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H$_2$FC

Integrating European Infrastructure to support science and development of Hydrogen- and Fuel Cell Technologies towards European Strategy for Sustainable, Competitive and Secure Energy

Final Report

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1 Executive Summary

The main impact of H2FC European Infrastructure can be summarized through improving essential existing research infrastructures, discovering of knowledge gaps and technical bottlenecks, executing of technical schools, expert workshops and conferences to spread existing and developed knowledge, execution of experimental work to externals and teaming the different FCH communities according the cohesion and an essential expansion of the European network. Nearly the complete project consortium can be meanwhile recognized as becoming integrated as active parts in boards or committees to the FCH Joint Undertaking 2.0, several international associations and organizations, e.g. HySafe Association, EERA and notable conferences like WHEC or WHTC, ICHS, EFC etc. In principle, more than 277 publications were edited, based on achieved results and project activities and reflect an impressive dimension of scope of project but also complexity. Several activities on the H2FC European Infrastructure objectives didn't end with the project; also all fixed targets were fulfilled and results to be achieved and reported within a series of 118 ordinary deliverables. Meanwhile some of the project targets became overtaken for further processing and development beyond the project, due to their attractiveness and importance related to the scientific content but also incorporated of novel ideas.

However, major project targets were to improve and modify existing research infrastructures and technical installations and furthermore guidelines, instructions, new measurement techniques and methodologies. Though, the range of themes covered by the project was enormous. It started at safety issues, including jet fires, deflagration, detonation, etc. followed by fuel cells including PEM and SOFC, facing test methods for single fuel cells and stacks, water content and its distribution, investigation and development of electrodes and membranes, further electrolyzer, material science (e.g. hydrogen embrittlement), hydrogen purity, clean up methods and investigation of purity, digital science, modelling and simulation concerning fuel cells and safety issues only to give a brief idea. A lot of installations became improved and can provide today as a kind of measurement techniques implementing methods in forefront means, measurement techniques which were not available before (higher resolution, new test methods and methodologies, expanding of dimensions from 2D to 3D, etc.).

The outstanding development of an e-laboratory has its major impact in getting developed and proved first time as a novel instrument for scientific cooperation which works without physical meeting and thus over distances. The e-laboratory demonstrates formidable its fruitful usability related to education and training of students, technicians, engineers etc. on the respective FCH themes. In this concern four technical schools had a major impact also in a sustainable manner as well as the expert's workshops and collaboration with notable conferences. The focus on technical bottlenecks and knowledge gaps has great impact and influence on the further development of technical infrastructures.

An additional major impact appeared by the execution of user projects within the transnational access activities. Around 100 user proposals received and around 68 user project became executed by H2FC consortium and finished by useable results. Especially from transnational access, industry, universities and others profits by getting executed experiments which were otherwise not financeable for those users. Each user project can get seen as small research project targeting on specific problems and ideas and the impact by spreading knowledge in this concern, is likewise enormous.

Apart from activities described in description of work, one target ranked on higher level was to team the different communities; the safety community, the fuel cell community and the community working on material science and technological development. This target was achieved and has its benefit in further collaboration by overcoming hurdles. The people involve were notable and influence their community respectively forward to be one community facing on installing and promoting “hydrogen as an energy carrier”. Last but not least, the community increased continuously and thus the collaboration of former separated experts. This has also an influence on the society (recognizing the community as a common and bigger one), public awareness and politicians, who knows meanwhile whom to ask about hydrogen and fuel cell technology, its status quo, further development and future prospects.

2 Summary Description of the Project and the main Objectives

H2FC*European Infrastructure* addresses the topic INFRA-2011-1.1.16 "Research Infrastructures for Hydrogen and Fuel Cells Facilities" and the related energy-chains, by compiling the leading European research institutions and organisations of the hydrogen community in one Project. A number of institutions and organizations, mainly national research centres, disposes a range of significant, partially unique test and analysis equipment, ranging from high stability fuel cell test rigs suitable for long-term durability testing, neutron beam and synchrotron devices, to facilities capable of assessing the risk of fire or explosion for hydrogen fuelled devices, components and systems. Their operation and maintenance incur considerable costs. For the academic teams from universities or small spin-offs - the typical drivers of new innovative hydrogen and fuel cell solutions - there is neither coordinated nor affordable access to this dispersed research infrastructure. So it is not surprising that virtually none of the new fuel cell materials that are published in academic journals are subjected to long-term durability testing on qualified test rigs. Similarly, without the appropriate advanced safety testing due to the limited access to suitable facilities, investment in the development of materials, components and devices has been lost in several cases. On the other hand the steady flow of innovation in this new field of research needs continuous adaptation to new directions, new materials and new solutions.

With the current fragmentation of the European research infrastructure and the uncoordinated approaches, the demand for effective support for the technology developers cannot be satisfied. Therefore H2FC*European Infrastructure* was built in order to integrate the European research community around rare and/or unique infrastructural elements that will facilitate and significantly enhance the research outcome.

Since the hydrogen and fuel cell community is scattered in terms of degree of maturity or industrial relationship, the first step to integrate this community and enhance the overall performance was to develop a virtual infrastructure around the participating national research centres and to invite researchers in SMEs, large industry and universities to use this infrastructure. Bridging national research centres and university research through joint access to the best European infrastructure is in line with the "European Research Area: New Perspectives, Green Paper 04.04.2007" underpinning this interaction of the European Research Area and the European Higher Education Area. Although some preliminary integration of safety research has been provided by the FP6 NoE HySafe, the bridging of the so far disjoint groups, dealing with hydrogen technologies on one side and fuel cells on the other, will further the understanding of the research requirements on both sides and help to install a worldwide leading, unique community and infrastructure respectively.

