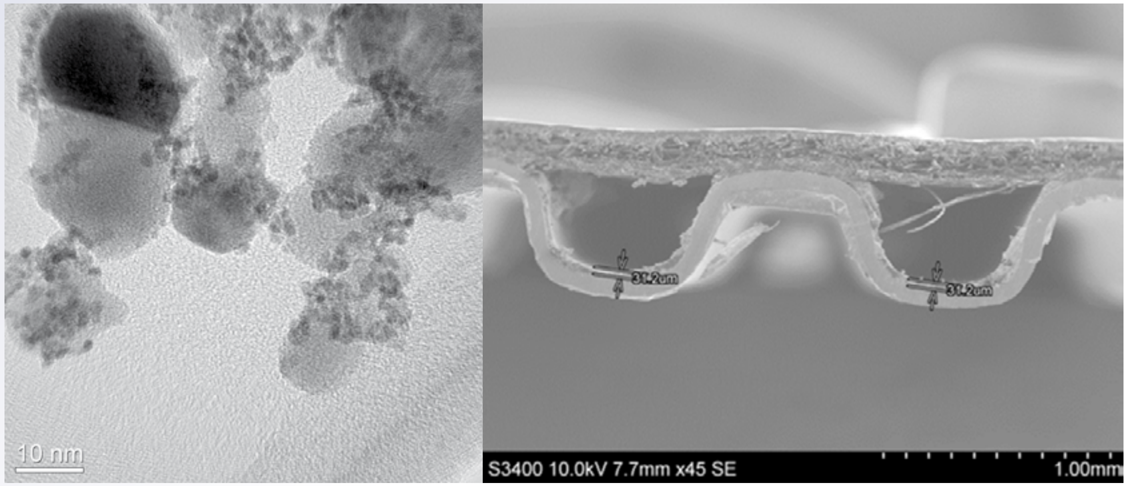

Figure 1: Examples of catalyst nanoparticles on support material (left) and of BPP combined with GDL by gluing (right).

→ thermal effects such as local temperature gradients influence on water transport to collaborative research and development of accelerated stress tests with European industry partners. Gas quality analysis and impact of impurities are also part of these activities.

High temperature membranes, fuel cell and electrolysers

SINTEF is involved in R&D activities on high temperature gas separation membranes for hydrogen production, recovery and purification, as well as high temperature fuel cells based on solid oxide electrolytes (oxygen ion- and proton conducting) for stationary and/or marine applications.

SINTEF has developed a unique membrane production technology based on thin Pd-alloy films supported on porous stainless steel tubes or micro-channels that gives very high hydrogen permeation (see Figure 2). Research is conducted with industry and with leading international groups in the field. Furthermore, ceramic mixed conducting dense ceramic membranes is a research area where SINTEF is focusing on the development of novel materials fulfilling process requirements (flux, stability), synthesis and shaping of planar and tubular membranes by scalable manufacturing routes, module design, assembly and testing.

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Figure 2: Hydrogen separation membranes prepared from thin Pd-alloy foils.

What are hydrogen jets

and why they are so important for safety provisions?

A gas jet is a coherent stream of gas that is projected into a surrounding medium, usually from some kind of a nozzle or aperture. So one of the associations with the word "jet" is quite obvious: a jet engine (Fig. 1) accelerates air in a continuous combustion process and thus generates a force which may drive the aircraft or integrated in a jet pack it might send you straight to sky, like Lars of Mars (Fig. 2).

Getting back to hydrogen safety the question might appear: "Why do you deal with jets in addition to some of them cut our skin?" Hydrogen, as long as stored in a container, is a very safe gas and does not pose any safety issues, as a pure hydrogen cannot react. The whole story changes when pressurised container or the piping network hs hydrogen leak.

Figure 1: A jet engine

Leaking gas could be in the form of plume when release velocity is small or jet for most of hydrogen releases from high pressure storage and equipment. Due to the overpressure in the container the hydrogen is injected with a high velocity (sonic and even super-sonic with storage pressure above about 40 bar) into the surrounding medium, which is air in the most cases. So a hydrogen jet is formed and in a certain region of this jet hydrogen and air are mixed, such that a combustible gas mixture is formed. The release rate and the mixing conditions determine the space covered by and the level of the associated hazard.

In past scientific work different approaches to describe these jets with increasing level of complexity have been investigated.

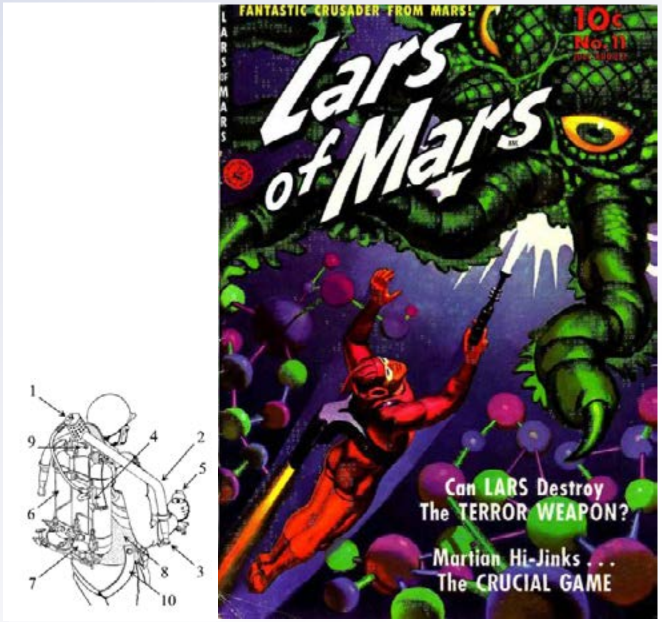

Figure 2: A classical jet pack application

The work started with rather slow free laminar jets of air into air, what implicitly avoids the complication of compressibility effects. Analytical solutions have been derived for these conditions. For momentum-dominated jets, when Froue number is relatively high, the properties like hydrogen concentration on the central axis can be scaled linearly with the inverse distance from release point and the distance to particular concentration is proportional to the release diameter. Thus, if the distance from the nozzle is transformed into a dimensionless distance by using the orifice diameter as the length scale, self-similarity of this simple jet model is observed. Figures 3 and 4 demonstrate different methods applied in jet studies The next step in approaching real world is accounting for the buoyancy effects. Hydrogen is about 14 times lighter than air, resulting in a very strong lifting force (what was used in the famous dirigibles). So the orientation of the orifice surface in relation to the gravity vector is now having an influence on the jet's shape. So when you eject hydrogen downwards it will soon return and look like an inverted fountain – if you could see hydrogen. A model for the buoyancy driven jet has been derived for instance by Xiao et al. [1]and resultsof simulations are shown in Fig. 5.

