H2FC e-newsletter

Issue 2
March 2015

Progress in Hydrogen and Fuel Cell Technologies

RESEARCH HIGHLIGHTS

UPDATE ON RESEARCH FACILITIES

COMMUNICATIONS

EVENTS

EDITORIAL 2

RESEARCH HIGHLIGHTS

Hydrogen technology permits to store CO_2 into fuel........ 4

Validation of the pressure peaking phenomenon 6

European H2FC Cyber-laboratory 8

Electrochemical hydrogen compression and separation: prospects and challenges 10

Thermal coupling potential between fuel cells and metal hydride tanks 12

H2FC TNA projects: Seeing the smallest atoms - neutron scattering investigations of novel hydrogen storage materials ...14

UPDATE ON RESEARCH FACILITIES

Neutron diffraction measurements under hydrogen atmosphere at cryogenic temperatures........16

COMMUNICATIONS

First responder training resources essential for transforming energy use 17

Final dissemination workshop of HyIndoor project 19

First international workshop on hydrogen safety training for first responders 22

FCH JU project "Support to safety analysis of HFC technologies" (SUSANA) 24

International Association HySafe: Research Priorities Workshop at US DoE 26

Global standards for hydrogen technology being made 27

H2FC EVENTS

European Technical School on Hydrogen and Fuel Cells 2015 (22-26 June 2015, Crete, Greece)........29

6TH International Conference on Hydrogen Safety (19-21 October 2015, Yokohama, Japan) 30

European Fuel Cell Technology & Applications Piero ....31 Lunghi Conference (16-18 December 2015, Naples, Italy)

CALENDAR OF EVENTS 32

Prof. Vladimir Molkov

Dear Colleagues,

Welcome to the 2nd issue of e-Newsletter "Progress in Hydrogen and Fuel Cell Technologies". This e-Newsletter is published by the European H2FC Research Infrastructure consortium to disseminate information and knowledge about main activities within the project "Integrating European Infrastructure to support science and development of Hydrogen- and Fuel Cell Technologies towards European Strategy for Sustainable, Competitive and Secure Energy" (www.h2fc.eu). The main driving idea behind this project is to bring together researchers from 19 leading European research organisations in the field of hydrogen and fuel cells, and scientists working in this field in Europe and beyond for productive collaborations to close existing knowledge gaps and technological bottlenecks. Transnational access (TNA) activities of the project allow researchers from all over the globe to apply for funding and access to world class facilities to carry out their experiments with the aid and expertise of the hosting project partners. The results of these TNA studies should be publicly available. As expected, this unique TNA aspect of the project is more popular in the final year of this four year project. Indeed, the project has become known to researchers in different countries due to the additional networking activities, including but not limited to European Technical Schools on Hydrogen and Fuel Cells (2012-2015, http://h2fc.eu/technicalschool), International Conference on Hydrogen Safety (next to be held in October 2015 in Yokohama, Japan), European Fuel Cells Technology & Applications Piero Lunghi Conference – EFC15" (next to be held in Naples, Italy, in December 2015), H2FC workshops, etc. The third H2FC thematic workshop titled "Integrating Safety Strategies and Engineering Solutions" was held in Emmetten (Switzerland) in the conjunction with the 9th International Symposium Hydrogen & Energy (http://hesymposium.ch/). At the end of this workshop the project coordinator Dr Olaf Jedicke moderated a lively round table discussion between international experts in safety and solid storage materials and system integrators. The third pillar of the H2FC project is joint research activities (JRA) of partners. JRA is aiming to further improve European infrastructure for hydrogen and fuel cell research, understand underlying phenomena, and develop new experimental methods and testing protocols to underpin smooth implementation of emerging HFC systems and infrastructure.

The project is unique in a sense that leading scientists from academia and research organisations are able to formulate and undertake fundamental research in the field. Indeed, whilst projects funded by the Fuel Cell and Hydrogen Joint Undertaking (FCH JU) are focused on today's industrial needs, this FP7 (Capacities - Research Infrastructure) project opens the opportunity for academics and researchers to formulate and proceed with a basic research agenda in the way they see it.

This e-Newsletter does not attempt to substitute any existing peer reviewed journal. The aim is to inform a wider range of stakeholders, including the European public, in recent progress in the area of hydrogen and fuel cell technologies. Authors were asked to make an effort to write their articles with a general audience in mind to facilitate understanding of current developments in the field not only by researchers but the public. Published contributions are rather short communications or notes than research papers. In addition to research highlights and updates of research facilities a reader could find here useful communications on recently finished and ongoing projects related to FCH research, relevant →

→ events like "HySafe Research Priorities Workshop" that was hosted in October 2014 by the US Department of Energy, as well as a calendar of forthcoming events.

The project will be formally closed in October 2015 and all partners acknowledge the European Commission for their continuous support of our research efforts to keep the leadership of European science in the field. To increase the efficiency of the EC funding of the infrastructure for hydrogen and fuel cell research, the H2FC consortium is currently investing in the development of e-Infrastructure that includes but not limited to H2FC Cyber-Laboratory and databases.

We hope that you will find our e-Newsletter informative and interesting for you and your colleagues. If you have any question, please feel free to contact the editorial board or the authors directly.

Yours sincerely,
Vladimir Molkov, co-editor, on behalf of the Editorial Board

Editorial Board

Hydrogen technology permits to store CO_2 into fuel

In the purpose of limiting world temperature increase, we need to reduce the global emissions of CO_2, the main greenhouse gas. One of the possible options is to capture and measure the emitted CO_2. The main issue is to find and to develop new applications using this molecule, while ensuring a favorable impact on the environment. The production of fuels starting from CO_2 could be one of the possible pathways to reach this aim; in fact the further use of this fuel will produce CO_2 as emission.

If the CO_2 comes originally from a fossil fuel, like when is separated from power plants off-gases, there is a secondary use of CO_2 increasing the energy produced from the same emission unit. If CO_2 is somehow taken from the environment, directly separated from the atmosphere or recovered from biomass treatment plants, the whole cycle becomes carbon free.

There are several technological solutions to transform CO_2 into a fuel, in general such products are hydrocarbon and require hydrogen to be synthesised. With the aim of producing a fully sustainable fuel hydrogen is produced by electrolysis from water. Figure 1 is a complete schematic of all possible pathways from CO_2 and H_2O to hydrocarbon fuel. From the combination of CO_2 and H_2O a synthetic gas called syngas can be obtained and is the first transformation step to obtain the final product. Syngas is a fuel mainly composed by CO and H_2 but also CH_4 and CO_2 are present in variable fractions. Currently the dominant syngas production process is coal gasification and methane reforming; the latter assures the highest H_2/CO ratio.

One solution to transform CO_2 while producing valuable syngas is the use of an electrolyser. CO_2 can be electrolysed into CO in high temperature fuel cells such as SOFC and MCFC. The electrochemical conversion of CO_2 can be performed by the use of carbon-free energies (such as solar or nuclear power) as a source of heat and electricity to allow the dissociation of CO_2. At the same time also H_2O can be transformed, in this case the process is called co-electrolysis. A promising means of efficient dissociation is achieved by high temperature electrolysis of CO_2 and/or H_2O in solid oxide cells (SOCs) to yield synthesis gas.

From the syngas obtained, is finally feasible to apply a liquid fuel synthesis, for example Fischer–Tropsch, which is a →

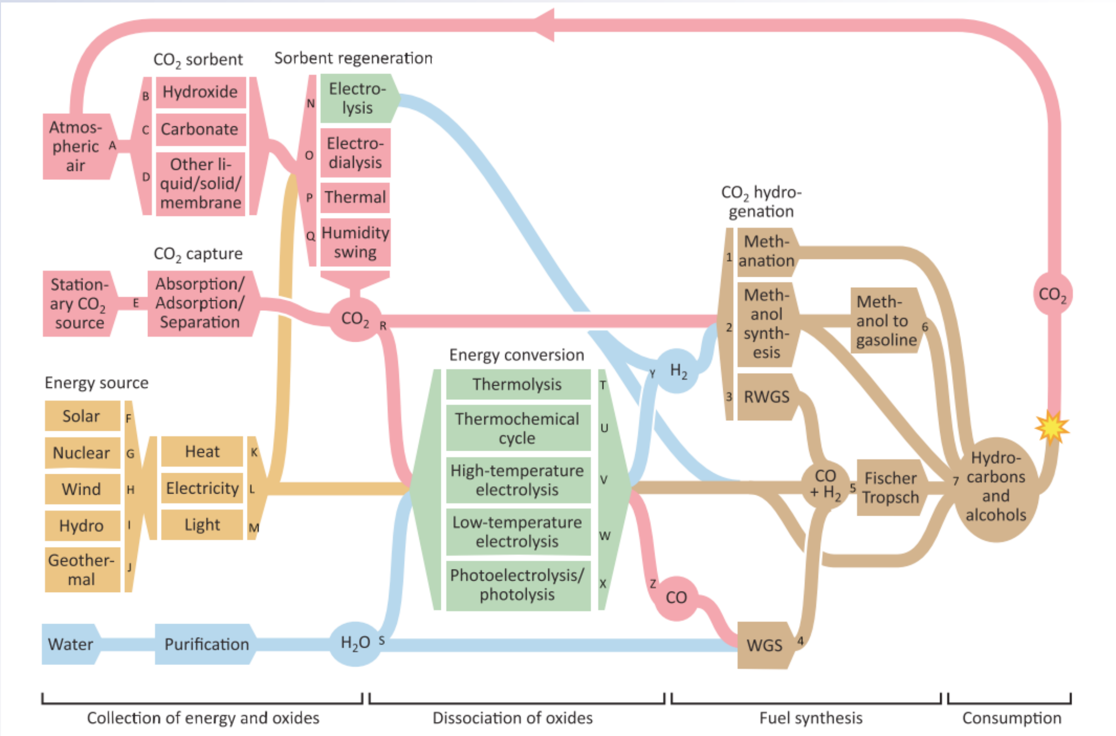


Figure 1: Pathways of CO_2 and H_2O to hydrocarbons fuel [1]

→ mature technology. The use of SOC for co-electrolysis (SOE) could be a reasonable choice from the point of view of different aims:

- Energy storage: power generation by RES is often unpredictable and troublesome to manage. Both for the national grids and for smart grid reality, storage of such energy can delay its utilisation and allow a more intelligent use of all the available sources. Concerning Europe, it could help the ratio of RES in the base load, reducing problem of regulation of the grid. The technology is convenient only if the electrical feeding comes from a renewable energy source, or an excess of power coming from some process, otherwise the storage and the reutilisation of energy is an intermediate step from the primary source to the final utilisation with a reduction of efficiency in the entire process;
- Production of syngas: this aspect is related to all consumers that require syngas for their applications. Here included the production of carbon-free fuel from syngas, for example using a Fischer-Tropsch reactor;
- Carbon Capture and Storage (CCS): according to the 2050 roadmap, the operation of the SOE in co-electrolysis helps the capture of CO_2, being it one of the reactants used for the feeding of the cell.

The combination of the three scenarios increases the convenience of the application. For sure an open topic is the size of the plant, especially between SOE, still facing the 100 kW scale up, and Fisher-Tropsch in orders of magnitude bigger. A trade off as to be found, probably closer to SOE technology thinking of a distributed energy system necessary to optimise electricity coming from RES.

The Fuel Cell Laboratory – University of Perugia is working on the concept of storing electrical energy into fuel using a co-electrolyser plus a Fisher-Tropsh reactor. The group is developing theoretical system models developed with Aspen Plus supported by experimental results obtained from SOE operation in co-electrolysis and small scale Fisher Tropsh reactor. Preliminary results, online with literature, show the feasibility of the concept able to store up to 70 % of electrical energy into liquid/solid fuel.

References

[1] C. Graves, S.D. Ebbesen, M. Mogensen, K.S. Lackner, Renew. Sustain. Energy Rev. 15 (2011) 1-23.