To summarise, the main objective of H2FC*European Infrastructure* is to generate a structured and integrated alliance based on complementary, state-of-the-art, or even beyond state-of-the-art unique infrastructures to serve the needs of the scientific hydrogen and fuel cells community and facilitate future research. In more detail, H2FC*European Infrastructure* general aims can be summarised as follows:

- To provide a single integrated virtual infrastructure to accommodate hydrogen and fuel cell communities' test and analysis facilities
- To provide transnational access for the hydrogen and fuel cell research communities to member state infrastructures

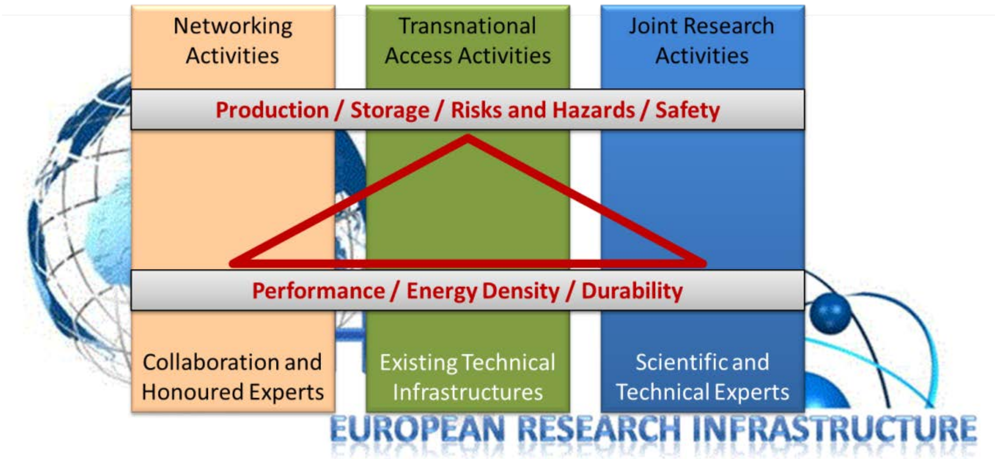
- To develop a number of expert working groups to enhance work at the provided facilities and to seek more general coordination in the aspects safety, performance and durability
- To provide central databases and libraries of safety, performance and durability data and modelling codes
- To coordinate relevant education and training, pertinent to the set-up, use and maintenance of hydrogen and fuel cell research, test and assessment facilities
- To integrate, enhance and improve on the existing infrastructure
- To coordinate actions with national and international bodies, with academic and industry demands

2.1 Overall Strategy and Objectives

The main objective of H2FC*European Infrastructure* was to realise a coordinated and integrated alliance based on complementary, state-of-the-art, or even beyond state-of-the-art unique infrastructures to serve the needs of the scientific hydrogen and fuel cells community and facilitate world class research. The key research topics identified by the consortium were:

- Understanding of reduction of degradation mechanism in principle to increasing performance of electrolysers, hydrogen storage systems and fuel cells generally
- Reducing hazards and risks associated with the use of hydrogen or hydrogen blended fuels and thereby ensuring the appropriate safety level of systems and big facilities
- Improving the storage technologies, in particular through advanced materials research

The three pillars the H2FC*European Infrastructure* was based on were networking activities, transnational access activities and joint research activities, sub-structured in 26 work packages. All activities were strongly interrelated and oriented along a long list of bottlenecks and knowledge gaps identified already at starting of project and further investigated during the project lifetime with the support of international experts.



[Fig.1] Thematic Structure of H2FC*European Infrastructure*

The integration activities of the networking constitute as general services the backbone of the networking activities and complete project [Fig.1] [Fig.3]. This project pillar accommodated 5 work packages: the central entry point for transnational access, the technical school and researchers exchange programme, the foresight knowledge and innovation, dissemination and public relation and at least the long term perspective of H2FC*European Infrastructure* and single activities.

The integration based on procedures for intense communication, procedures to screen and monitors the field for new developments and periodically update the joint research activities, procedures to monitor opportunities for additional funding for the further development of the infrastructure and common research, and procedures for regularly disseminating the services and results. In workshops measurement technologies became presented and discussed for further improvements and necessities and good practice gets disseminated to both, internal and external technical experts at respective infrastructures. Industry focussed technical schools, academic courses and a special e-journal distributed the knowledge openly and documented the capabilities to the external community.

Removing the national access barriers alone is unlikely to provide the required integrated and coordinated high performance infrastructure, as the most sophisticated facilities are not located in a single member state, and many member states simply do not possess national resources of this type at all. Therefore H2FC*European Infrastructure* focused on providing open access to the community on scientific and technology level. As such, transnational access became introduced as a second project pillar to the project [Fig.1] [Fig.3] and was subdivided into 15 single work packages. Each work package covered the individual specific information to installations added to the list of transnational access facilities. 14 Partners participated to the transnational access through more than 50 technical installations to be used for solving problems in fuel cell and hydrogen research and development. Its objective was to provide free of access to sophisticate and also conventional technical installations and big research facilities and under this light to execute single experiments and test procedures as well as providing advice and support in reporting the results officially in respective scientific journals and conferences.

Joint research activities were designated to build the third pillar [Fig.1] [Fig.3] of the project and were subdivided in four work packages. The H2FC*European Infrastructure* gathers facilities with a high level of measurement capability and the ability to carry out measurement under all H_2 and Fuel Cell relevant conditions to maintain the European level of competitiveness. However, continuing progress in the field results in the necessity of updating the existing instrumentation and methodologies in order to have them best adapted to the operating conditions found to be relevant in respect of new hydrogen technologies applications.

The main purpose of the joint research activities were to improve the competitiveness of European research infrastructure for the whole hydrogen energy chain and fuel cell technologies with a major emphasis given to the development of all kind of characterisation methods, instrumentation, protocols, experimental chambers etc. liable to improve the study, analysis and understanding of the current H_2 and FC technology bottlenecks. As such, the joint research activities strongly support the deployment of hydrogen and fuel cell technologies by enhancing the capability of existing high level research infrastructures and their services. This in turn is expected to enhance fundamental research activities in the field and to help overcome current bottlenecks which hinder also the hydrogen and fuel cell market entry. Since these are essentially due to material properties and component durability in the presence of hydrogen the joint research activities were organised in the following four work packages. The first two work packages addressed more specifically safety and risk assessment related to hydrogen public deployment and durability of material, components and systems at economically relevant performance levels. As such the main objectives of the first joint research work package focused on improving facilities and methodologies for investigations of basic hydrogen properties and behaviour. The second one focused on improving facilities and methodologies for investigations of materials, components and systems of the entire hydrogen energy chain and fuel cells technologies.