The next level of complexity is introduced by jets generated from pressurised inventories above the critical pressure ratio, which is already provided with a pressure in the container above 1.9 bar. With such pressures ratios hydrogen will be accelerated to the local speed of sound in the leak orifice. That means it reaches Mach number 1 and with further increase of storage ressure could exceed M=1 being supersonic! At higher pressures hydrogen has to go through very complex expansion processes and shocks when it has to adapt to the ambient pressure of 1 bar. These jets are called under-expanded jets. With modern CFD (Computational Fluid Dynamics) tools accounting for the compressibility effects these processes may be simulated with acceptable →

→ accuracy. However, the numerical costs are quite high. So instead some engineering solutions have been invented which bridge the well-defined zone upstream the release nozzle to the domain with the fully expanded gas. Some of these models are called virtual nozzle models, because they modify the real nozzle size and position to mimicking a release from a reservoir without the expansion zone, but with the same gas release rates.

From here we might try to introduce further levels of complexity related to jet studies. This is partially done withinexperiments in the transnational access and in the joint research of the www.h2fc.eu project. Phase change or a reaction of the mixed gases in the jet bring a lot of new physics and chemistry. The jets where hydrogen and air react are called ignited jets or jet fires. An ignited jet is preferred from the standpoint of safety. Although these jets generate quite considerable amount of heat into the environment – in fact, the heat release from an ignited hydrogen/air jet is far less critical compared to any other flammable gas/air jets. However, the fully mechanistic description of the heat transfer of a jet fire to surrounding structures is quite difficult and yet to be addressed further in detail (see Fig. 6 with snapshorts of hydrogen flame impinging on a barrier wall [2]).

Phase changes are observed when cold hydrogen is injected into humid air or when hydrogen is released from liquid containers at cryogenic temperature into the ambient. At such low temperatures – around 20 K – hydrogen has a similar density as air at standard conditions. In the mixing zone of the jet the entrained air will cool down and might even condensate. Condensation of water or even air in these jets acts like a volume/mass sink of the entrained air that "kills" momentum of hydrogen cold jet in humid air much faster compared to "normal" conditions.

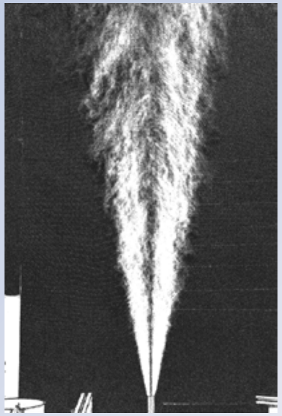
Fig. 3: Background oriented Schlieren photograph of a vertical hydrogen jet (source: KIT/HYKA)

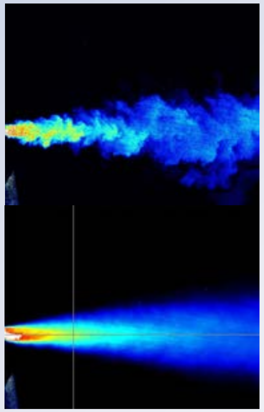
Fig. 4: A turbulent jet (top: laser snapshot, bottom: time averaged) (source: KIT/HYKA)

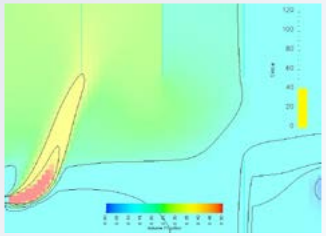
Figure 5: Buoyancy driven jet (KIT simulation of HySafe SBEP3


Figure 6: Impinging jet fire [2]

The final gaps to reality are to account for transient behaviour and include real geometries and structures in the surrounding. Actually there are neither stationary, nor free jets in reality. The gases might hit obstacles or a wall downstream (impinging jets), or might attach to parallel walls. Such wall attached jets can mix only on the free side with air, what increases the length of their flammable envelop. Another issue is, that a typical orifice generated in accidental conditions won't have a perfect circular shape. So some research is directed to the influence of the actual orifice shape.
Still a lot has to be done when it comes to jets and the full understanding of the associated phenomena and their safety implications.

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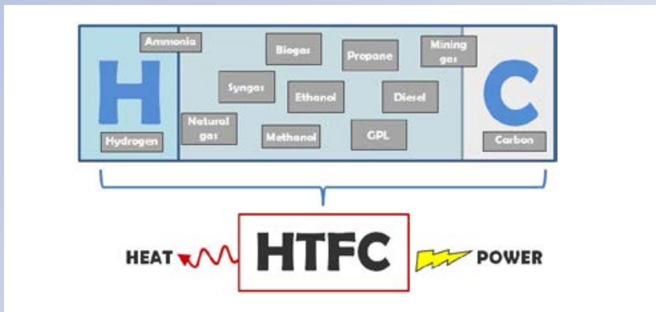
[1] Non-boussinesq integral model for horizontal turbulent strongly buoyant plane jets, J. Xiao, J. Travis, and W. Breitung, Proc of the 16th Int Conf on Nuclear Engineering, Orlando, Fla, USA, May 2008

[2] A study of barrier walls for mitigation of unintended releases of hydrogen; W.G. Houf, G.H. Evans, R.W. Schefer, E. Merilo, M. Groethe Int Journal of Hydrogen Energy 36 (2011) 2520–2529