Giovanni Cinti, University of Perugia, Italy,

giovanni.cinti@unipg.it

Validation of the pressure peaking phenomenon

Introduction

The pressure peaking phenomenon (PPP) was discovered in 2013 by researchers at Ulster by carrying out analytical and numerical studies [1]. However, experimental evidence was missing until recently. PPP takes place when a gas is being released into an enclosure with vent(s). Usually one would expect that in such situation a pressure within the enclosure would grow monotonically from an initial pressure to a steady-state pressure somewhat above the initial one. Generally, this steady-state pressure depends on the flow rate of gas, volume and vent size of the enclosure. In the case of hydrogen the pressure dynamics is "strange" - a transient process of pressure change from the initial to the steady-state is not monotonous and undergoes the peak. It is a unique phenomenon that is characteristic only for hydrogen compared to other fuels. In fact, it can be observed to different extent for other gases lighter than air, e.g. helium.

A release of hydrogen from a pressure relief device (PRD) or ruptured pipework indoors can result in unacceptable overpressures within the enclosures capable of causing major damage and possible collapse of the structure. Figure adopted from [2] shows an example of the overpressure dynamics during hydrogen release from 35 MPa storage tank in a garage through a typical PRD of 5.08 mm diameter. The pressure dynamics has a distinguished peak. The destructive for civil structures like a garage overpressure of 10-20 kPa is exceeded in seconds. The steady-state overpressure of about 15 kPa is reached only after about 50 seconds from the start of release. Figure 1 also demonstrates that for the same mass flow rate of 390 g/s there is no pressure peak for propane, as it is heavier than air, and practically indistinguishable little peak for methane (as it is lighter than air).

The validation experiments were performed within the HyIndoor project, by the Karlsruhe Institute of Technology (KIT).

Methodology

This hazardous phenomenon takes place when a release rate is comparatively large and all vent(s) area is occupied by gases flowing out of the enclosure. Paper [3] presents the model and the nomogram to calculate the lower limit of hydrogen flow rate that would bring hydrogen concentration in enclosure to 100% by volume, i.e. when gases flow only out of the enclosure. The nomogram [2] was applied to pre-calculate this limit of gas release rate and vent height and width for experimental programme at KIT. Above this lower limit of flow rate the model of PPP described in [1] can be applied to calculate the dynamics of overpressure in the enclosure.

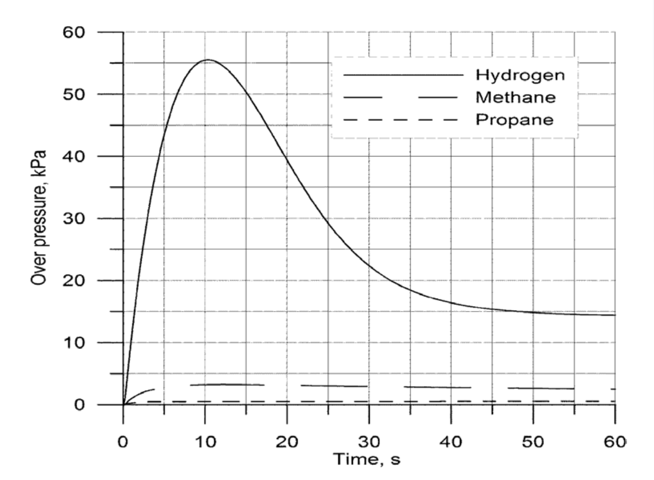


Figure 1. Pressure dynamics in a 30.4 m³ volume garage with a single vent 10 x 25 cm for a constant mass flow rate release of hydrogen, propane and methane of 390 g/s from 35 MPa storage through a 5.08 mm diameter PRD.

Experimental installation

The experimental installation is the framework structure of an enclosure of size HxWxL=1.00x0.98x0.96 m, which is made of aluminium profile rails 45x45 mm fixed together by assembly brackets, bolts and nuts. The internal diameter of the release nozzle is specified to 5 mm, located at the center of enclosure 10 cm above the floor and directed vertically upward. Round vent of either 10 mm or 16.5 mm diameter was located centrally at the top of the front panel.

Results

Experiments with release of gas into the vented enclosure filled with air are performed with two different gases: air and helium. Figure shows the results of experiments with release of 2.8 g/s and 1.44 g/s of air into the enclosure. Comparison with model prediction using the discharge coefficient CD=0.72 gave very good results both in pressure dynamics and steady-state overpressure. As predicted by the theory, there is no pressure peak in this case due to the fact that there is no difference in densities between the released gas (air) and gas initially being in the enclosure (air). Figure compares the results of helium release with mass flow rate of 0.5 g/s and 1 g/s into the enclosure with 10 mm and 16.5 mm vent

→ diameter respectively and the model predictions. The dynamics of the theoretical curve for the left figure tend to overestimate somewhat the experimental curve, while calculated overpressure dynamics on the right graph is just under the experimental pressure transient.

Conclusions

Four experiments with release of air and helium into vented enclosure were used to validate the model of pressure peaking phenomena (PPP). It can be concluded that the PPP can represent a new hazard and has to be accounted for when undertaking hydrogen safety engineering (HSE) design for all indoor HFC systems.

References

[1] S. Brennan and V. Molkov, Int. J. Hydrog. Energy, 38 (2013) 8159–8166.

[2] S. Brennan, D. Makarov, and V. Molkov, in Proceedings of the 6th International Seminar on Fire and Explosion Hazards, Leeds, UK (2010).

[3] V. Molkov, V. Shentsov, and J. Quintiere, Int. J. Hydrog. Energy, In Press (2014).

Volodymyr Shentsov*, Mike Kuznetsov**, Vladimir Molkov*
*HySAFER centre, Ulster University, UK,
v.shentsov@ulster.ac.uk, v.molkov@ulster.ac.uk
**Karlsruhe Institute of Technology, Germany,
mike.kuznetsov@kit.edu

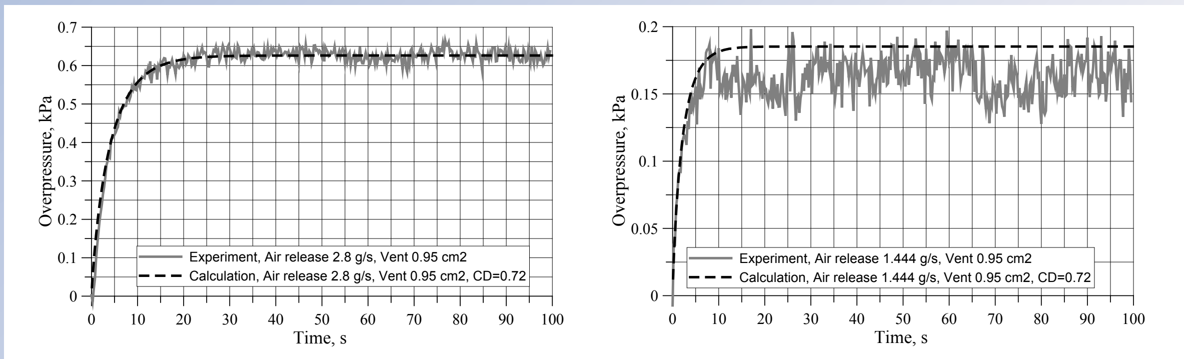


Figure 2: Pressure peaking phenomenon calculations (black dashed lines) against experiments (grey solid lines), air release 2.8 g/s (left) and 1.44 g/s (right).

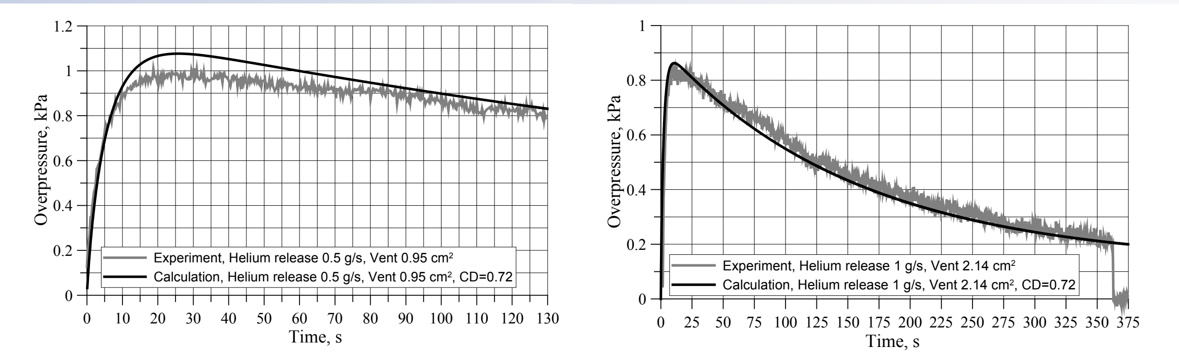


Figure 3: Pressure peaking phenomenon calculations (black lines) against experiments (grey solid lines), helium release 0.5 g/s (left) and 1 g/s (right).

European H2FC Cyber-laboratory

The H2FC European Research Infrastructure (http://www.h2fc.eu) Cyber-Laboratory provides open access, for European stakeholders, to modelling and engineering tools in the field of hydrogen and fuel cell technologies. The rationale for the establishment of the H2FC European Cyber-Laboratory stems from the fragmented nature of previous hydrogen and fuel cell research. This has led to shortfalls in the usefulness of developed tools with some areas of H2FC research being neglected, as well as a lack of experimental validation, review and testing of the tools and models developed. These inadequacies, in previous methods of hydrogen and fuel cell research, have led to the establishment of the H2FC European Cyber-Laboratory. As more modelling and engineering tools become available, and are added to this platform, an ever increasing spectrum of H2FC phenomena will be reliably addressed and made available to the H2FC community.

The Cyber-Laboratory has been created using three headings; namely Fuel Cells, Safety and Storage. Under each of these headings are the 'Modelling' and 'Engineering' tools related to each of these areas. For example, when considering Safety, under engineering tools there are currently a total of seven tools available including; the hydrogen jet parameters tool [1], two blowdown tools (Adiabatic and Isothermal), [2], two pressure peaking phenomenon tools (constant mass flow and blowdown), [3], [4] as well as a flame length and deterministic separation distance tool [5]. A fuel cell tool is also currently available which computes mass balances at the anode and the cathode of an operating PEM fuel cell [6]. A number of storage engineering tools and a number of additional safety tools are also scheduled for inclusion.

Regarding modelling, freely available software, 'HyFOAM' is currently under development for hydrogen safety science and engineering. Within this software, using the OpenFOAM CFD toolbox (produced by OpenCFD Ltd at ESI group), will be embedded selected physical models. As part of this modelling development two published (and peer reviewed) physical models are being implemented into this HyFOAM software suite. The first of these, a high pressure hydrogen release and dispersion model, is near completion and results obtained from this model are briefly introduced within the case study described below. The second model under development is the multi-phenomena deflagration model developed by the HySAFER Centre at the University of Ulster [2], [7]. Following this work other models will then be considered for inclusion, for example it is anticipated that a 2D fuel cell model developed by the Atomic Energy and Alternative Energies Commission (CEA) will also be made available to the HyFOAM software suite.

Each engineering or modelling tool provided to the Cyber-Laboratory will be accompanied by an appropriate description, or user manual where appropriate, which will detail the calculations performed, how each tool should be used, and most importantly, its applicability range and limitations. For inclusion an engineering or modelling tool must be associated with peer reviewed and previously validated research and publication(s).

It should be noted that 'HyFOAM' is the name given to the CFD modelling tools provided to the H2FC Cyber-Laboratory. Each model was developed using an appropriate OpenFOAM solver as a basis, then required modifications were made to the original source code in order to tailor it specifically to hydrogen and the scenarios under investigation. Open access to the source code, which allows for extensive customisability, is the core rationale behind choosing OpenFOAM for this work.