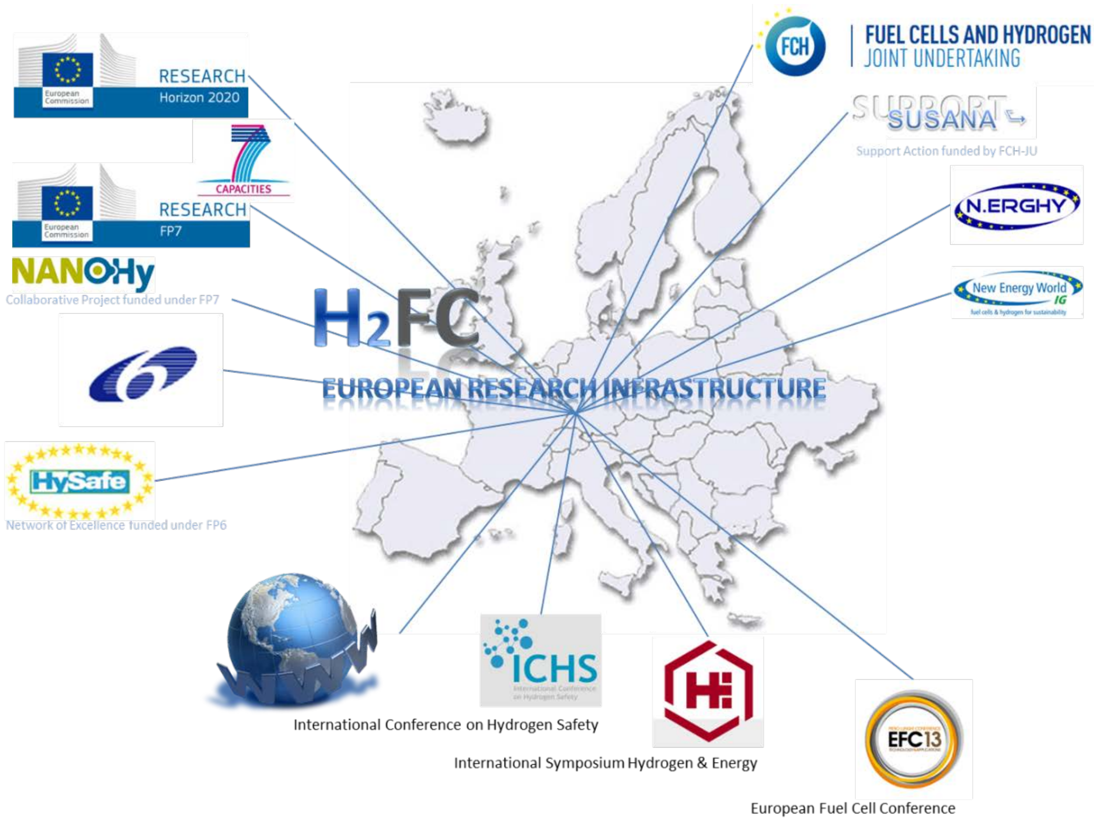
The last two work packages were dedicated on the major objectives to establish a robust common framework of methodologies, protocols and open simulation tools that constitute a necessary step toward hydrogen technology assessment before commercialisation. As such, developing and implementing adapted measurement methods and protocols for hydrogen technology benchmarking were the third work package while the development of a digital e-laboratory was the main objective covered by the last work package under joint research activities.

2.2 Progress by Integration

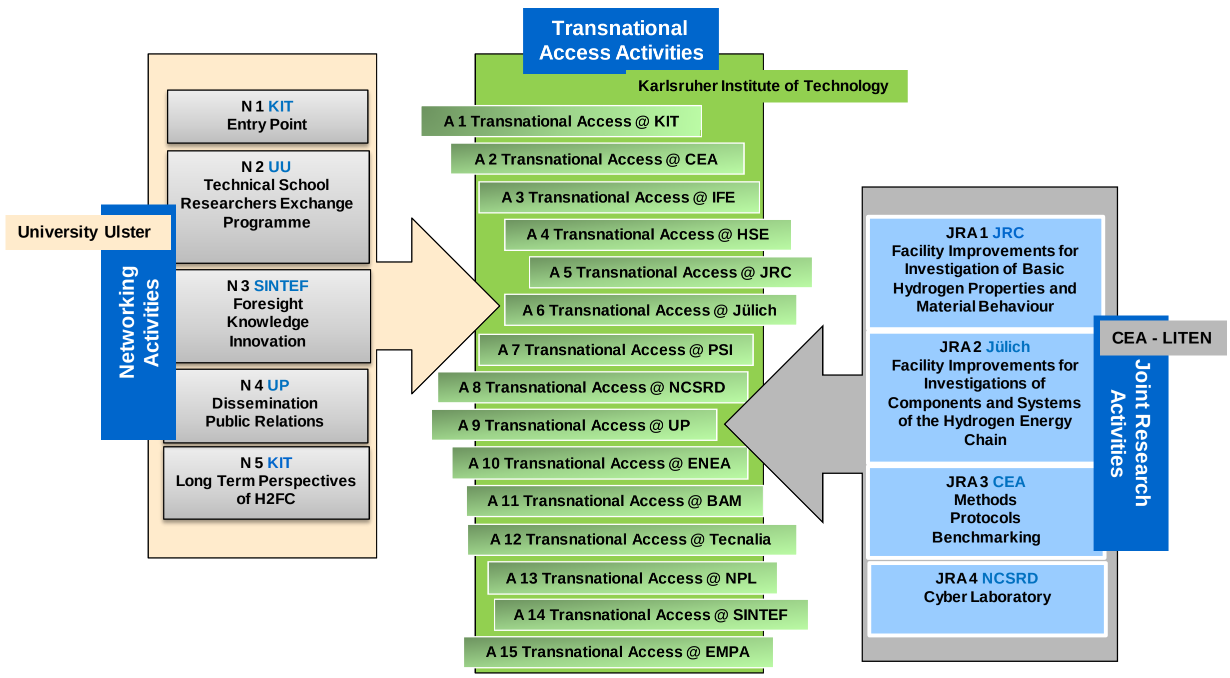
Members of the hydrogen and fuel cell community are numerous, ranging from basic research laboratories, e.g. in the case of solid hydrogen storage or intermediate temperature fuel cells, to industry in the case of hydrogen production and transportation, liquid hydrogen properties or fuel cell system integration and optimization. Moreover, historically there has been no commonly organised access to test and analysis facilities owned by national research centre type organisations (including high profile universities) in respect to hydrogen and fuel cell development. But most important appeared that exchange of knowledge was done by conventional paths especially through journals and explicit conferences only.

This state-of-the-art sets the basis for designing integrated European hydrogen and fuel cell research infrastructure entitled as H2FC*European Infrastructure*, which defines the main objective of the project. The coordinated building up and providing access to an integrated, high capacity and quality research infrastructure evidently was a significant improvement. It is in fact the first time that the formerly separate expert groups from fuel cell research and hydrogen research are working on a common program. Thereby H2FC*European Infrastructure* offers a unique opportunity where both sides will benefit from the close cooperation, improve understanding of the problems and challenges of the other group, and learn how to use better the existing and future capacities. While EU actions supporting the ERA concept in the specific area of hydrogen and fuel cell research exist (e.g. Marie-Curie actions and networking activities), and while there is an increasing number of demonstration projects in hydrogen and fuel cells, there was no action for the integration of the research, testing and assessment infrastructures used in this area.