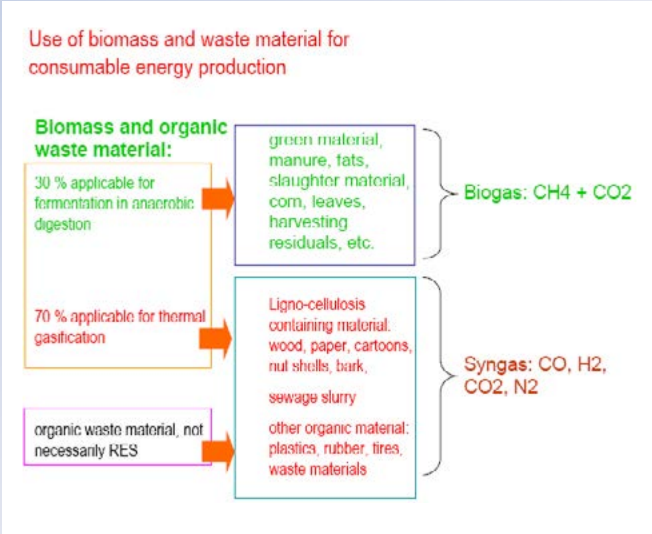
The biogas to high temperature fuel cell chain

Though a fuel cell is usually associated to the use of hydrogen – in particular this is the case for the transport sector and fuel cell electric vehicles (FCEV) – the term itself points to the flexibility of these electrochemical devices fom the point of view of the fuel (i.e. it is not called hydrogen cell). Especially where there are no stringent restrictions in terms of weight and footprint (such as in FCEV) and there is a necessity for high-quality power with low emissions, and a fuel available, there fuel cells can be employed to maximum flexibility and effectiveness.

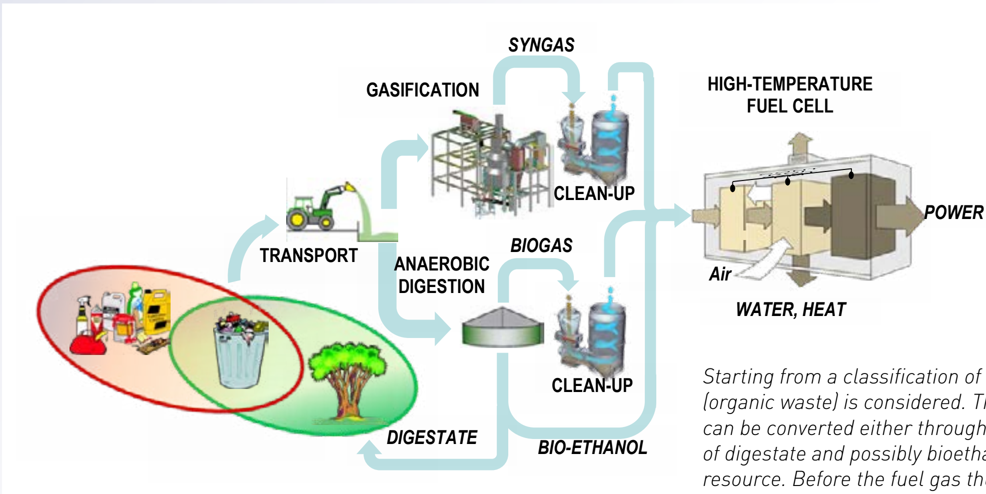


Fuel cells are the most suited technology for small-scale, clean and high-efficiency power generation; high-temperature fuel cells (HTFC, specifically molten carbonate fuel cells – MCFC – and solid oxide fuel cells – SOFC) in particular are suited to the biomass or waste-to-energy chain due to their capacity to convert carbon-based fuel. Carbon and hydrogen, together, are the building blocks of the life cycle on the planet.

The crucial link between the conversion of raw material to clean power is clean-up and conditioning. Thus, from any kind of feedstock, after opportune processing for the production of a viable fuel carrier (for example by gasification or anaerobic digestion), a thorough purification step is mandatory before the gas can be converted in a HTFC. This ensures both that the fuel cells perform and last longer and that the ultimate emissions will be equally pure, consisting of CO2 and water.

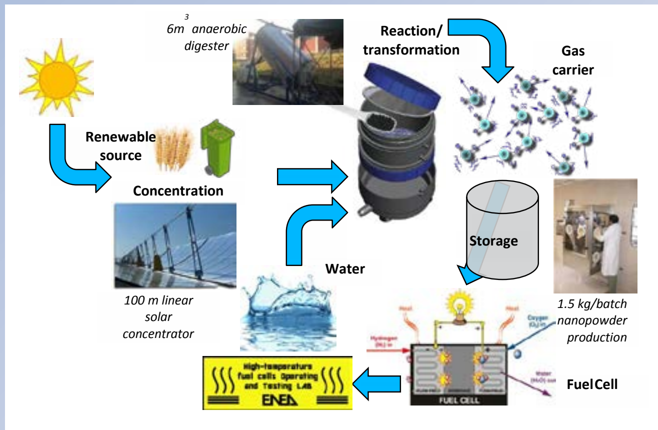


At ENEA, the entire chain from biomass to energy is under study and development, in close contact with industry, academia and the local territory. Several technological pathways are possible and most are investigated in the Technical Unit for Renewable Sources at the Casaccia research centre, just north of Rome. →



Starting from a classification of waste and biomass, the overlapping area (organic waste) is considered. This feedstock needs to be gathered and can be converted either through anaerobic digestion (with sub-production of digestate and possibly bioethanol) or gasification, depending on the resource. Before the fuel gas thus produced can be fed to a (high-temperature) fuel cell, in-depth cleaning has to be carried out

→ For the H2FC Infrastructure project, ENEA offers up-to-date research facilities for dealing with specific technological issues of some of the key links in the waste-to-energy chain.