Example case study

This brief case study describes the implementation of a selection of the engineering and modelling tools on the H2FC European Cyber-Laboratory and how they can be used to analyse an experimental scenario, in this case the high pressure release and dispersion of hydrogen from an orifice. The experimental work used for this study was undertaken by Shell and the Health and Safety Laboratory (UK) [8],[9]. Quasi-steady-state regime of hydrogen release was targeted in the simulations. The main experimental details are as follows (NB: the atmospheric turbulence intensity and turbulence length scale were estimated from the experimental data provided):

- Nozzle diameter = 3 mm
- Release mass flow rate = 0.045 kg/s (hydrogen pressure = 10.0 MPa)
- Wind = 1.1 m/s (in the direction of release)
- Estimated atmospheric turbulence intensity, I=14.5 % (in pipe: I=3 %)
- Turbulence length scale, l=0.88 m (in pipe: l=0.07 ×D_H)

Simulations were undertaken using both ANSYS FLUENT and HyFOAM, for comparison, solving the Reynolds averaged Navier-Stokes equations. The same calculation domain was also used for both sets of simulations. As the effective nozzle concept was used to model the underexpanded hydrogen jet, the first step to create the calculation domain was to →

→ calculate the effective nozzle diameter. This calculation can be performed using the 'Hydrogen jet parameters' engineering tool available on the H2FC European Cyber-Laboratory. Using the provided experimental details the effective nozzle diameter was calculated to be equal to 0.021 m (as shown in Table 1 and Table 2). Using this value a calculation domain measuring L × W × H = 18 × 7.0 × 5.33 m, consisting of 227,040 CVs, was created.

Shown in Figure 1 are the results obtained from the ANSYS FLUENT and HyFOAM simulations performed. The ANSYS FLUENT solver used implicit linearisation of the governing equations, SIMPLE algorithms of pressure-velocity coupling, the MUSCL scheme for convection terms and the central-difference second-order accurate scheme for diffusion terms.

Input values

Hydrogen pressure in reservoir	p_1	100	bar
Hydrogen temperature in reservoir	T_1	287	K
Orifice diameter	d_3	0.003	m
Ambient pressure	p_4	1.01325	bar

Table 1: 'Hydrogen jet parameters' engineering tool: Input values

Output values

Density in the reservoir	ρ_1	7.93293693439089	kg/m3
Density at the orifice	ρ_3	4.85976216063454	kg/m3
Pressure in orifice	p_3	49.0397290763015	bar
Velocity in orifice	V_3	1213.602	m/s
Temperature at the orifice	T_3	235.5[illegible]	K
Diameter of effective nozzle exit	d_4	0.0210176659203809	m
Density in effective nozzle exit	ρ_4	0.10[illegible]35	kg/m3
Velocity in effective nozzle exit	V_4	1168.24231039099	m/s
Temperature in effective nozzle exit	T_4	238.669438669439	K
Mass flow rate	$\dot{m}$	0.0416892273503775	kg/s

Effective diameter = 0.021 m

Table 2: 'Hydrogen jet parameters' engineering tool: Output values

These settings were then also applied, where possible, to the HyFOAM simulations performed. The solver utilised throughout the HyFOAM simulations was 'reactingFoam'. As shown in Figure 2 both models performed well to provide results close to experimental data recorded.

Additionally, for this scenario, the H2FC European Cyber-Laboratory could also be used to estimate the required flame length and separation distance (should ignition occur), as well as the pressure dynamics resulting from this release if it was to occur inside an enclosure, rather than to atmosphere. An additional safety engineering tool to be added will also calculate the location of a user specified hydrogen concentration in an unignited jet. This tool could be used to further validate the simulation results.

Following the end of the H2FC project the European Cyber-Laboratory will be contained within the e-Infrastructure portal for H2FC research. The European Cyber-Laboratory will then form one of three sections within this e-Infrastructure, the other two being 'Education & Training' and 'Databases'. The goal of this work is to provide and make readily available, to European Stakeholders, a European Cyber-Laboratory that will be worth maintaining after the end of the H2FC project for the benefit of both the FCH scientific community and industry. Currently, access is only granted to registered users. If you wish to participate, please send an email to sharepoint@h2fc.eu.

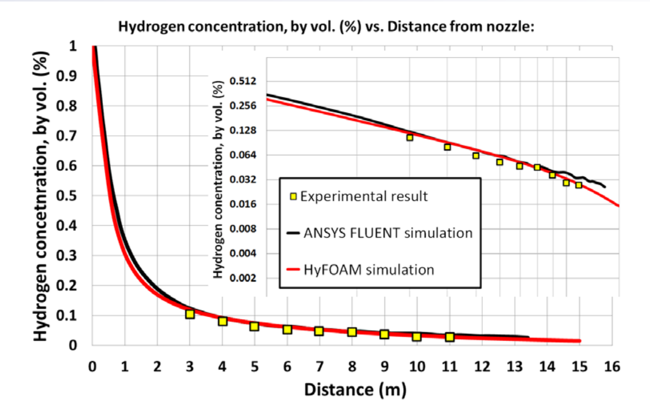


Figure 1: Comparison between experimental, ANSYS FLUENT and HyFOAM results

References

[1] V. Molkov and M. Bragin, Nonequilibrium Phenomena: Plasma, Combustion, Atmosphere, Torus Press Ltd, (2009) 332–338.

[2] V. Molkov, Fundamentals of Hydrogen Safety Engineering, parts I & II. bookboon.com, ISBN: 978-87-403-0279-0, 2012.

[3] V. Molkov, V. Shentsov, and J. Quintiere, Int. J. Hydrog. Energy, 39 (2014) 8158–8168.

[4] S. Brennan and V. Molkov, Int. J. Hydrog. Energy, 38 (2013) 8159–8166.

[5] V. Molkov and J.-B. Saffers, Int. J. Hydrog. Energy, 38 (2013) 8141–8158.

[6] J.-P. Poirot-Crouvezier, Ph.D. Thesis, Grenoble INP – Grenoble Institute of Technology, France (2000).

[7] J. J. Keenan, D. V. Makarov, and V. V. Molkov, Int. J. Hydrog. Energy, 39 (2014) 20467–20473.

[8] L. C. Shirvill, P. Roberts, C. J. Butler, T. A. Roberts, and M. Royle, Proceedings of the 1st International Conference on Hydrogen Safety, Pisa, Italy (2005).

[9] P. Roberts, L. C. Shirvill, T. A. Roberts, C. J. Butler, and M. Royle, Proceedings of Hazards XIX Process Safety and Environmental Protection Conference, Manchester, UK (2006).

James KEENAN, HySAFER centre, Ulster University, UK,

j.keenan@ulster.ac.uk

Electrochemical Hydrogen Compression and Separation: Prospects and Challenges

The Department of Science and Technology of South Africa developed the National Hydrogen and Fuel Cells Technologies (HFCT) Research, Development and Innovation (RDI) Strategy. The National Strategy was branded Hydrogen South Africa (HySA). The overall goal of HySA is to develop and guide innovation along the value chain of hydrogen and fuel cell technologies in South Africa. A promising possibility to utilise platinum-group metals (PGM) as electro-catalysts is to electrochemically compress hydrogen to reduce hydrogen compression and storage costs. The same principle can also be used for hydrogen purification.

A substantial capital investment will be required for the installation of a suitable hydrogen infrastructure for distribution to end-users, and utilizing the most efficient technology available from the start is of key importance. Current hydrogen storage and distribution methods account for about half of the exergy content of the hydrogen itself.

An electrochemical hydrogen compressor (Figure 1) typically consists of three functional components, i.e. a cathode, an anode and a membrane. The anode and cathode is connected to a DC power source that controls the current. Low pressure hydrogen is fed to the anode, where the hydrogen is oxidised to produce protons and electrons. The proton diffuses through the membrane to form discharged hydrogen and the electrons moves through the electric circuit. This process will continue until the supply of electricity or hydrogen is stopped.

Although PEM compressor cells have been known since the 1960's (Perry et al., 2008, Wong et al., 2004), limited work has been done on their development. Knowing the main limiting factors that influence the efficiency and throughput of electrochemical compression cells can aid to prioritise and identify areas for research. Comparing current experimental performance indicators with theoretical limitations can indicate the room of improvement and aid in setting development targets.

Expected areas of concern include membrane resistance, back diffusion, gas diffusion layer compression, gasket seal failure and water management.

Electrochemical compression offers a number of advantages over mechanical compression, (1) solid-state operation (no moving parts), (2) very low noise levels, (3) suitable for small scale operation and (4) relatively high efficiency (Rohland et al., 1998; Ströbel et al., 2002). It is likely that PEM compressor cells will have a significant role to play in fuel cell cars and hydrogen fuelling stations as well as small electrolyzer units that may form part of a decentralised hydrogen infrastructure.

The safety aspects of the electrochemical compression are also worth of mentioning. Hydrogen is fed on the low pressure side and discharged on the high-pressure side, thus eliminating a risk associated with high-pressure electrolysers, resulting in oxygen and hydrogen both present in the pressure vessel and separated just by a thin membrane.

HySA Infrastructure Center of Competence http://www.hysainfrastructure.org/ developed first in South Africa fully automated prototype of the EHC system. Figure 2 shows typical compressionresults and Figure 3 shows the EHC system.

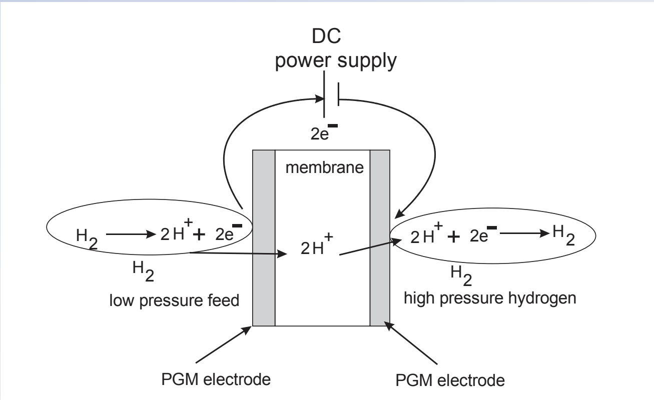


Figure 1: Schematics of the electrochemical hydrogen compressor.

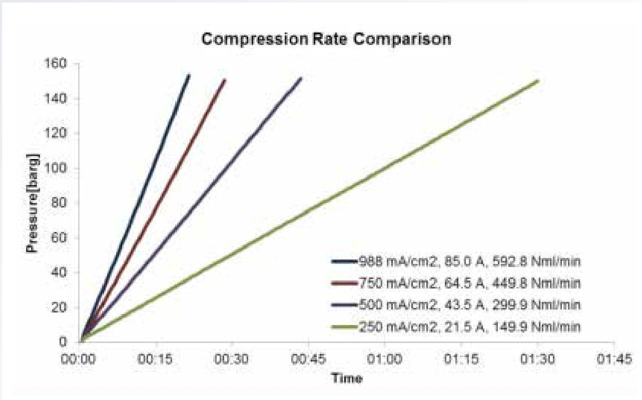


Figure 2: Typical H2 compression results.

Figure 3: Fully functional EHC system prototype developed by HySA Infrastructure.

→ The EHC system can also operate as a very efficient hydrogen separation unit. Conventional membrane-based separations and purification of hydrogen mixtures typically involve the use of polymeric membranes that do not provide sufficient selectivity as well as are not chemically and thermally stable. High-selective separations can be achieved by using palladium membranes that are rather costly. Electrochemical hydrogen separation combines high selectivity of separations as well as provide relatively affordable costs in comparison of palladium-based membranes. The typical flux densities of the hydrogen achieved in the electrochemical separation process are much higher than in conventional membrane separations. This is due to the fact that the mechanism of the hydrogen transport is fundamentally different in the electrochemical separation systems. Hydrogen is transported in the form of charge carries, e.g. in the form as protons, and the flux is proportional to the current density applied, but not to the concentration gradients between the feed and the permeate side. Selectivity values of the electrochemical separation are also very large as only hydrogen is anodically oxidized to form protons over a catalyst, typically, Pt, and the other components of the gas mixture, such as permanent gases, such as Helium etc., remain neutral charge.