Specifically, EU national research centres and universities with unique infrastructures provided access to the hydrogen and fuel cell scientific community, with particular attention to provide access to researchers located in member states and candidate countries where a reduced number of infrastructures are available. On the other side the project focused on industry needs as such, to get educated and instructed about news, scientific results and technical opportunities regarding measurement and technical development. The industry perspective was supported by the advisory council and confirmed in those dissemination activities, which links the infrastructure, joint research and networking activities to the industry driven FCH JU 2.0, EERA, specific conferences and technical schools and further activities generated out of H2FC*European Infrastructure* [Fig.2].



[Fig.2] Build interconnections of H2FC*European Infrastructure*



[Fig.3] Structure of the activity blocks and work package sub-structure of H2FC*European Infrastructure*

3 Summary Description of the main S&T Results and major Achievements

3.1 Introduction to the Joint Research Activities

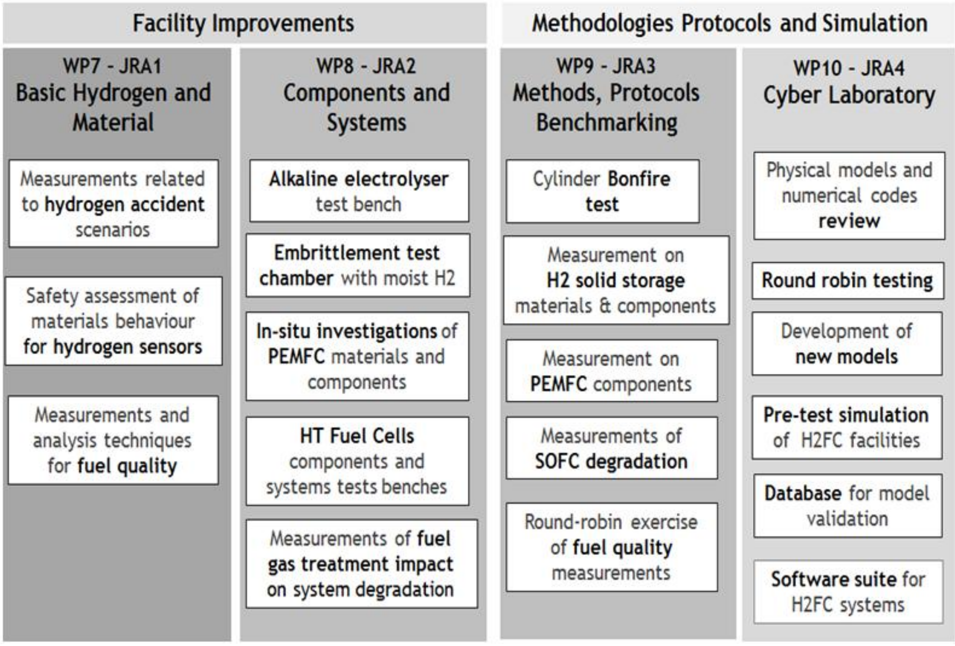
The H2FC European Infrastructure gathers facilities with a high level of measurement capability and the ability to carry out measurement under all H2 and Fuel Cell relevant conditions. However, continuing progress in the field results in the necessity of updating the existing instrumentation and methodologies in order to have them best adapted to the operating conditions found to be relevant in respect of new hydrogen technologies applications. It was the main purpose of the Joint Research Activities to improve the competitiveness of European research infrastructure for the whole hydrogen energy chain and fuel cell technologies with a major emphasis given to the development of all kind of characterisation methods, instrumentation, protocols, experimental chambers etc. liable to improve the study, analysis and understanding of the current H2 and FC technology bottlenecks.

As such the JRAs are expected to strongly support the deployment of hydrogen and fuel cell technologies by enhancing the capability of existing high level research infrastructures and their services. This in turn is expected to enhance fundamental research activities in the field and to help overcome current bottlenecks limiting hydrogen and fuel cell market entry. Since these are essentially due to material properties and component durability in the presence of hydrogen the JRAs are organised in the following four work packages. The first two are addressing more specifically test devices improvement and upgrading [Fig.2] [Fig.4].

- Improving facilities and methodologies for investigations of basic hydrogen properties and material behaviour
- Improving facilities and methodologies for investigations of materials, components and systems of the entire hydrogen energy chain and fuel cells technologies

The last two are establishing a robust common framework of methodologies, protocols and open simulation tools for hydrogen technology assessment.

- Developing and implementing adapted measurement methods and protocols for hydrogen technology benchmarking,
- Developing open software suit in a “cyber laboratory”



[Fig.4] Structures and substructures joint research activities of H2FC*European Infrastructure*

3.2 Major Achievements to the Joint Research Activities

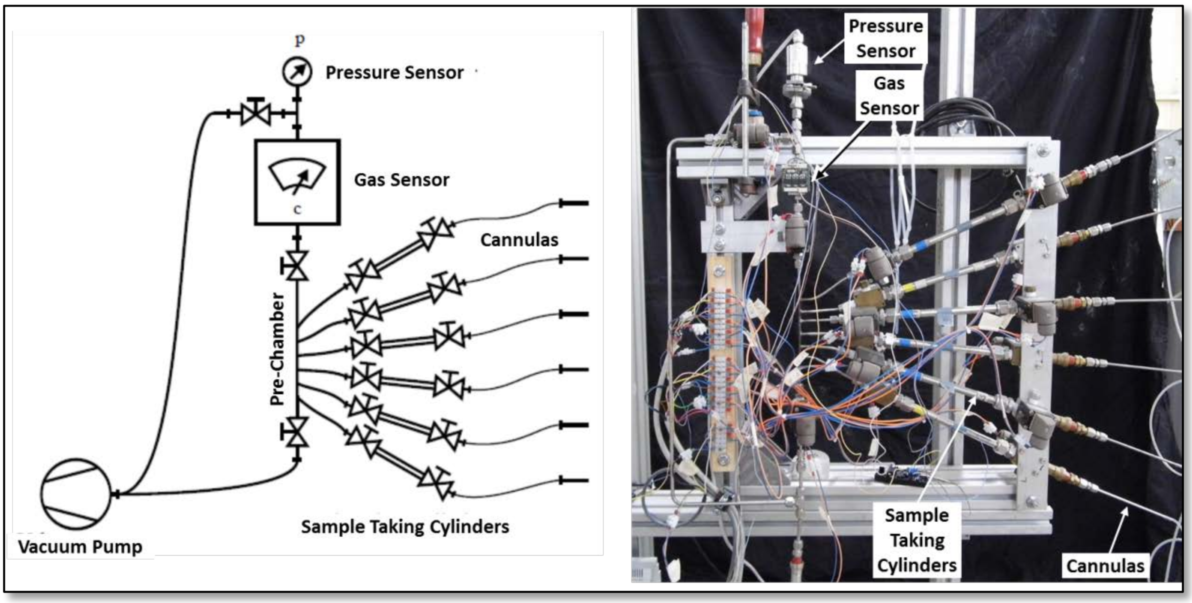
3.2.1 Improvement of Facilities and of Measurement Methodologies related to the Investigation of Hydrogen Properties and Behaviour