Currently, Transnational Access is provided for the study of clean-up materials for biogas treatment, for the field testing of advanced optical equipment for biogas analysis and for the long-term testing of metallic components in SOFC stacks.

The potential of today's waste flows in terms of recoverable material and energy is enormous, but waste is often also a sink of undesirable and harmful leftovers and auxiliary elements which should be separated from the useful components. Optimization of the waste-to-fuel-to-energy chain therefore means finding the right balance in terms of manufacturing cost, operating reliability and technological complexity. ENEA can help to design the solutions for this challenge putting state-of-the-art facilities and years of research experience in the field at your disposal.

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H2FC Transnational Access Project:

Characterisation of high pressure hydrogen release flammability profiles

Introduction

Understanding of the dispersion behaviour of high-pressure hydrogen jets released in close proximity to a surface is not fully established. However, since there are indications that the extent of the flammable region is increased compared to a free-jet, a better understanding of this phenomenon is required to enable safety distances to be specified with greater certainty.

A group of researchers from Europe and Canada commissioned the Health and Safety Laboratory (HSL) in the UK to carry out experimental work using the HiPress facility (Figure 1). The HiPress facility is capable of holding 100 litres of hydrogen at up to 1000 bar, which may then be used for experiments such as those described here. The rig has previously been used for a range of research activities, including simulations of hydrogen vehicle refuelling station accidents and investigations into spontaneous ignition of hydrogen leaks.

The main aims of the research were:

- To gain a better understanding of the dispersion behaviour of an unignited high-pressure hydrogen jet released close to a surface, particularly the distance to the lower flammable limit (LFL)
- To gain a better understanding of the influence of surface proximity on ignited high-pressure hydrogen releases, particularly
- To generate experimental data with which to validate CFD modelling

Figure 1: HiPress rig at HSL

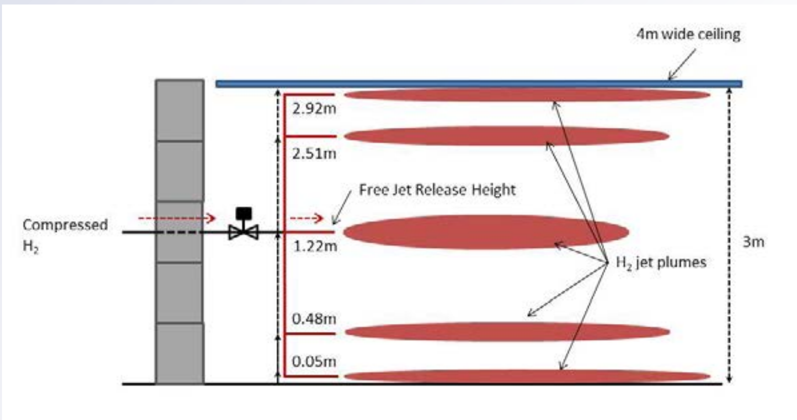

Figure 2: Release scenarios tested at HSL

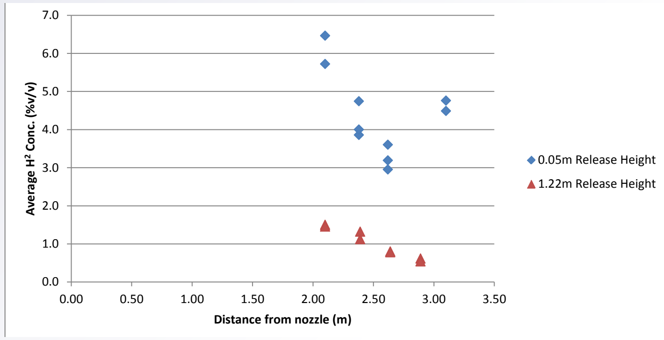

Figure 3: Comparison between distances to LFL for free-jet and ground releases

Release Conditions

Two flow conditions were chosen: 425 barg released through a 0.64 mm nozzle and 150barg through a 1.06 mm nozzle. The hole sizes quoted were used in order to keep the flow rate constant at approximately 7 g/s and a common distance to LFL.

Proximity to two surfaces were investigated; the ground and a ceiling, with releases at five separate heights: 0.05 m, 0.48 m, 1.22 m, 2.51 m and 2.92 m (Figure 2). 1.22 m represents a free jet height in which the ground and ceiling surfaces play no role in the evolution of the hydrogen jet plume. →

→Main Findings

- Distance to LFL increases the closer to a surface the hydrogen is released, in comparison with free-jet releases (Figure 3);
- The effect on the distance to LFL and the flame length is slightly less for releases close to the ceiling than was observed for releases close to the ground, probably due to buoyancy effects;
- The distance to LFL for a higher pressure release is increased compared with an equivalent lower pressure release at the same mass flow rate;
- The longest flame length was observed for a release from 425 bar through a 0.64 mm nozzle, 0.05 m from the ground. The flame length, 4.8 m, was two times the length of the equivalent free jet release (Figure 4).

This work was undertaken by the Health and Safety Laboratory under contract to EU Project H2FC. Its contents, including any opinions and/or conclusion expressed or recommendations made, do not necessarily reflect policy or views of the Health and Safety Executive.

This work was carried out with the support of the European Community, the European Research Infrastructure H2FC Project and its partner, the University of Quebec.