References

[1] K.A.Perry, G.A. Eisman and B.C. Benicewicz, J. Power Sources, 177 (2008) 478-484.
[2] B. Rohland, K. Eberle, R. Ströbel, J. Scholta and J. Garche, Electrochimica Acta, 43 (1998) 3841-3846.
[3] R. Ströbel, M. Oszcipok, M. Fasil, B. Rohland, J. Jörissen and J. Garche, J. Power Sources, 105 (2002) 208-215.
[4] F. Barbir and H. Görgün, J. Appl. Electrochem., 37 (2007) 359-365.
[5] T. Wong, F. Girard and T. Vanderhoek, Electrochemical hydrogen compressor, US Patent Application: 2004 0211679 A1.

Dmitri BESSARABOV, North-West University, HySA Infrastructure Center of Competence, Potchefstroom, South Africa,

Dmitri.Bessarabov@nwu.ac.za

Thermal Coupling Potential between Fuel Cells and Metal Hydride Tanks

Efficient H_2 storage is a significant technological barrier towards the widespread application of hydrogen powered devices and vehicles, as the volumetric energy density of uncompressed hydrogen gas is very low. In this direction, metal hydrides (MH) are being considered as promising hydrogen storage alternatives due to their inherent high gravimetric hydrogen content, and significant scientific research is devoted to the development of MH-based upscaled storage systems and their testing (in terms of storage capacity, charging/discharging kinetics, reversibility and cycling, etc.) at different operating conditions [1]. As a matter of fact, commercial MH tanks became very recently available for stationary applications building on the distinct advantages of Magnesium Hydride, i.e. its high reversible gravimetric capacity (7.6% w/w), flat reaction plateau at low pressures, and low cost due to the abundance and facile extraction/processing of Mg. In particular, coupling and thermal integration of a solid oxide fuel cell with a magnesium hydride tank has been investigated at pilot scale in [1].

Hydrogen desorption from metal hydrides (MHs) is an endothermic reaction that requires significant heat fluxes to be provided to the MH bed in order to maintain the desired desorption mass fluxes. The production of the required thermal power for heating MH tanks eventually reduces the overall power efficiency of Fuel Cell (FC) systems, taking into account that part of the produced electrical power will be used at some point for the tank heating process.

The MH tank heating problem could be efficiently resolved by the design of integrated MH/Fuel Cell systems, where the excess thermal power produced from fuel cells under normal operating conditions is redirected towards a MH tank to sustain H_2 desorption. The feasibility and self-sustainability of such an integrated system can be studied by considering the basic thermodynamics of the elementary reactions taking place; namely hydrogen oxidation in the FC and hydrogen desorption in the MH tank. Besides thermodynamics, the dynamics of the coupled system should be studied in detail in order to optimise system design and determine typical operating conditions, where the desorption kinetics in the tank and heat transfer are both sufficiently fast for the production of the required electrical power.

From a thermodynamic point of view, Fuel Cells (FCs) are electrochemical devices that efficiently convert the Gibbs free energy of hydrogen oxidation directly to electrical work. The overall reaction is strongly exothermic with an enthalpy change approximately equal to $\Delta H_f=-240$kJ/mol H_2 (standard enthalpy of water formation). However, given that the entropy of the system is reduced during water formation ($\Delta S_f=-44$J/(kmol H_2O)), only part of this energy is available for producing electrical (non-expansion) work according to the change of the Gibbs Free Energy $\Delta G_f=\Delta H_f-T\Delta S_f$. Under standard conditions, approximately 220 kJ/mol H_2 are available for the production of electrical power in the FC. However, joule heating in the internal electrical circuit, and primarily in the membrane (ohmic overpotentials), is the primary source of energy dissipation in the system, resulting at approximately of 50 % energy loses (in the form of heat) at maximum power conditions. This eventually reduces to 110kJ/mol the amount of the produced electrical energy out of the initial 240 kJ/mol of the reaction enthalpy at standard conditions. This amount of energy easily covers the heating demands of even the most thermodynamically stable MHs available today, e.g. Magnesium Hydride with $\Delta H_f=-75$kJ/mol H_2, Sodium Alanate with $\Delta Hf=-45$kJ/mol H_2 etc., and thus we expect that such an integrated system can be self-sustainable from the thermodynamic point of view, namely it will not require the use of external heating sources, as long as it is efficiently designed for sufficiently fast heat transfer and minimum heat loses to the environment.

The basic parameter for selecting the appropriate MH and FC combination is the typical operating temperature of each component. The typical operating temperature of a FC, Tfc, is primarily a function of the composition of the ion conducting membrane that separates the anode and cathode porous electrodes and the basic electrochemical reactions occurring at the Membrane Electron Assembly (MEA). In the case of Proton Exchange Membrane FCs, for example, the electrodes are separated by a thin hydrogen ions membrane, e.g. Nafion, and water is formed at the cathode electrode. Such PEM FCs exhibit an optimal power production at $50<\text{Tfc}<100$ °C. In the case of Solid Oxide FCs (SOFC), the membrane is composed of a ceramic material conducting oxygen ions at temperatures well above $\text{Tfc}>600$ °C, while High Temperature PEM FCs operate at temperatures $140<\text{Tfc}<220$ °C.

This wide range of FC operating conditions has a profound impact both on the selection of the MH component for the coupled MH/FC system, as well as on the dominant heat transfer mechanism between the two components. Apparently, the MH for the integrated system should be selected so that it bears both sufficiently fast desorption kinetics at a temperature several degrees lower than Tfc, but also a sufficiently high →

→ pressure Van't Hoff plateau so that the tank satisfies the inlet H_2 pressure requirements for normal FC operation. Furthermore, the dominant heat transfer mechanism in coupled systems depends also on the typical operating temperature of each component and the required heat fluxes to maintain steady state desorption condition. For the case of lower temperature PEM fuels cells (Tfc<100 °C), convecting air cooling can be used to remove excess FC heat and maintain constant desorption rates at the MH tanks. At higher temperatures however, e.g. high temperature PEM FCs, where air moisture acts a strong oxidating agent for the metal parts of the integrated system, thermal liquids can be used for efficient heat transfer. For the case of very high temperature FC's, e.g. Solid Oxide Fuel Cells with a typical operating temperature above 600 °C, radiation could be a major mechanism for heat transfer.

Finally, the dynamics of such integrated systems require the solution of the coupled flow, heat and mass conservation equations, along with the appropriate desorption kinetics in the MH tanks, in order to optimise system design for efficient heat transfer and determine the typical operating conditions that fulfill power production requirements in the FC. Typical examples of three coupled systems are given in the following references; PEMFC with AB2-type MH [2], HT-PEMFC with Sodium Alanate [3] and SOFC with Magnesium Hydride [4].

Such studies have focused on integrated system design to optimise heat transfer and responsiveness from the FC to the external walls of the MH tank, and demonstrated that the poor effective thermal conductivity of MH medium itself (typical in the order of 0.1–5W/m/K) remains the most important barrier to heat transfer, at later times in the process and larger tanks, when the medium closer to the tank walls becomes concentration depleted and higher temperature gradients are required for evaporation from the central (core) part of the medium. Thus poor conductivity within the MH tank may lead to a rapid temperature and pressure drop that could eventually result in very low pressure of the produced H_2, failing to satisfy the required FC specifications.

References

[1] B. Delhomme, A. Lanzini, G.A. Ortigoza-Villalba, S. Nachev, P. de Rango, M. Santarelli, P. Marty, P. Leone, Int. J. Hydrogen Energy 38 (2013) 4740-4747.

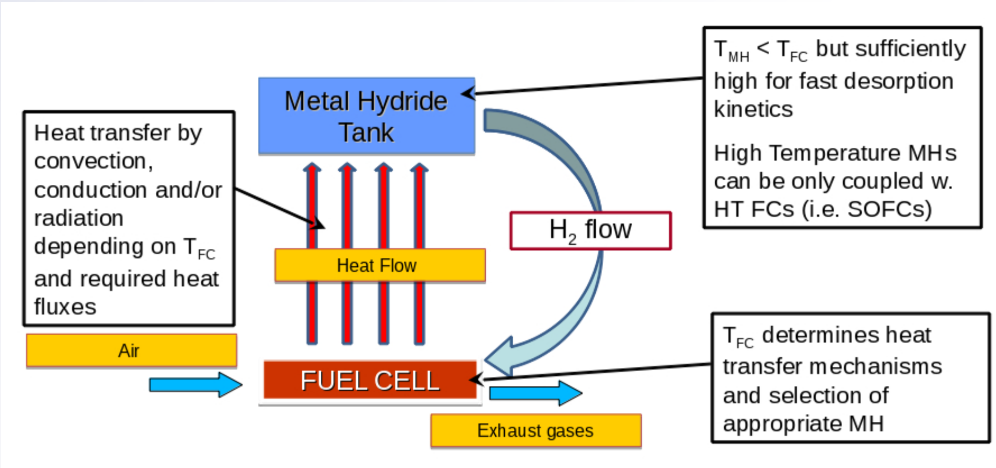
[2] B.D. MacDonald, A.M. Rowe, J. Power Sources 161 (2006) 346-355.

[3] A. Yiotis, M. Kainourgiakis, G. Charalambopoulou and A. Stubos, H2FC Technical Report (2014).

[4] A. Yiotis, M. Kainourgiakis, L. Kosmidis, G. Charalambopoulou and A. Stubos, J. Power Sources 269 (2014) 440-450.

Andreas Yiotis*, Michael Kainourgiakis, Georgia Charalambopoulou, Athanassios Stubos
*EREL, NCSR Demokritos, Greece,

yiotis@ipta.demokritos.gr



H2FC TNA projects: Seeing the smallest atoms – neutron scattering investigations of novel hydrogen storage materials

Hydrogen stored chemically bonded in solid materials is much more compact and safe than hydrogen gas stored under high pressure. An intensive effort is being made to improve hydrogen storage material to satisfy the entire list of demands for applications in vehicles: high hydrogen content by weight, rapid hydrogen absorption and desorption at moderate temperatures and pressures, low degradation on cycling, low price and non-hazardous properties.

In order to intelligently improve the properties of materials, it is necessary to know their structure at atomic level. X-ray diffraction is the dominant technique to reveal the structure of crystalline materials, but it usually fails to give reliable information about the position of light atoms in the presence of much heavier ones. Neutron diffraction is another technique which is equally sensitive to light and heavy elements and is therefore an invaluable tool to determine the structure hydrogen-containing materials (Fig.1). It is much less available than X-ray diffraction since large-scale facilities such as nuclear reactors or spallation sources are required to produce neutron beams of sufficient intensities.

The nuclear research reactor JEEP II at Institute for Energy Technology, IFE (Kjeller, Norway) (Fig.2a) is a part of the H2FC infrastructure and offer neutron scattering instrumentation for structural investigation of materials for hydrogen storage materials and fuel cell technology to European researcher. The instrumentation includes the high-resolution neutron diffractometer PUS (Fig. 2b) which has proven very effective for crystal structure determination of hydrogen storage material.