The first joint research activity was centred on the improvement of facilities and of measurement methodologies related to the investigation of hydrogen properties and behaviour. It was tailored to have a direct impact for facilitating basic researches on hydrogen safety and risk assessment and was organised in three main work tasks dealing respectively with:

1. Understanding hydrogen properties in mixtures upon accident scenario
2. Improving and integrating the capabilities of hydrogen sensors in testing facilities
3. Developing measurements and analysis techniques for fuel quality

The first task of the first work package concentrates on hydrogen behaviour and consists of three complementary subtasks focusing on the production of gradient mixtures and on the study of cold jet and on laser diagnostics for distribution and flow characterization. It was entitled under “Improved Measurements to Produce Controllably Defined Gradient Mixtures”.

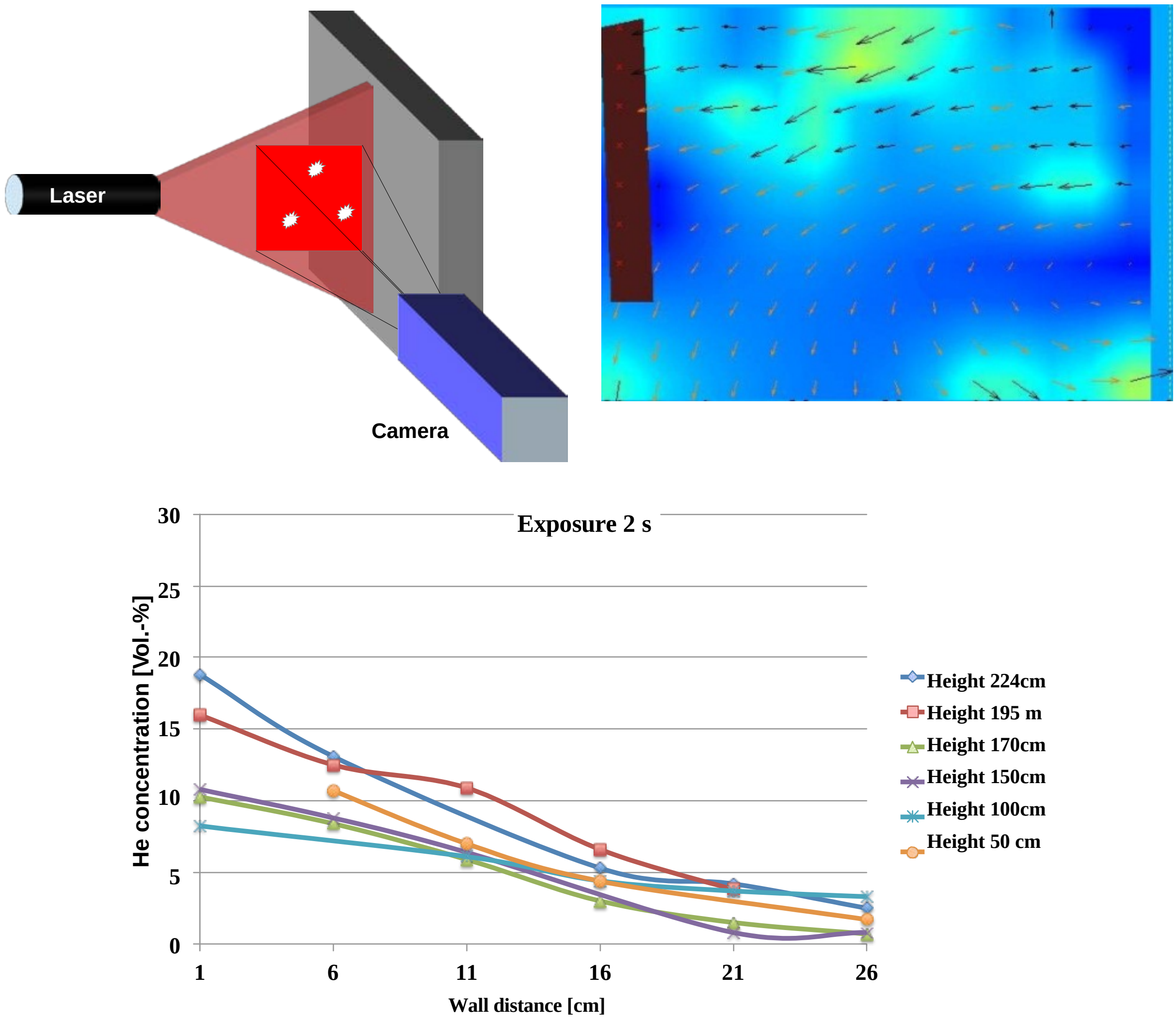
The pressure effect of accidental combustion of released hydrogen inventories depends mainly on the effective flame speed. Flame acceleration (FA), even reaching detonations (deflagration to detonation transition, DDT), is widely studied using close combustion tubes filled with homogeneous H2/air/O2 mixtures while in reality, inhomogeneous mixtures prevail. FA and DDT studies for real accident scenarios are required. Due to difficulties in producing mixtures with defined concentration gradients and to measure gradients in such mixtures, a survey was performed to compile available technologies and evaluate data of related experiments to extend the scope of the established σ- and λ-criteria. A few experiments were conducted at differently scaled facilities (in partners' facilities) to evaluate the predictive capabilities of these criteria and to fill possible gaps as well as to assess the applicability and strategies to introduce the validated criterions in CFD codes. Based on the outcome of literature survey, an automated measurement system for high resolution (concerning space and time) H2-concentration measurements in air was designed and assembled [Fig.5]. The new system based on the well-established manual measurement procedure, which comprises a thermal conductivity sensor and several mobile sample taking cylinders (STCs). The method was successfully used for years at KIT for the determination of spatial hydrogen distributions in air and gives reliable results but has several disadvantages as for example that it is very time consuming and it is only possible to do one measurement with one STC during one experiment. To improve the method the discontinuous procedure of sample withdrawal and offline analysis had to be changed into an automated cyclic procedure where sample withdrawal alternates with analysis of the sample. Also the possibility to monitor several STC-positions with one sensor was desired. So the new prototype measurement system consists of six sample taking cylinders, one hydrogen sensor, one vacuum pump and several fast acting electric valves as well as one pressure sensor for process monitoring [Fig.5].