Phil Hooker, HSL

phil.hooker@hsl.gsi.gov.uk

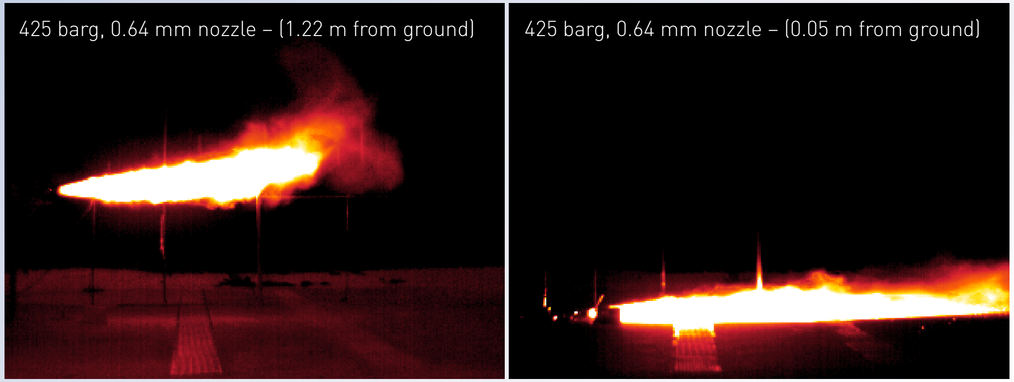

Figure 4: Comparison between ignited free-jet and ground release under equivalent release conditions

Research facilities in Empa and their use in H2FC

The Hydrogen & Energy laboratory at Empa addresses scientific questions and technological problems from hydrogen in solids to hydrogen as an energy carrier. The investigations range from the fundamental aspects of the hydrogen interaction with solids e.g. the physisorption and chemisorption of hydrogen on the surface, the hydrogen induced structural changes of solids like metal insulator transitions, the occupation of interstitial sites by deuterium and the thermodynamics of hydrogen in the lattice. Our experience ranges from hydrogen sorption in metals, hydrogen in metallic nanoclusters, hydrogen adsorption on carbonous nanostructures, electrochemical hydrogen sorption in intermetallic compounds to p-element complex hydrides. We have developed instruments for the specific investigation of hydrides and we have demonstrated several solid hydrogen storage systems.

Because of our experience in energy storage, Empa is a reference for synthesis, characterization and investigation of materials for hydrogen storage. Several Trans National Actions (few examples are listed below) were and will be established and the output of these scientific collaborations represents the state of the art of the current research on hydrogen storage and synthetic fuels.

Switzerland–The Netherlands

Raman spectroscopy on MgHx nanoparticles produced by spark discharge generation
Anastasopol Anca from Delft University of Technology measured in our Raman setup the signal from MgHx nanoparticles under different experimental conditions (temperature and pressure).

Switzerland–Spain

Catalytic combustion of hydrogen
Prof. Asunción Fernández from Consejo Superior de Investigaciones Científicas CSIC measured the catalytic combustion of hydrogen in the ad-hoc built reactor for gas conversion and methanation research.

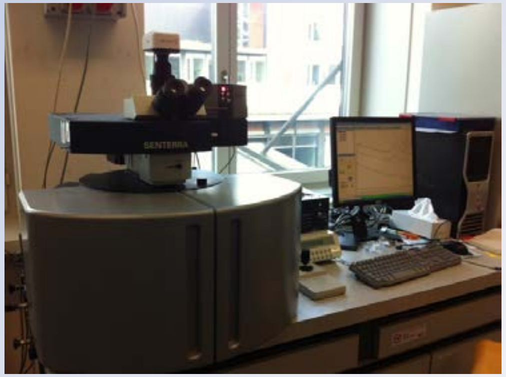


Fig. 1: Raman setup (left) and Raman cell for high pressure experiments (right).


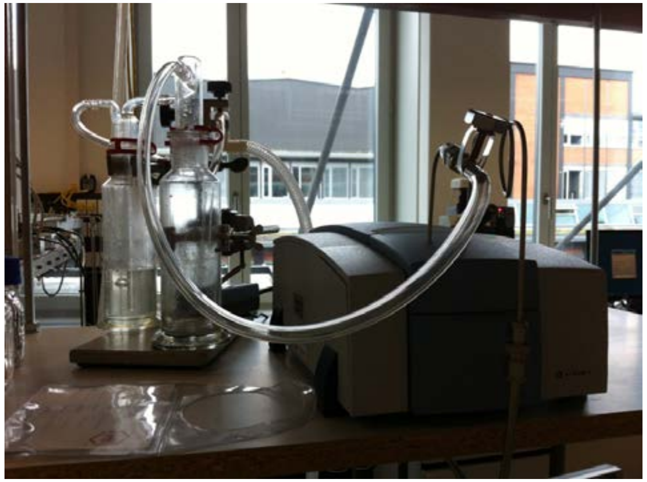

Fig. 2: Reactor for catalytic reactions (left) and IR spectrometer, monitoring the gaseous species.

New in the lab!

Bridging the Hydrogen Pressure Gap in XPS to Elucidate Hydrogenation Reactions

The understanding and the optimization of complex gas solid reactions such as the formation/decomposition of hydrides require insightful analyses of the elements present on solid surfaces. X-ray photoemission spectrometry is a powerful technique in this respect. A new experimental approach is used here in order to study materials exposed to high hydrogen pressures while keeping the analysis chamber in high vacuum.

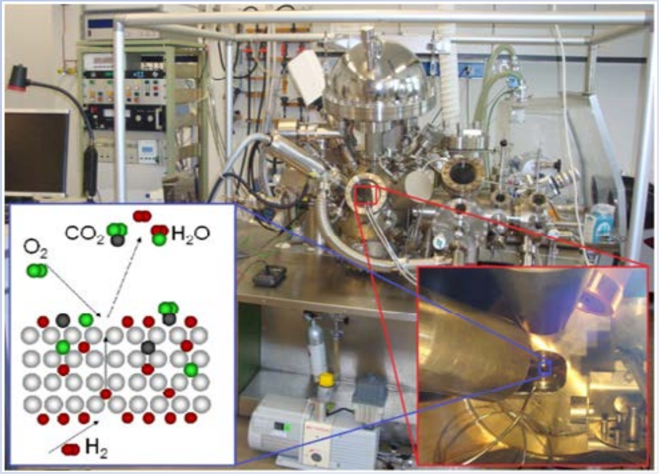

Figure 3: XPS setup in the Laboratory for Hydrogen and Energy at Empa. Bottom right inset: new membrane specimen holder for in-situ high pressure analysis. Bottom left inset: schematic representation of surface reactions on a Pd-H surface generated by hydrogen permeation through a Pd membrane.