Five user projects have been performed with the PUS instrument under the H2FC transnational access program. Four of the projects concern the structure of materials based on borohydride anions (BH_4^-). All the users provided samples enriched with the isotope 11B since natural boron contains the

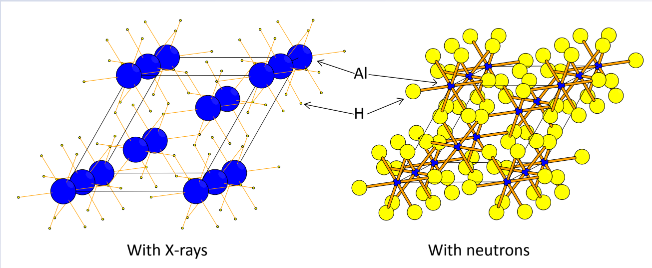


Figure 1: A hydrogen storage material (AlH_3) as seen with X-ray diffraction (left) and neutron diffraction (right).

strongly neutron absorbing isotope 10B. Moreover, the hydrogen isotope deuterium (2H or D) was used since natural hydrogen gives a high background. One of the projects concerned $LiCe(^{11}BD_4)_3Cl$, which is not only interesting for hydrogen storage but also as a Li-ion conductor for batteries. Neutron diffraction was necessary to locate both lithium and hydrogen (Fig. 3) which is necessary to understand the mechanisms of Li-ion conductivity. Two user projects concern ammoniated borohydrides, $Sr(^{11}BD_4)_2{\bullet}2ND_3$, $Mg(^{11}BD_4)_2{\bullet}2ND_3$ and $Mg(^{11}BD_4)_2{\bullet}6ND_3$ where the positions of the positively charged H on NH_3 relative to the negatively charged H on the BH_4 is particularly interesting, since they can easily recombine to neutral H_2 gas molecules. $Li_2(^{11}BD_4)Im$ is a porous material with bridging imidazolate (Im) ligands, the first of its kind, which may store hydrogen adsorbed on the surface →

Figure 2: a) The JEEP II reactor operated by IFE (Kjeller, Norway) is a neutron source for material science. b) The neutron diffractometer PUS at JEEP II is suitable to determine the structure of hydrogen-containing materials.

→ in addition to the bulk. Reliable information about orientations of the BH4 ions from neutron diffraction is essential to aid the synthesis of similar compounds. Lastly, the crystal structure of the intermetallic NdGa and its deuteride was investigated. NdGa is shows a magnetocaloric effect which can be tuned the hydrogen content and the materials is therefore relevant from a broader energy perspective.

Exciting H2FC experiments are scheduled for 2015, including measurements of hydrogen adsorption sites on metal-organic frameworks at cryogenic temperatures and hydrogen (proton) distribution in proton-conducting membrane materials for PEM fuel cells!

Magnus H. Sørby, Institute for Energy Technology, Norway
magnuss@ife.no

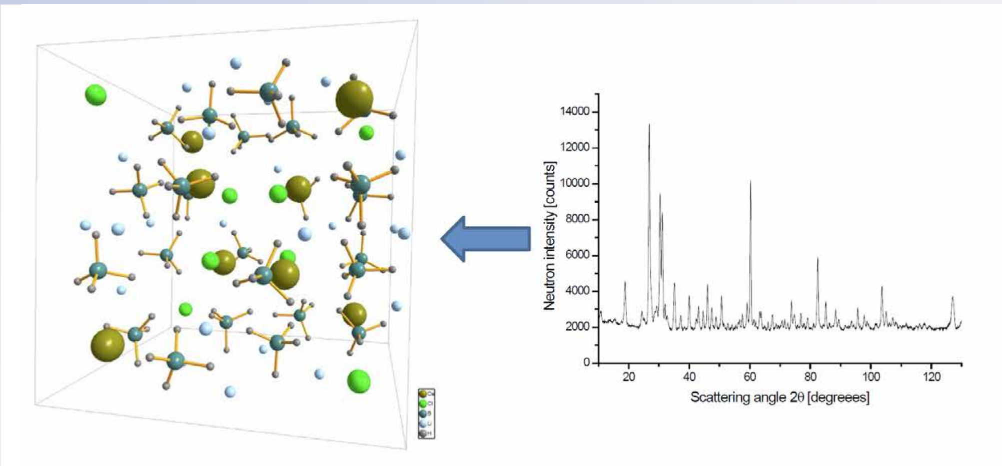


Figure 3. The crystal structure of LiCe(BH4)3Cl (left) as determined from neutron diffraction data (right).

Neutron diffraction measurements under hydrogen atmosphere at cryogenic temperatures

Neutron diffraction is the best and often only experimental technique to locate hydrogen atoms in crystalline solids such as hydrogen storage materials. The H2FC infrastucture JEEP II (IFE, Kjeller, Norway) offer European researchers the possibility to collect neutron diffraction data for materials under various conditions, e.g. at temperatures ranging from 8 to 1300 K.

Measurements under hydrogen atmosphere were originally limited to ambient and elevated temperatures. Due to requests from users, the infrastructure has recently been upgraded to allow measurements under hydrogen atmosphere at low temperatures. This is particularly useful for the investigation of hydrogen adsorption on high-surface materials such as metal-organic frameworks.

The upgrade posed some engineering challenges due to the size of the sample container and the limited space inside the cryostat, but the system works well and is being used in an on-going user project.

Magnus H. Sørby, Institute for Energy Technology, Norway

magnuss@ife.no

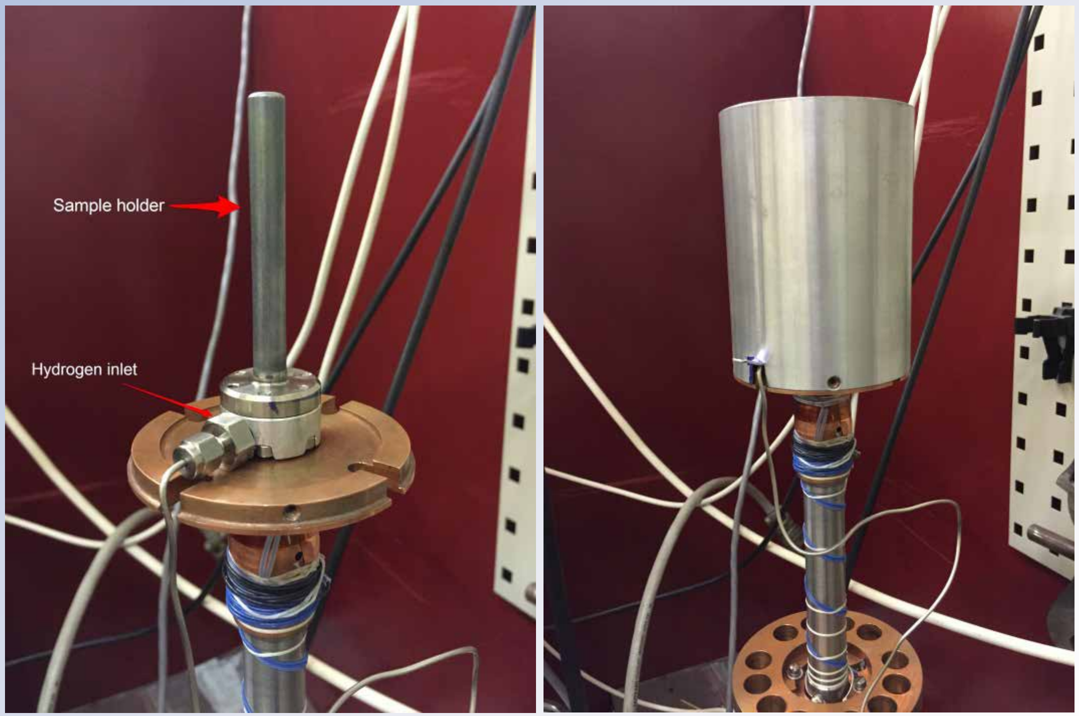


Figure 1: Left: The modified neutron diffraction sample container with an inlet for hydrogen gas at the bottom, mounted on the cold finger of a cryostat. The sample is contained in the hollow, cylindrical part of the sample holder. Right: The modified sample container is inside the first of three aluminum temperature shields required to reach temperatures down to 8 K.

First Responder Training Resources Essential for Transforming Energy Use

A properly trained first responder community is critical to the introduction of hydrogen fuel cell applications and their transformation of how we use energy. Resources that provide accurate information and current knowledge are essential to effective hydrogen and fuel cell related first responder training programs. Hydrogen and fuel cell emergency response information has been included in multiple training programs in the United States. Examples include the U.S. Department of Energy's Hydrogen Emergency Response Training for First Responders, developed and managed by Pacific Northwest National Laboratory (PNNL), and a program developed by the California Fuel Cell Partnership (CaFCP) for the California Office of the State Fire Marshal. Additionally, emergency responder education for alternative fueled and electric vehicles, including hydrogen fuel cell vehicles, has been developed and delivered by the National Fire Protection Association (NFPA) and other organisations around the United States.

To help advance first responder training efforts, PNNL has developed a three-tiered hydrogen safety education program using the Occupational Safety and Health Administration and NFPA frameworks for hazardous materials emergency response training. The first tier of the program was initiated in 2006-2007 with the development and distribution of an online course, Introduction to Hydrogen Safety for First Responders (http://hydrogen.pnl.gov/FirstResponders/), designed to provide an awareness-level overview of hydrogen to help first responders

- Understand the properties of hydrogen, how it compares to other fuels and the safety mechanisms of hydrogen systems
- Recognize and identify hydrogen vehicles, stationary power generators, storage containers and refuelling equipment
- Identify typical ignition sources and other potential hazards and
- Execute initial "awareness-level" response actions.

The course has had over 31,000 visitors to date. In moving forward, PNNL is working with the National Fire Academy (U.S. Fire Administration) to enable a wider distribution of the training materials and to better support participant certification.

The second tier of the program is an operations-level classroom curriculum developed in 2008-2009 that includes a fuel cell vehicle burn-prop for hands-on training. The classroom content covers hydrogen and fuel cell basics, hydrogen vehicles, stationary facilities, emergency response and incident scenarios. Hands-on training demonstrates hydrogen flame characteristics using props for student participation in rescue evolutions. The course has been delivered to 1,000 participants at fire training centers in Washington, California and Hawaii, where hydrogen and fuel cell technologies are being developed and deployed.
New approaches can help meet the specific needs of first responders and presentation styles of training organizations and can complement existing training programs. The experience gained from developing and deploying the first two program tiers led to the third tier: a collaborative effort between PNNL and the CaFCP to develop a National Hydrogen and Fuel Cell Emergency Response Training Resource. The resource is intended to be a single repository of current, accurate hydrogen and fuel cell-related information and to reduce duplication among training programs. This approach should enable government and private training →

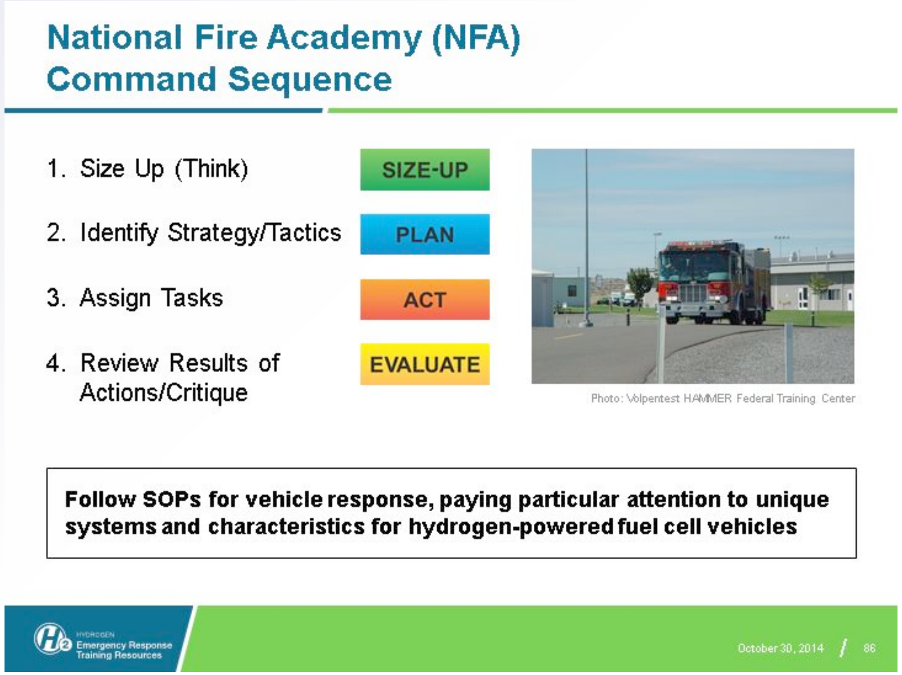


Figure1: An example slide from the National Hydrogen and Fuel Cell Emergency Response Training Resource.

organizations to develop their own programs based on consistent and current content and messaging about hydrogen and fuel cells [1].