[Fig.5] Sketch (left side) and image (rights side) taken from apparatus of the prototype measurement system

The components are controlled via software programmed in ProfiLab Expert 4.0. The samples are collected within a time span of less than one second by a pre-evacuated small STC, so the determined concentration corresponds to a very sharp frame concerning space and time compared to other analysis methods. From the cylinder the sample is then transferred into the pre-evacuated hydrogen sensor where it remains until the analysis is completed. The new system allows measurement cycles with duration of about 6 s and is designed for the extension to a maximum number of 15 sample taking cylinders that are analysed subsequently. Several software modes are available for sample taking and analysis. Different calibration parameters and parameters for the analysis procedure can also be chosen by the user.

A series of 60 experiments using sampling probes method and PIV technique was performed for the testing of the channel [Fig.1.6]. In every experiment the light gas was injected from a pressurized tank through ten injection planes close to the rear wall, where the highest concentration establishes. In the direction of the open channel front the concentration decreases. Later, up to 36 gas samples (16 cm³ each) were taken from the channel and analysed individually offline. The He-effusion behaviour of the facility became investigated by varying the initial pressure in the main tank. The variation of the delay time between effusion process and sample taking also caused a fast concentration decrease. The strong buoyancy of He in air leads to a withdrawal of the He from the channel and to an air ingress into the channel after relatively short time. The mixture cloud was found to be not-stationary to a large extent and can only be treated as quasi-stationary for a very short period of time.

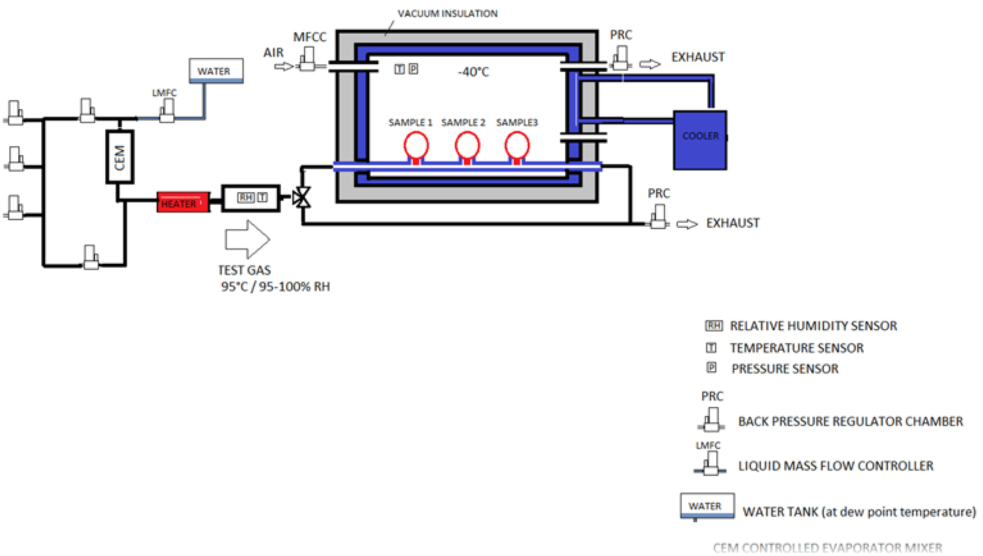


[Fig.6] Hydrogen concentration profiles vs. distance to the wall after 2 s time delay at different positions (image below); the laser beam scheme (to the left) and PIV images (to the right) of light gas flow in presence of vertical wall

The figure above [Fig.6] demonstrates an example of light gas distribution after 2 s of time delay. Close to the rear wall the mean measured light gas concentration is 15-20 Vol.-%. This value decreases in the direction of the front wall with an averaged slope of about 0.6 Vol.-%/cm. At a distance to the wall of 26 cm the mean concentration is still 2-4 Vol.-%. The horizontal gradients show a tendency towards linearity. About 75% of the injected He leaves the monitored area of the channel during the time period up to the sample withdrawal. The knowledge gained during the present work demonstrates a suitable method for the generation of a defined horizontally oriented light gas concentration gradient in semi-confined channel geometry. The knowledge provides the basis for numerous combustion experiments with H2-air-mixtures in a similar geometry. The results of the systematic measurements can also be used for the validation of complex flow numerical simulations. The next task within the work package was entitled as “Facility and Experiments

Improvement for Safety Assessment of Materials Behaviour using Hydrogen Sensors". Sensor aging and environmental disturbances produce changes in sensor responses limiting the ability to measure the absolute value of target gas concentrations and may require frequent sensor calibration. Taking into account the importance of the long-term stability of chemical sensor signals for their practical use in various applications, a new experimental facility was designed and constructed at the JRC IET, which will offer the possibility to perform accelerated life tests to investigate the long term stability and lifetime of sensors for novel sensor applications. Accelerated life time (ALT) tests provoke the onset of ageing mechanisms by increased temperature, humidity, voltage or vibrations. The stress can be applied permanently, steadily increasing or through cycling. The environmental conditions are chosen according to the application and will lie within the normal operating parameters of the component under test. For the ALT testing of hydrogen sensors, the both the degree of stress and the frequency of stress will be the means of accelerating degradation, these can be combined with exposure to corrosive or poisoning substances in the future.

In order to simulate more closely the real operating conditions of a hydrogen safety sensor a highly instrumented chamber is required which will allow temperature and relative humidity to be changed and monitored (in addition to hydrogen concentration changes) during the duration of the accelerated lifetime tests. A new environmental chamber has been designed and partially constructed. It comprises a vacuum insulated 20l stainless steel instrumented chamber and a dual gas flow heating and cooling system. The experiments on the sensors performed in flow-mode, limiting the amount of hydrogen necessary for the experiment and also enabling fast temperature changes and high flow levels. The sensor casings and electronic boards can either be exposed to varying temperature and humidity conditions or held at the appropriate ambient conditions of the application [Fig.7].