The Hydrogen and Energy group is very active in dissemination and outreach of our scientific highlights and welcomes every year scientists from all over the world in the annual Symposium on Hydrogen and Energy. We are looking forward to the next edition in Emmetten in January! http://hesymposium.ch/

Elsa Callini, A. Borgschulte, A. Züttel, EMPA

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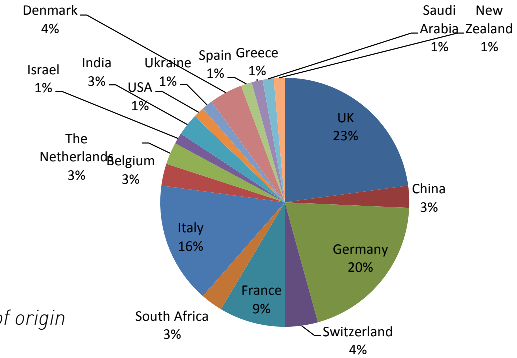
European Technical School on Hydrogen and Fuel Cells 2014

The Technical School (TS) is a key element of the networking activities within the H2FC project. The TS2014 was organised by the project partners and coordinated by the University of Ulster. The 3rd European Technical School on Hydrogen and Fuel Cells took place from the 23rd to the 27th of June 2014. The school was held at the Aegean Pearl Hotel, Rethymnon, Crete (Greece).

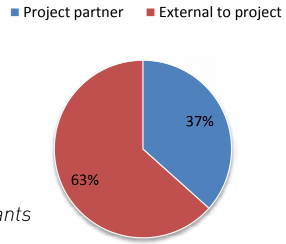
The sessions at the 3rd European Technical School addressed the themes of hydrogen safety, hydrogen production and storage, and fuel cells. The school was structured to ensure maximum synergy and cross-fertilization between these areas. The programme of the school included: lectures on selected topics of primary interest for the development and exploitation of the H2FC European infrastructure; work-in-progress poster session; a workshop on transnational access and instrumentation methods; Cyber Laboratory session, which consisted of two expert panels on hydrogen safety, hydrogen storage and fuel cells, and addressed scientific bottlenecks through modelling and simulations; an advanced research workshop followed by panel and round table discussions. For the first time participants of the TS2014 were able to test H2FC Sage Framework, especially adjusted to hydrogen and fuel cell models.

The popularity of the school is growing. In 2014, the technical school gathered 71 participants, the highest number so far compared to the schools held in 2012 and 2013. The participants, including academics, researchers and post-graduate students, came from 19 countries around the globe. Although the vast majority of them were from the EU states there were representatives from USA, India, China, Israel, Ukraine, New Zealand, the Republic of South Africa and Saudi Arabia. TS2014 brought together researchers and scientists from academia, research organisations and industry, as well as from different communities, i.e. hydrogen safety, hydrogen production and storage, fuel cells.

There were 45 participants from outside the project (12 external participants funded by the project, and 33 external, self-funded participants) and 26 participants from H2FC →



Country of origin



Ratio of external participants to project partners

→ partner organizations. Thus 63 % of participants were external to the project (compared to 41 % last year at TS2013). Those who received funding were asked to deliver either oral or poster presentations. Overall, during the school 9 topical lectures, 36 oral presentations and 9 posters were delivered. The contents of all sessions were replicated on USB drives and were given to the participants as a part of their delegate pack. Prior to the start of the school the materials from the TS2014 were made available to the participants within the designated area of H2FC website: https://iaikit-sp2.iai.kit.edu/h2fc/TechnicalSchool2014/

In general, the feedback from all the attendees was very positive. The majority of attendees would definitely recommend the school to others or plan to attend next school. It was announced that the 4th Technical School will take place at the end of June 2015.

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Towards the Italian Fuel Cells and Hydrogen Platform

The Italian Energy Strategy

One of the main weaknesses of the Italian productive system is the heavy dependence on importation of fossil fuels, mainly natural gas. In 2013, 50 % of its production was reliant on gas, importing 85 % from abroad, mostly from Algeria and Russia, two countries with high political instability. This makes the system critically vulnerable and any disruption or shortage in its energy supply could severely affect the Italian economy. The government in its efforts to improve its energy system and to achieve the commitments under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol, published, in March 2013, its National Energy Strategy. It specifies the objectives that will be promoted in the coming years to achieve major challenges in sustainable development and to ensure energy competitiveness respective to international concurrence. This strategy focuses on four main objectives: reducing the energy cost gap; achieving environmental objectives; improving security of supply; encouraging sustainable growth through development of the energy sector.

The Strategy also includes ensuring a close relation of R&D activities and prioritization of projects identified by the European Commission's SET-Plan. High priorities include the research on: renewable technologies and innovative solutions with low visual effect, on smart grids and storage systems, furthermore, materials and energy efficiency solutions, project development on methods of capture and confinement of CO2, and on research aimed at the exploitation of deposits of endogenous resources.

Those priorities are also highlighted in the Action Plan for Energy Efficiency published in July 2014.

The high energy efficiency that fuel cells can bring, along with the wide variety of resources that can be used as a fuel, make it an attractive technology to be considered in order to reduce GHG emissions and achieve economic growth. The development of fuel cell/hydrogen technology can open a diversity of markets to both budding and established Italian industry and thereby develop opportunities for substantial new jobs.

The Italian fuel cells and hydrogen community

In Italy it is evident the presence of an active scientific community on hydrogen and fuel cells, an industrial sector which is committed to turn the innovative technological opportunities of those technologies into effective business opportunities and several public institutions which are active in supporting the integration of the actions of the scientific community and industry.

However, those initiatives often remain dispersed and efforts not integrated with the result of the absence of a critical mass and a reduction of the probability of success in European and international funding programs. Activities are mostly performed by experts and involve the technical community, failing to arrive at the level of the decision makers which are indeed in the position to establish a national framework and identify guidelines and priorities in accordance with the other European countries. In fact, despite repeated attempts to stimulate a unique government intervention, a national platform on FC&H2 has not yet been launched as in other countries of the world, meanwhile the development of hydrogen as energy carrier requires a coordinated effort for the development of critical technologies for the whole hydrogen cycle (production, delivery, storage, conversions and end use applications) and the overcoming of barriers . in other words, it requires the Country system.