The national training resource uses PowerPoint to provide a large amount of quality information for first responder training organizations. The 130 slides are divided into six sections covering the background and overview of fuel cell technologies, hydrogen and fuel cell basics, hydrogen-fuelled vehicles, stationary facilities, management of hydrogen-related emergencies and practical exercises. PowerPoint note pages are included with the slides to help instructors tailor and incorporate content to meet their needs.

These materials are adaptable for different presentation styles, from higher level overviews to more comprehensive classroom training. A training template accompanies these materials to guide the delivery of a variety of training regimens to various audiences. Three example uses of the slides are provided in a companion Word file. The slides and Word file are available as a free download at http://h2tools.org/fr/nt/.

To remain vital and useful, these resources require concerted efforts beyond general maintenance. Future initiatives will focus on new presentation materials and methods to enhance the learning experience, including new images, videos and 3-D simulation tools. There may also be opportunities to integrate these hydrogen and fuel cell resources with other alternative fuel training programs to reach broader audiences. Regardless, this effort will include collaboration with a variety of first responder trainers, facility and equipment providers and other interested persons to ensure its relevance and efficacy.

References

[1] Barilo, N., "The H Factor," NFPA Journal, May/June 2014, available online at http://www.nxtbook.com/nxtbooks/nfpa/journal_20140506/index.php#/80.

Nick BARILO, Pacific Northwest National Laboratory, Richland, WA 99354, USA

nick.barilo@pnnl.gov

Final Dissemination Workshop of HyIndoor project

HyIndoor project, sponsored by Fuel Cell and Hydrogen Joint Undertaking (FCH JU) had run from 2012 to 2014. Its objective was to perform pre-normative research on safe indoor use of fuel cells and hydrogen systems. The project addressed the issue of safe indoor use of hydrogen and fuel cells systems for early markets (e.g., forklift refuelling and operation, back-up power supply, portable power generation, etc.). It aimed to provide scientific and engineering knowledge for the specification of cost-effective means to control hazards specific to the use of hydrogen indoors or in confined space and develop state-of-the-art guidelines for European stakeholders. It was carried out by a team including representatives from industry, government research centers and academia. The following ten partners had participated in the HyIndoor research:

- L'Air Liquide SA (France)
- The CCS Global Group Ltd (UK)
- Commissariat a l'Energie Atomique et aux energies alternatives (CEA, France)
- National Center for Scientific Research "DEmokritos" (Greece)
- Karlsruher Institute fur Technologie (KIT, Germany)
- Health and Safety Executive (HSE-HSL, UK)
- HyGear Fuel Cell Systems B.V. (HFCS, The Netherlands)
- Ulster University (UK)
- Lagrange SARL (France)

The research was structured around three major areas – hydrogen accumulation and dispersion in enclosed spaces, vented deflagrations, and hydrogen fires in confined spaces. The results of the three years of research were used to compile guidelines for indoor fuel cell installation and use, and also to report on recommendations for RCS. These results were presented to the public at the Final Dissemination Workshop of HyIndoor project, which took place December 11, 2014 at Les Loges-en-Josas, France. The workshop had been attended by fifty participants from nine countries representing stakeholders from both industry and academia.

The workshop was intended to present to interested stakeholders the outcomes of the HyIndoor research which had been included in Guidelines and Recommendations to RCS. For this purpose the presentations by project partners were arranged to reflect the structure of the Guidelines and to include major research findings which were used to formulate the recommendations.
The recommendations were aimed at creating inherently safer application of hydrogen and fuel cell technologies in enclosed spaces.

In order to disseminate these findings, an invitation to attend had been distributed to the leading European stakeholders, working in hydrogen safety area, including representative of academia, industry and regulating authorities.

The principal part of the workshop consisted of 13 presentations by project participants, organized in six sessions. The following topics had been presented:

Session 1 "General safety strategies for inherently safer hydrogen use indoors"

- Safety objectives, phenomena and consequences map
- General rules, best practices and safety strategies

Session 2 "Ventilation of unignited releases"

- Passive and forced ventilation systems with one vent
- Comparative analysis of ventilation with one and two vents
- Pressure peaking phenomenon validation

→

Figure1: Workshop picture

Session 3 "Mitigation of hydrogen indoor deflagrations"

- Vent sizing correlation for low strength equipment and buildings
- Localized mixture deflagrations: Inventory limit and mitigation by venting
- Overview of experimental findings in HyIndoor project

Session 4 "Dealing with hydrogen jet fires"

- Jet fire experiments in laboratory scale facility
- Observations from real scale indoor fire experiments
- CFD and engineering tools for fire characterization

Session 5 "Sensors for hydrogen detection"

- Assessment of sensor performance and selectivity

Figure 2: well-ventilated jet-fire

Session 6 "Concluding session and roundtable discussion"

- Proposal for RCS amendment and practical examples

Presentations were followed by a round table discussion, which involved both project participants and representatives from the industry and academia attending the workshop. Discussion involved the proposed recommendations for inclusion into RCS materials, a strategy for dissemination of the results to the national/international regulatory bodies, and knowledge gaps left unresolved following the project.

Suggestions for inclusion in RCS stemming from the project research results had been reported, discussed and agreed upon by the project partners. The following 18 recommendations had been proposed for inclusion in RCS documents:

Figure 3: IR image of vented deflagration through passive vents

- Account for the effect of thickness of the wall supporting the ventilation vent (thicker wall can inhibit vent efficiency)
- Account for the effect of horizontal ducts (should be avoided as they inhibit ventilation)
- Account for the effect of vent position (wall location is preferable over the roof one)
- Account for the effect of rain cover (can inhibit ventilation)
- Account for the effect of the height of the single vent location (Higher location on the wall is preferable)
- Account for the effect of obstruction in front of vent openings (should be avoided as it inhibit ventilation)
- Account for the effect of vent shape (for the same area, vertically stretched vent is more efficient than horizontally stretched one)
- Methodology for calculation of maximum hydrogen concentration for the steady release in the enclosure with one vent using passive ventilation model
- Modelling approach for calculation of hydrogen concentration for the steady release in an enclosure with two openings natural ventilation.
- Account for the effect of number and location of vents (multiple vents at different heights and on opposing walls are preferable to a single vent of the same area)
- Account for the effect of vent distribution (multiple vents should be located as low and as high as possible for the maximum separation distance)
- Mitigation of hydrogen build-up in cases of passive/natural ventilation being insufficiently effective (through using forced ventilation, devices limiting flow rates and detection devices)

→

- Account for the effect of pressure peaking phenomena (PPP, vent sizing should be designed to exclude damaging effects of PPP)
- Mitigation of deflagration effects through limitation of hydrogen inventory and methodology for calculation inventory upper limit (if it is necessary to have higher hydrogen inventory, additional safety measures, such as passive or force ventilation, or provision of pressure relief vents should be utilized)
- Methodology for calculating vent sizing for deflagration in low strength equipment and buildings
- Universal correlation for jet fire length determination and calculation of three deterministic separation distances
- Account for the effect of sensors positioning
- (optional) Use of flow restrictors to limit the risk of hydrogen accumulation above lower flammability limit (LFL) and/or reduce jet flame length

Several remaining knowledge gaps issues had been identified in the course of the project and during the discussion and were proposed as potentially important topics for the follow-up research:

- The effect of the wind on the passive ventilation in the enclosure
- The effect of obstructions on the overpressure following deflagration in the enclosure
- Delayed ignition of hydrogen jet and subsequent deflagration
- The effect of radiation of fire evolution in enclosed space
- The effect of water vapour condensation

Participants also discussed potential strategies for dissemination of project finding to national and international regulatory bodies.

All presentations made during workshop will be made available to public in January/early February 2015 on the Hyindoor project website at the workshop webpage (http://www.hyindoor.eu/?page_id=274).

Boris Chernyavskiy, HySAFER centre, Ulster University, UK

First International Workshop on Hydrogen Safety Training for First Responders

Fuel Cell and Hydrogen (FCH) technologies and applications both in transport and energy sectors are on the market today but awareness and knowledge of these new technologies amongst fire authorities and First Responders remain limited. Adequate training is therefore required to provide knowledge and essential skills on how to handle potential incidents/ accidents involving FCH systems and infrastructure and how to protect the general public without putting the lives of First Responders at risk. HyResponse, which is a Coordination and Support Action (CSA) project, supported by the European Commission Fuel Cell and Hydrogen Joint Undertaking, aims to establish the world's first comprehensive training programme for First Responders. Its core objectives are threefold: educational training including state-of-the-art knowledge in hydrogen safety, operational "hands-on" training on mock-up real-scale hydrogen and fuel cell installations, and innovative virtual reality training reproducing in detail an entire accident scenario, including the effect of First Responders' intervention. The project is coordinated by the French Academy for Fire, Rescue and Civil Protection Officers (ENSOSP). Other partners of the consortium include Air Liquide, the University of Ulster, FAST/EHA (European Hydrogen Association), CCS Global Group, CRIsis Simulation Engineering (CRISE) and AREVA Stockage d'Energie.

Figure 1: Participants of HyResponse workshop.

The First International Workshop on Hydrogen Safety Training for First Responders, organised within the framework of the HyResponse project, took place on the 3rd and 4th of September 2014 at the French Academy for Fire, Rescue and Civil Protection Officers (ENSOSP) in Aix-en-Provence, France. More than 70 participants from Belgium, Canada, France, Germany, Holland, Italy, Slovenia, Spain, Syria, Poland, UK and US attended the workshop.

The two day event disseminated the main results and recommendations of the HyResponse project and shared experiences from other programmes around the world. Colonel Françis Mené, ENSOSP Director, began the workshop by greeting the participants, introducing the ENSOSP and outlining the main objectives of the workshop. He also stressed the importance of hydrogen safety training for First Responders. The main achievements and development perspectives in the framework of Horizon 2020 were then presented by Bert De Colvenaer, Executive Director of the FCH Joint Undertaking. "We have to be proactive in safety management, work together and share knowledge, draw conclusions and plan the future" he said. This was followed by a presentation on "US Perspectives on Hydrogen and Fuel Cells" by Kym Carey, Project Manager in the Fuel Cell Technologies Office of the US DoE, who stated: "Our analysis efforts explore not just upfront costs, though those are very important, but also life cycle costs as these are used to guide our R&D efforts. We continue to leverage other hydrogen and fuel cell activities in the US and globally to multiply and maximize the impact of our efforts". Ahmed Essam Aly, Communications Manager from the European Hydrogen Association (EHA), presented a summary of EU and national developments regarding FCH technologies. He said "EHA is working closely with all the national associations and the decision makers to ensure that hydrogen and FC technologies are going to be adapted within the new energy and transportation national plan of each European country". Following an overview of the HyResponse project by Marc Lopez (project coordinator) and François Laumann from ENSOSP, Adrien Zanoto, Industrial Risk Management →

→ Representative from Air Liquide Advanced Business, presented the topic "Fuel Cell Statistics and Feedback". He also demonstrated videos of experiments that compared ignition of hydrogen, CNG and LPG. An "Overview of HyResponse educational training programme" was then delivered by Svetlana Tretsiakova-McNally from Ulster University, who presented modules and sections of the developed International Curriculum on hydrogen safety training for First Responders as one of the HyResponse project deliverables. A presentation on the "HyResponse Operational training platform" was given by Franck Verbecke, AREVA ES, who introduced different HyResponse intervention training platforms, including didactic systems, hydrogen behaviour platforms and mock-up real-scale transport and hydrogen stationary installations. The innovative "Virtual Reality training platform" was presented by Eric Maranne, CRISE, who mentioned that "the virtual training aims to train First Responders in teamwork assessment of the accident scene and decision making in different scenarios".