[Fig.7] Schematic layout of the accelerated life time test chamber

Work is on-going beyond the project to identify most important parameters for accelerated lifetime tests, but initial results point to the temperature ramp rate as the key variable. The results of the testing campaign revealed that both the temperature range and ramp rate needs particular consideration while developing the testing protocols. The test results will provide valuable information to guide manufacturers and users as to which sensors can best withstand the environmental conditions for their application. The new SenteF-ALT is now at disposition to sensors manufacturers for testing lifetime and degradation of sensors under specific operating conditions.

A further task was entitled as "Assessment of Hydrogen High Pressure Material and Component Damage". It focuses on the assessment of destructive and non-destructive methods for the micro-structural characterisation of operation damage in high pressure components and their materials. This object of the assessment are on on-board hydrogen storage tanks of type IV, i.e. made of an external shell made of carbon fibre reinforced composite and an internal metal (type 3) or plastic polymer (type 4). The micro-structural mechanisms contributing to the ageing and degradation of high pressure hydrogen pressure tanks are not yet completely understood. To study of the morphology of the defects present in this composite material and the stress-induced damage, several tanks (some of which cycled or over-pressurised) and tank samples have been analysed with different techniques available at JRC. Three different tanks used in GasTeF for fast filling studies and fatigue tests have been investigated within H2FC: a type 3 of 40 litres volume, a type 4 of 29 l and a 19 litres type 4. These tanks have 70 MPa Nominal Working Pressure (NWP). Tanks have been X-ray examined in as received status and after hydrogen filling and fatigue experiments performed in GASTEF. In addition a section has been cut from a virgin Type 4 29 l tank and has been used to assess the potentials of X-ray and tomography for non-destructive examination of the liner plus composite assembly. Microstructural examination and micro computed tomography (CT) has been made on samples from the composite wrapping. A further study focused on breathing apparatus tank used by fire brigades. These tanks are type 4 cylinders 6.8 litres of standard volume. Breathing apparatus tanks are filled with compressed air at a nominal working pressure of 30 MPa and their proof pressure is 45 MPa. The interest in this tank is given by the fact that it experienced the highest achievable pressure just before bursting, thus it is expected to contain the highest level of defects. From this tank samples from the composite wrapping have been extracted for micro computed tomography and for microscopy examinations.

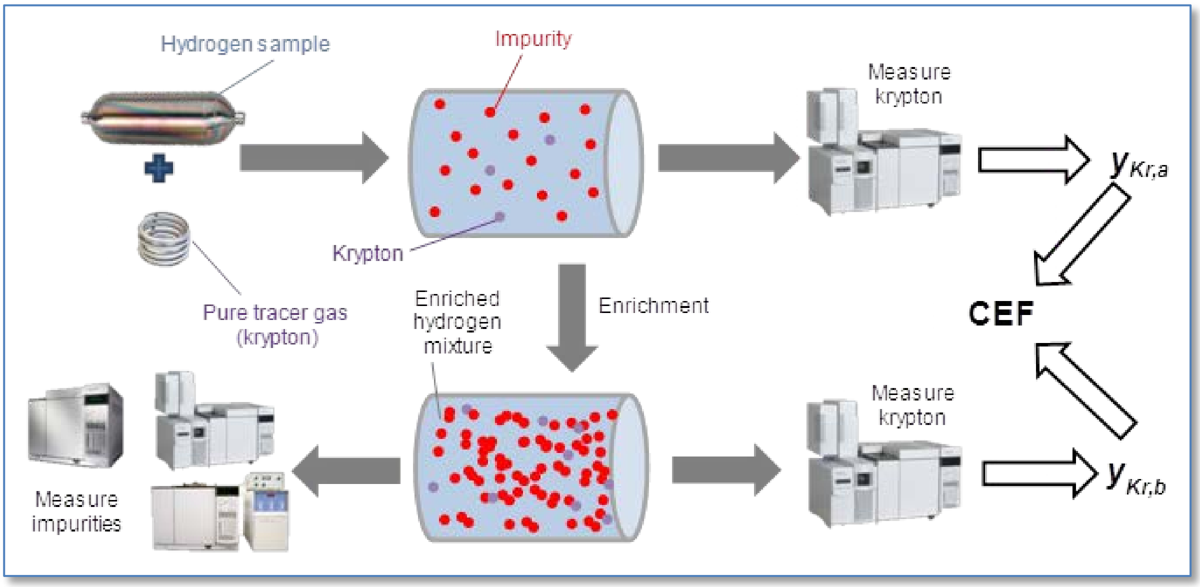
To identify and assess the above mentioned damage mechanisms, an (1) investigation was performed to the available options to detect global liner deformation by x-ray radiography, (2) developed and optimised a microscopic X-ray tomography technique for the assessment of fibres-composites damages, (3) performed destructive micro-structure analyses by means optical and scanning electron microscopy, to provide a base-lines for comparison for (2) [Fig.8].

[Fig.8] An example of multi-scale structure characterisation: from full component (top left), to micro imaging (CT shot, top right), to isolation and quantification of crack parameters (bottom pictures)

The work performed in the task devoted to the "Improvement of Testing Facilities for Performance assessment of Hydrogen Safety Sensors" was presented in two deliverables D7.4 and D7.5. For security reasons, new and emerging hydrogen sensors have ultra-short response times in the range of milliseconds, however, currently these response times cannot be measured, validated or certified according to current standard test methods. The aim of the task was (1) the extension of the BAM sensor testing system for the measurement of the response times down to 1 millisecond of gas sensors; (2) the integration of two 3-way electronically controlled valves for rapid switching (≥ 1 ms) of the gas streams; (3) the development of software program for chamber control (solenoid valves) and for data acquisition with time synchronization and graphical visualization. The Response Time Analyser, consisting of two 3-way valves for fast change of gas streams and control and data acquisition recording signals in the millisecond range was build up and taken in operation.

Task „Development of Measurements and Analysis Techniques for Fuel Quality" was orientated to the hydrogen enrichment device produced at Argonne National Laboratories which was initially investigated as a method that could potentially be used to improve hydrogen purity analysis by helping to lower limits of detections of current analytical equipment. The method works by removing a known amount of hydrogen from a sample of hydrogen fuel (through the use of a heated palladium membrane) to enrich the impurities in the sample to amount fraction levels that can be measured accurately using current analytical techniques such as gas chromatography. By calculating the enrichment factor (determined by measuring the changes in gas properties such as pressure, volume and temperature of the sample during hydrogen removal) the original impurity concentrations can be calculated. Although the method does work well, there was room for improvement, for example the uncertainty could be reduced and the method would not work during an air leak or membrane failure. Therefore NPL have developed a new method which uses Krypton as a tracer compound which is measured before and after enrichment.