Promoting the Country system on fuel cells and hydrogen

The University of Perugia and ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic development), whose representatives are Prof. Gianni Bidini and Eng. Angelo Moreno, are promoting the establishment of the Italian Fuel Cells and Hydrogen Platform for the development of fuel cells and hydrogen in order to provide guidance on the priorities of the country system. The intention is to bring to the attention of decision makers the issues related to the development of hydrogen technologies and fuel cells and ask them concrete actions to define appropriate national strategies.

→

→ Main objectives of the Platform are:
1. to develop a strategy for research and development oriented towards the promotion of excellence and industrial competitiveness in the field of fuel cells and hydrogen (FCH2). The National Platform integrates and coordinates with the European Platform (FCH2-JU) and international programs;
2. to define a shared strategy for research, development, demonstration and Application (RSDA) to foster the competitiveness of the industrial national system and promote the progressive introduction of solutions compatible with the environment and sustainable for cost and quality, based on the use of FCH2;
3. to promote the hydrogen vector as regards as the reduction of CO2 emissions and their negative effects on the environment;
4. to involve national public and private operators in the definition of the vision and a strategic research agenda that, taking into account the specificity of the territory, identifies the priorities for the development and application of FCH2 and promotes the growth of skills and competitiveness of the country;
5. to promote the efficiency of the national system of research, development and Demonstration- application on FCH2 and avoid fragmentation for the benefit of the public and private investments;
6. to set up a short, medium and long term FCH2 perspective, by identifying the technical, organizational, financial, regulatory, educational and informative necessary tools.

More than 100 organizations between universities, research centers, public administrations and companies are cooperating at the establishment of the platform. It currently under performance the mapping of the Italian FCH2 community which will be hopefully finalized within the end of October 2014 and whose aim is to identify skills, activities and expected future developments.

http://www.europeanfuelcell.it/survey/

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International Conference on Hydrogen Safety

Objective

The objective of the International Conference on Hydrogen Safety (ICHS) is to improve public awareness and trust in hydrogen technologies by communicating a better understanding of both the hazards and risks associated with hydrogen and their management. Since the ICHS focuses on safety issues and measures to encourage more extensive use of hydrogen-based technologies, its contents are different from other hydrogen conferences.

The first five conferences were held in 2005, 2007, 2009, 2011 and 2013 in Pisa (Italy), San Sebastian (Spain), Ajaccio (France), San Francisco (US) and Brussels (Belgium), respectively. Their success showed that the matter of hydrogen safety is of interest to the public and to the scientific and engineering community.

The fourth and fifth conferences of this series were organized by HYSAFE together with European Commission and in collaboration with H2FC, and aimed to improve public awareness and trust in hydrogen technologies by communicating a better understanding of both the hazards and risks associated with hydrogen and their management.

In all the conference's editions the University of Pisa took care of the Scientific Programme.

Effort has been done in order to better coordinate the Conferences within the H2FCEuropean Infrastructure project. In fact, starting from 2013, a session within the ICHS conference is related to fuel Cells related safety issues (for example in 2013 it was "Sensors & FC/Electrolysis Safety"). This session is organized by H2FC European Infrastructure consortium. Moreover many H2FC European Infrastructure partners contributed, with papers, to the Conference.

ICHS conference series include thematic plenary sessions, topical lectures, and parallel oral and poster sessions. The conferences seek to facilitate (enable/strengthen) the near term introduction of hydrogen technologies in the market pla ce.

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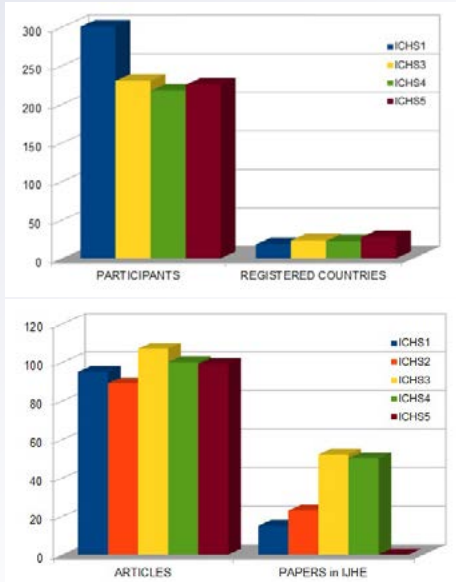
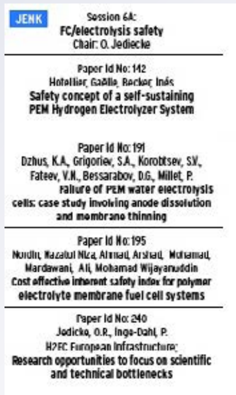


Some numbers


JENK

Session 6A:
FC/electrolysis safety
Chair: O. Jedicke

Paper Id No: 142
Hotellier, Gaëlle, Becker, Inés
Safety concept of a self-sustaining PEM Hydrogen Electrolyzer System

Paper Id No: 191
Dzhus, K.A., Grigoriev, S.A., Korobtsev, S.V., Fateev, V.N., Bessarabov, D.G., Millet, P.
Failure of PEM water electrolysis cells: case study involving anode dissolution and membrane thinning

Paper Id No: 195
Nordin, Nazatul Niza, Ahmad, Arshad, Mohamad, Mardawani, Ali, Mohamad Wijayanuddin
Cost effective inherent safety index for polymer electrolyte membrane fuel cell systems

Paper Id No: 240
Jedicke, O.R., Inge-Dahl, P.
H2FC European Infrastructure:
Research opportunities to focus on scientific and technical bottlenecks

Program of the FC Safety session on 10 September 2013

SESSION	ICHS1	ICHS2	ICHS3	ICHS4	ICHS5	ICHS6*
Legal Requirements and Standards	X	X	X	X	X	X
Hydrogen Behavior and Consequences	X	X	X	X	X	X
Ignition,Flammability, Fire and Explosion	X	X	X	X	X	X
Quantitative Risk Assessment, Safety Studies and Risk Mitigation	X	X	X	X	X	X
Production, Materials and Storage	X	X	X	X	X	X
Education, Training and Lessons learned	X	X			X	
Safety on Transport and Distribution	X	X	X	X	X	X
Safety Related Initiatives	X	X				
Sensors and FC/Electrolysis Safety					X	X
Mixed/blended H2 fueling stations and vehicles						X

* In progress

Next ICHS Advertisement

ICHS 2015 will focus on progress in safety of hydrogen technologies and infrastructure, as crucial/essential means to enable smart hydrogen solutions for global energy challenges.