Figure 2: Operational training exercises.

The first presentation session was followed by a visit to the ENSOSP operational training platform where a demonstration of firefighting operations was witnessed by the participants. The stages of fire initiation, development and extinction through the intervention of First Responders were compared on four vehicles containing different types of fuel: LPG, CNG, hydrogen pressurised to 35 MPa, and hydrogen pressurised to 70 MPa. The demonstration was followed by a visit to an exhibition of FC applications at the AREVA ES site.

Adrien Zanoto started the second day of the workshop with a presentation entitled "Hydrogen Refuelling Station", followed by a presentation by Randy Dey, President of The CCS Global Group, about ''Regulations, Codes and Standards relevant to First Responders''. Franz Petter from the State Fire Department and Emergency Medical Service Hamburg introduced the topic of Hydrogen Strategic Planning and initiated a discussion on 'What will happen if hydrogen-powered vehicles are involved in fires?' After that, the participants visited a virtual reality training centre in ENSOSP where they learnt more about the virtual reality simulator developed within the HyResponse project and were involved in the completion of exercises for two different hydrogen accident scenarios.

Kurt Vollmacher from CTIF (International Association of Fire and Rescue Services) started the afternoon session of the workshop by reporting on the "Purpose and actions of CTIF's commission for extrication and new technology". Steven C. Weiner from Pacific Northwest National Laboratory, Washington, had shared the experience gained in the US during the First Responder awareness programme. He said: "Collaboration will continue to be an essential element of our future work in first responder training." Vladimir Molkov, University of Ulster, ended the second day by introducing the MSc course in Hydrogen Safety Engineering at Ulster University and stated: "Hydrogen economy depends on public acceptance. To promote public awareness and trust in hydrogen technologies we need well educated and trained staff". The workshop concluded with a round table discussion, during which Tom Van Esbroeck, CTIF, commented on the need to combine general hydrogen safety training with virtual reality and field training for First Responders. The materials presented at the workshop are publically available (http://www.hyresponse.eu/workshop.php).

The Second HyResponse International Workshop on Hydrogen Safety Training for First Responders will take place on 20–22 April 2016. By this time at least 50 First Responders will have been trained by the partners of the HyResponse project during three face-to-face pilot training sessions of one week duration.

FCH JU project HyResponse (12 June 2013 – 31 May 2016)
http://www.hyresponse.eu/

Svetlana Tretsiakova-McNally, HySAFER centre, Ulster University, UK

s.tretsiakova-mcnally@ulster.ac.uk

FCH JU project "Support to safety analysis of HFC technologies" (SUSANA)

As Fuel Cell and Hydrogen (FCH) systems and infrastructure are becoming more widely used within the public domain, having previously been limited to industrial applications, there is an increased demand for efficient safety engineering tools such as Computational Fluid Dynamics (CFD). CFD simulations are complimentary to costly experimental studies, and often it is the only affordable way to develop safety strategy and/or engineering solutions. The project "Support to safety analysis of hydrogen and fuel cell technologies" (SUSANA) will facilitate the use of CFD as a contemporary tool for inherently safer design of FCH systems and facilities. The SUSANA project is funded by the Fuel Cell and Hydrogen Joint Undertaking (FCH-JU), (grant agreement No. 325386). The total project value is €2,119,670. The project duration is September 2013 – August 2016. The project consortium is built of partners who are key players and experts in modelling and numerical simulations relevant to hydrogen safety and engineering: Karlsruhe Institute of Technology (Germany); Ulster University (UK); National Centre for Scientific Research "Demokritos" (Greece); Joint Research Centre of the European Commission (the Netherlands); Health and Safety Laboratory (UK); Element Energy (UK) and AREVA (France).

The project aims to develop "CFD model evaluation protocol for safety analysis of hydrogen and fuel cell technologies", which is targeted at the stakeholders involved in the use or evaluation of CFD analysis, e.g. technology developers, safety engineers, regulators and safety officials responsible for the permitting process, etc. The aim is achieved through the following objectives:

- Review the state-of-the-art in CFD modelling for safety analysis in FCH technologies.
- Update and enhance the verification and validation procedures for CFD models/codes/simulations.
- Compile the best practices guide in simulations of problems specific to safety of FCH technologies.
- Develop CFD Model Evaluation Protocol for the assessment of
  - the capability of CFD models to accurately describe relevant physical phenomena, and
  - the capability of users to follow the correct CFD modelling strategy for FCH technologies.
- Create the infrastructure for implementation of the CFD Model Evaluation Protocol, including:
  - Database of problems for verification of codes and models against analytical solutions;
  - Database of experiments for validation of simulations;
  - Project website to support experts' forum and provide open access to the databases, the best practices document, benchmark exercise specifications, available benchmark results, etc.
- Establish the experts group for use of complementarities and synergies of the project partners and external to the project experts, and for the implementation of the Protocol.
- Provide cross-fertilisation of expertise and experience in the field.
- Disseminate project results to stakeholders.

The project objectives are reflected in the structure of project's Work Packages (WP), described below and schematically shown in Figure 1:

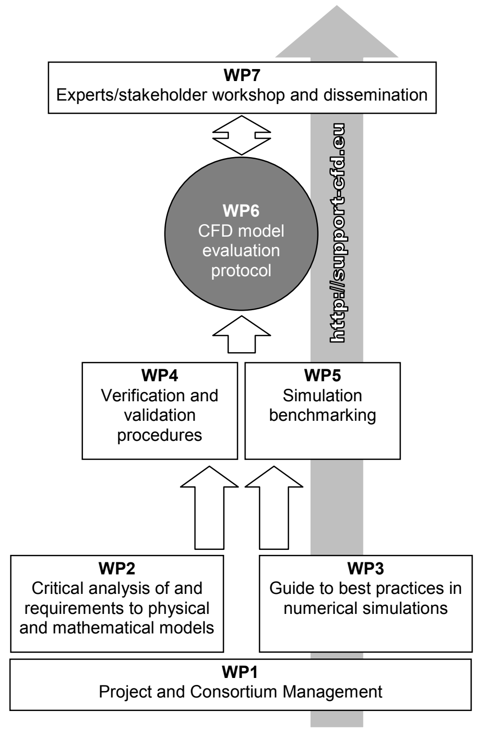


Figure 1: SUSANA project structure.

WP1 "Project and Consortium Management" deals with general project management and maintenance of the project website.

WP2 "Critical analysis of and requirements to physical and mathematical models" will review models of physical →

→ phenomena related to the safety of FCH technologies. The output will be a critical survey of physical models with associated mathematical models, including governing equations and source terms.

WP3 "Guide to the best practices in numerical simulations" gathers together the state-of-the-art knowledge of partners to appraise the choice of models, initial and boundary conditions, calculation domain and numerical grid, numerical schemes etc.

WP4 "Verification and validation procedures" will develop the organisational and technical framework for the demonstration of the credibility of models and codes, to ensure they provide correct results from the perspective of their intended use.

WP5 "Simulation benchmarking" will elaborate on benchmarking as an essential part of the implementation of the CFD Model Evaluation Protocol. It will put into action the validation procedures identified in WP4.

WP6 "The CFD Model Evaluation Protocol" is the paramount purpose of the project and includes the compilation of outputs from WP2-WP5.

WP7 "Experts/stakeholder workshop and dissemination" makes the project outputs available to all interested stakeholders using various dissemination routes (workshop, seminar, website, publications, etc.), and gathers feedback.

The project achievements up to this point include the design and launch of the project website (http://support-cfd.eu), the completion of the "State of the art review concerning FCH technologies", the Intermediate report „Best practices in numerical simulations", the commencement of the assembly of the verification problem database, the first part of the model validation database and the formulation and fulfilment of the first benchmarking exercise.

Dmitriy MAKAROV*, Vladimir MOLKOV
*HySAFER centre, Ulster University, UK

hydrogen@h2fc.com
dv.makarov@ulster.ac.uk

International Association HySafe Research Priorities Workshop at US DoE

International Association for Hydrogen Safety, HySafe held a research priorities workshop in Washington DC in conjunction with the International Energy Agency (IEA) Hydrogen Implementing Agreement (HIA) Hydrogen Safety Task definition meeting.

The research priorities workshop attracted 38 experts from around the globe covering the Americas, Europe, and Asia. This was two days of presentations (36) and discussions to identify the current State-of-the-Art and research needs to promote the safe deployment of hydrogen technologies in the global energy infrastructure. Dr. Andrei Tchouvelev, president of HySafe gave the opening welcome. Dr. Sunita Satyapal, Program Director for the U.S. Fuel Cell Technologies Office provided opening remarks welcoming the international experts on hydrogen safety. HySafe is producing a document based on this workshop that will outline research needs and priorities to help accelerate to assist commercialisation of hydrogen technologies.

Attached below is an outline of the workshop.

HySafe Research Priorities Workshop
November 10–11, 2014

- Welcome and Opening Remarks (Dr. Andrei Tchouvelev, President HySafe)
- Fuel Cell Technologies Office (FCTO) Welcome (Dr. Sunita Satyapal, Office Director)
- Software Tools (1)
  - Introduction
  - Integration Platforms
    - HyRam
    - SAGE
    - Cyber-Laboratory and its hydrogen safety engineering tools (www.h2fc.eu)
    - Canadian Platform
- Software Tools (2)
  - QRA Tools
    - Gaps, Methods, Models Tools
  - Reduced Model tools
    - State of the Art for Gaseous Release Models
    - Correlations for venting of localized and full volume deflagrations in low strength equipment and buildings
  - Deterministic separation distance from stationary & on-board hydrogen storage tank: calculation of blast wave decay
- California Station Rollout
- Indoor
  - Passive ventilation of enclosures with one vent, the uniformity criterion, and validation of pressure peaking phenomenon for unignited releases
  - Regimes of indoor hydrogen jet fire and pressure peaking phemonenon for jet fires
  - Hyindoor, passive ventilation
  - Effect of wind on passive ventilation
- Unintended Release
  - Gas phase
    - Delayed ignition
    - Simulation of hydrogen release from TPRD under the vehicle
    - Combustion of inhomogeneous mixtures
- Unintended Release
  - Liquid phase
    - Knowledge gaps in liquid hydrogen safety
    - Vision for Validating the LH2 Plume Model @ T < 80K
- Storage
  - Gaps in Safety of Storage in Solid-state-systems
  - Effect of heat release rate and resin glassing temperature on fire resistance rating in bonfire test
- Hydrogen Safety Learnings and Training
  - Learnings and Direction – Hydrogen Safety Panel and First Responder Training
  - Hydrogen Emergency Response Training Program for First Responders – HyResponse
- Applications
  - HRS – fast filling
  - Turbine
  - PEM Electrolizer
- Country Safety Programs
  - ISO
  - US
  - Norway
  - EU
  - FCH-2-JU
  - Japan
  - Germany
  - UK
- Materials Compatibility / Sensors
  - Metals
  - Components
  - Sensors

Jay Keller, Zero Carbon Energy Solutions, Inc. USA

Jay.Keller@ZCES-Inc.com

Global standards for hydrogen technology being made

Introducing hydrogen and fuel cell technology is a global necessity, and this means that global standards are necessary, among a few other things. So it is logical that this is done under the roof of the world standardization organization ISO in its Technical Committee 197 "Hydrogen Technologies". The latest plenary of this committee was held on 4th and 5th December 2014 in Japan, together with a few working group meetings during the days before.

The plenary took place at HyTrec, the "Hydrogen Energy Test and Research Center". It is located on the southern island of Kyushu, near Fukuoka. Fukuoka is the most important city on Kyushu and known for its university and other institutes of higher learning. HyTrec has quite a few installations for performing pressure testing of vessels made of composite material with an operating pressure of 70 MPa or more, as they are used in fuel cell cars and at their refilling stations. Not many institutes in the world can do this. Valves, flow meters, couplings, and other accessories can be tested as well.

Figure 1: HyTrec building.

The focus of ISO TC 197 right now is on hydrogen refuelling stations and their components. During the three days prior to the plenary various working groups had met to focus on different aspects (dispensers, hoses, compressors, valves, etc.). The matter is urgent, because the European Commission has recently published a directive on alternative fuel infrastructure, and now European standards are needed to apply it in real life. The European standard body CEN will adopt the ISO papers as soon as they exist, and this should be soon. So the working groups go ahead under full steam. The European Commission, represented by the Joint Research Centre in Petten, is now also an official partner of the TC and sent a representative to the TC plenary.

One item which was finished recently is the revision of the basic paper on safe handling of hydrogen (TR 15196). The working group which had done this was disbanded during the plenary, and publication of the paper is expected for early 2015.

Figure 2: Not surprisingly the Japanese delegation was the biggest, but the composition was rather international.

The next plenary is expected to be held in September 2015 in the USA.

During the meeting some of the test installations of HyTrec were presented to the participants. And on one of the days a Honda Clarity was available for test rides. Usually this vehicle is used as part of the official fleet of the Fukuoka prefecture; the governor frequently uses to get to his appointments. There are two large dusters in the trunk to make sure that the immaculate appearance of the car is by no means disturbed by some dust.

Not far away from HyTrec there is a research centre for the industrial application and storage of hydrogen, called HYDROGENIUS, as part of the new campus of the Kyushu University. The centre comprises the five sectors fatigue and crack, polymers, tribology (friction and wear), thermophysical properties, and safety. There is also a hydrogen refilling station dispensing gas under 35 MPa. This is enough for the Honda FCX Clarity, but certainly the installation will be upgraded to 70 MPa sooner or later.

Figure 3: Honda Clarity as official car of the Fukuoka prefecture.

Figure 4: Some of the participants had the chance to test the seats.

→ The Japanese frequently show how to connect tradition and modern times in an interesting way. Travellers (or shoppers) in Japan have known for centuries that warm water does miracles to tired feet. So it is little wonder that a traditional Japanese foot bath is part of HYDROGENIUS – with the water of course being delivered by a fuel cell. Unfortunately the device was not working at the time of the ISO plenary.

Ulrich Schmidtchen, BAM, Germany

ulrich.schmidtchen@bam.de

Figure 5: Refilling station as part of the HYDROGENIUS research centre at the Kyushu University.

Figure 6: Using leak detectors is not part of the refilling procedure in other parts of the world. Apart from this there is no difference.

Figure 7: Fuel cell foot bath.

European Technical School on Hydrogen and Fuel Cells 2015

The European Technical School on Hydrogen and Fuel Cells 2015 is funded by the European Commission under the H2FC project and coordinated by the University of Ulster. The sessions at the European Technical School on Hydrogen and Fuel Cells 2015 address the themes of hydrogen safety, storage and fuel cells. The programme will include topical lectures, outcomes of H2FC transnational access, e-infrastructure for hydrogen and fuel cell research: hydrogen safety, storage and fuel cells, hands-on training session for use of the Cyber-laboratory and poster presentations on state-of-the-art research.

- Date: 22th June 2015 – 26th June 2015
- Venue: Aquis Arina Sand hotel, Heraklion (Crete, Greece)
- Fee: 850 Euro
- Registration Deadline: Registration in the TS2015 is first-come, first-served. Applications are accepted in the order in which they are received. Register early. Limited available. The fee covers six nights (Sunday 21–Saturday 27) accommodation on a single occupancy, full board basis. Attendees may check in from 15:00 on Sunday the 21 June and must check out by 12:00 on Saturday the 27 June. The fee also includes attendance at all sessions, an electronic copy of course materials, a welcome reception, private coffee breaks and a farewell dinner at Arolithos Village including transfer. Please submit your registration form as soon as possible! Place are limited.
- How to Apply for the Technical School
  A) Self-funded participants
  Self-funded participants will pay a registration fee to attend the Technical School. Places are limited. Please submit your registration form as soon as possible. You can find the form on the website http://www.h2fc.eu/technicalschool. Payment details will be provided on receipt of your registration form. If you are planning to arrive with accompanying person(s) please contact Dr Wookyung Kim at H2FCtechnicalschool@ulster.ac.uk to discuss arrangements at your earliest convenience.
  B) Participants from within the H2FC project
  Please follow the registration process for self-funded participants and the University of Ulster will arrange a block invoice per partner.

Figure 1: Aquis Arina Sand hotel in Heraklion.

Figure 2: Conference room for the school 2015.

Further information is available on the website http://www.h2fc.eu/technicalschool

Contact: Dr. Wookyung Kim w.kim@ulster.ac.uk

6th International Conference on Hydrogen Safety

HySafe invites you to the unique Hydrogen Safety Conference

With the endorsement of:

IPHE International Partnership for Hydrogen and Fuel Cells in the Economy · European Commission · HYDROGEN IMPLEMENTING AGREEMENT · U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy FUEL CELL TECHNOLOGIES OFFICE · New Energy World JU · Ministry of the Interiors The National Fire Corps ITALY

Organizing Institutions:

HySafe · Technova Inc.

In Collaboration with:

H2FC European Infrastructure Project · ISO/TC 197 HYDROGEN TECHNOLOGIES

ICHS 2015 CONFERENCE **SCOPE**

The 6th International Conference on Hydrogen Safety (ICHS 2015) will be held in Tokyo, Japan on October 14-17, 2015 under the auspices of the International Association for Hydrogen Safety (HySafe). The first five biennal conferences since 2005 succeeded in attracting the most relevant experts from all over the world, by providing an open platform for the presentation and discussion of new findings, information and data on hydrogen safety – covering the wide range of areas from basic research to applied research and development to standardization and regulations. As commercialization of hydrogen fuel cell electric vehicles is imminent and other hydrogen applications are being increasingly deployed globally, 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. Therefore, the conference seeks papers in a wide range of hydrogen safety topics like (but not limited to) Regulations Codes and Standards, safety in H_2 infrastructure, safety solutions for the implementation of H_2 technologies, hydrogen and hydrogen blends behavior, physical effects, consequence analysis, incidents, accidents and near misses, hydrogen effects on materials and components, safety of energy storage, risk management and fuel cells related safety issues. A detailed list of ICHS 2015 Themes and Topics is shown below. All contributions to ICHS 2015 will be evaluated exclusively in the light of their scientific content and relevance to hydrogen safety.

ICHS 2015 CONFERENCE **STRUCTURE**

ICHS 2015 will include thematic plenary sessions, topical lectures, and parallel oral and poster sessions. The conference seeks to facilitate (enable/strengthen) the near term introduction of hydrogen technologies in the market place.

CONFERENCE ORGANIZING **COMMITTEE**

Akiteru Maruta, Marco Carcassi, Andrei Tchouvelev, Marc Steen, Iñaki Azkarate, Thomas Jordan, Jay Keller, Suguru Oyama, Antonio Ruiz.

CONFERENCE SCIENTIFIC **COMMITTEE**

Iñaki Azkarate, Daniele Baraldi, Herve Barthelemy, Luc Bauwens, Pierre Benard, Gilles Bernard-Michel, Dag Bjerketvedt, Marco Carcassi, Fabio Dattilo, Sergey Dorofeev, Vasco Ferreira, Marco Frezza, Javier Garcia, Oliver Gentilhomme, Stuart Hawksworth, Olaf Jedicke, Thomas Jordan, Shoji Kamiya, Jay Keller, Armin Keßler, Alexei Kotchourko, Frank Markert, Akiteru Maruta, Ad Matthijsen, Vladimir Molkov, Pietro Moretto, Ernst-Arndt Reinecke, Antonio Ruiz, Ulrich Schmidtchen, Trygve Skjold, Marc Steen, Andrei Tchouvelev, Andrzej Teodoreczyk, Alexandros Venetsanos, Franck Verbecke, Steven Weiner, Jennifer Wen, Jinyang Zheng.

European Fuel Cell Technology & Applications Piero Lunghi Conference

Events March–December 2015

09.03.–11.03.2015	9th International Renewable Energy Storage Conference & Exhibition, IRES 2015 www.eurosolar.de/en/index.php/ires-conference-series/ires-2015	Germany, Düsseldorf
09.03.–13.03.2015	4th International Conference on Multifunctional, Hybrid and Nanomaterials Hybrid Materials 2015 www.hybridmaterialsconference.com/	Spain, Barcelona
17.03.2015	11th International Hydrogen & Fuel Cell Technical Conference, Exhibition & International Brokerage Event www.climate-change-solutions.co.uk/event/11th-international-hydrogen-and-fuel-cell-event/	United Kingdom, Birmingham
13.04.–17.04.2015	Hannover Messe Group Exhibit www.h2fc-fair.com/	Germany, Hannover
21.04.–23.04.2015	Hazards 2015 www.icheme.org/events/conferences/hazards-asia-pacific-2015.aspx	Kuala Lumpur
27.04.–28.04.2015	HFC 2015, Hydrogen + Fuel Cells: Vancouver Hydrogen + Fuel Cells Summit www.hfc2015.com/	Canada, Vancouver
03.05.–06.05.2015	International Conference on Hydrogen Production www.ich2p.org/ich2p14/index.php?conference=ich2p&schedConf=ich2p15	Canada, Oshawa
03.05.–06.05.2015	EVS 28, 28th International Electric Vehicle Symposium & Exhibition, including Fuel Cells & Fuel Cell Systems www.evs28.org/	South Korea, Goyang
06.05.–07.05.2015	All-Energy 2015 Exhibition & Conference www.all-energy.co.uk/	United Kingdom, Glasgow
24.05.–28.05.2015	227th ECS Meeting www.electrochem.org/meetings/biannual/curr_mtg.htm	USA, Chicago

Events March–December 2015

15.06.–19.06.2015	ACHEMA 2015 www.achema.de/	Germany, Frankfurt
22.06.–26.06.2015	European Technical School on Hydrogen and Fuel Cells http://h2fc.eu/technicalschool	Greece, Crete
30.06–03.07.2015	5th European PEFC & H2 Forum www.efcf.com/	Lucerne, Switzerland
19.07.–24.07.2015	30th International Symposium on Shock Waves www.ortra.com/events/issw30/Welcome.aspx	Tel-Aviv, Israel
26.07.–31.07.2015	14th International Symposium on Solid Oxide Fuel Cells www.electrochem.org/meetings/satellite/glasgow/	United Kingdom, Glasgow
30.08.–04.09.2015	NURETH 2015 http://nureth16.anl.gov/	USA, Chicago
11.10.–14.10.2015	World Hydrogen Technologies Convention 2015 www.whtc2015.com/	Australia, Sydney
19.10.–21.10.2015	6th International Conference on Hydrogen Safety www.ichs2015.com/	Japan, Yokohama
17.11.–20.11.2015	3rd Zing Hydrogen & Fuel Cells Conference www.zingconferences.com/conferences/3rd-zing-hydrogen-fuel-cells-conference/	Mexico, Cancun
16.12.–18.12.2015	European Fuel Cell Technology & Applications Piero Lunghi Conference www.europeanfuelcell.it/	Naples, Italy

H2FC partners

Imprint

Editor: H2FC

Edited by: Olaf Jedicke, Thomas Jordan, Vladimir Molkov

Design, Layout: Wilfrid Schroeder, KIT; Anke Veser, PS; Olaf Jedicke, KIT

Karlsruhe Institute of Technology (KIT)
Kaiserstraße 12, 76131 Karlsruhe, Germany

Contact: Olaf Jedicke
Telephone: +49 721 608-25274
E-mail: olaf.jedicke@kit.edu
Internet: www.h2fc.eu

February 2015

H2FC European Infrastructure, an Integrating Activity funded by the European Commission under FP7 Capacities Program. Grant agreement No. FP7-284522