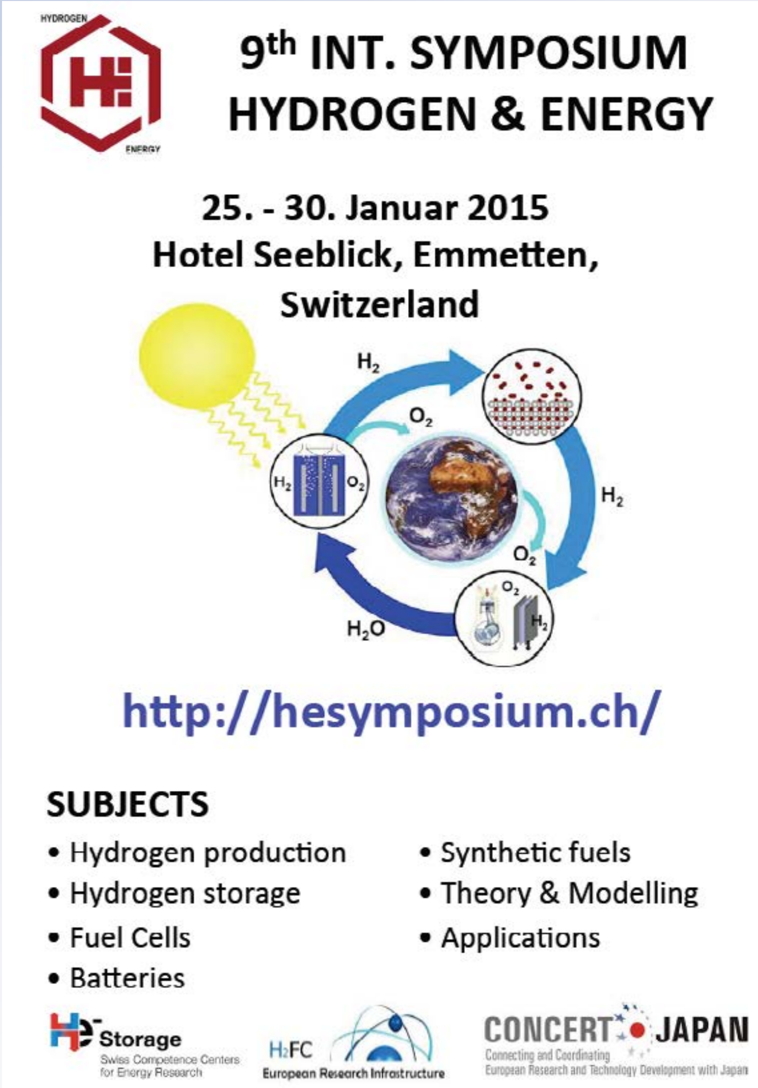
Alessia Marangon, Marco Carcassi, Industrial and Civil Department, University of Pisa, Italy.

carcassi@ing.unipi.it

Next H&E Symposium advertisement

The 9th International Symposium "Hydrogen & Energy" serves as an information platform of the fundamental science and the frontiers of research in Sciences and Technology of Hydrogen & Energy (Hydrogen Production, Hydrogen Storage, Hydrogen Applications, Theory and Modelling, Fuel Cells, Batteries, Synthetic fuels).

Prof. Dr. Andreas ZÜTTEL
Laboratory of Materials for Renewable Energy (LMER)Basic Science FacultyInstitute of Chemical Sciences and Engineering (ISIC)École polytechnique fédérale de Lausanne (EPFL) EMPA Materials Science and TechnologyDiv. Hydrogen & Energy, Dept. Energy, Environment and Mobility



Events January–May 2015

19.01.–22.01.2015	World Future Energy Summit, WFES 2015	United Emirates, Abu Dhabi
03.02.–05.02.2015	FSFC 2015	France, Toulouse
25.02.–27.02.2015	The Energy & Materials Research Conference, EMR2015	Spain, Madrid
25.02.–26.02.2015	International Fuel Cell Bus Workshop	USA, California
25.02.–27.02.2015	11th International Hydrogen & Fuel Cell Expo, FC EXPO 2015	Japan, Tokyo
09.03.–11.03.2015	9th International Renewable Energy Storage Conference & Exhibition, IRES 2015	Germany, Düsseldorf
09.03.–13.03.2015	4th International Conference on Multi-functional, Hybrid and Nanomaterials – Hybrid Materials 2015	Spain, Barcelona
March, April 2015	11thInternational Hydrogen & Fuel Cell Technical Conference	United Kingdom, Birmingham
13.04.–17.04.2015	Hannover Messe Group Exhibit	Germany, Hannover
21.04.–23.04.2015	Hazards 2015	Kuala Lumpur
27.04.–28.04.2015	HFC 2015, Hydrogen + Fuel Cells: Vancouver Hydrogen + Fuel Cells Summit	Canada, Vancouver
03.05.–06.05.2015	EVS 28, 28th International Electric Vehicle Symposium & Exhibition, including Fuel Cells & Fuel Cell Systems	Korea, Goyang
06.05.–07.05.2015	All-Energy 2015 Exhibition & Conference	United Kingdom,Scotland, Glasgow

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