In addition to several other benefits, this device allows the enrichment factor to be calculated accurately as proven by an uncertainty budget carried out at NPL. Although this device now works well, it needs further testing with gas samples containing reactive species such as hydrogen sulphide. Also, alternative membranes that can show improved performance would need to be tested. There is scope for further improvements by implementing a new enrichment device design, this will also be investigated. In addition a literature review was performed on all gas analysis techniques that can be used to perform hydrogen purity analysis (this covered offline, online and enrichment techniques).



[Fig.9] NPL's Hydrogen Impurity Enrichment Device (using Krypton tracer compound)

Several analytical techniques described in the report D7.7 became identified that have been validated as suitable offline methods for performing quality assurance of hydrogen provided by hydrogen refuelling stations. It is however evident that there are some impurities listed in ISO 14687-2 where validated methods and traceable gas reference standards do not yet exist, in particular for total halogenated compounds. In other cases such as for measurement of ammonia and formaldehyde, the analytical techniques do exist but they cannot achieve the desired limits of detection. Pre-concentration or enrichment devices are then necessary to concentrate the impurities in the sample. As the number of refuelling stations in the UK increases (1.100 are expected to be in operation by 2030), it will become more difficult to perform offline hydrogen purity analysis to meet the demands of the refueller. Therefore it is important to further develop online purity analysers so that these instruments can perform in-situ purity analysis of the hydrogen provided at the refuellers, whilst the offline methods provide accurate and robust validation of the online measurements. Currently there are no commercially available hydrogen purity analysers that can perform measurement of all impurities listed in ISO 14687-2 but instruments are available or being developed for measuring a group of target species. There have been several approaches to designing an online analyser including the use of FTIR and mass spectrometry. One instrument, the HEMS instrument, has an in-situ enrichment device for measuring the impurities in hydrogen by mass spectrometry at very low levels. Further development of these instruments to include a wider range of measures (including reactive and adsorptive species), validations against traceable standards and reductions in cost would lead to promising instruments for installing in hydrogen refuelling stations. A publication summarises the results. Its content can be mirrored briefly: In contrast to current petrol engines, fuel cell vehicles require much higher purity fuel during operation to prevent degradation of the fuel cell system. ISO 14687-2 provides a list of 13 different impurities with associated maximum limits that must not be exceeded when providing hydrogen to a fuel cell vehicle. It provides a summary of the offline, online and impurity enrichment techniques that can be used for performing quality assurance of fuel cell hydrogen. As a large number of hydrogen refuelling stations are expected to be installed across the globe in the near future, it is not likely that robust purity analysis can be carried out for all hydrogen provided to fuel cell vehicles as a full analysis as specified in ISO 14687-2 can only be performed by a few advanced gas laboratories around the world. Therefore, in addition to summarising analytical methods for hydrogen purity analysis, this paper will propose potential solutions for meeting these anticipated demands for quality assurance.

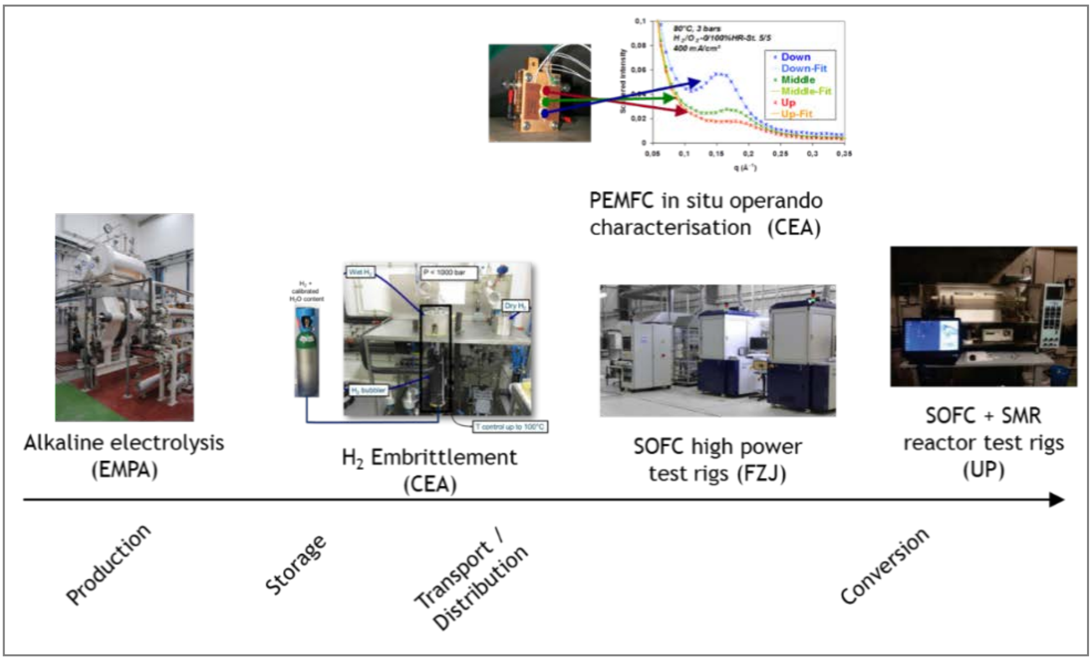
3.2.2 Facility Improvements for Investigations of Components and Systems of the Hydrogen Energy Chain and low and high Temperature Fuel Cells

The second Joint Research Activity is centred on the "Facility Improvements for Investigations of Components and Systems of the Hydrogen Energy Chain and low and high temperature Fuel Cells". A major focus was given to improve existing measurement techniques and develop accurate characterisation and analysis methodologies of degradation phenomena (also including component failure from fatigue), either by enhancing already existing experimentation instrumentation or by developing further high resolution or versatile in situ methods that constitute one of the best way to investigate basic phenomena related to component evolution or degradation upon operation.
The R&D bottlenecks addressed in this JRA are:

- Identification, understanding and influencing phenomena of degradation (and failure) in hydrogen and fuel cell related components
- Implementation of on-line, non-invasive diagnostics and advanced characterisation methods
- Development of methods for accelerated testing of fuel cell and hydrogen components
- Characterisation of system components under severe operating conditions

The work package was organised in five tasks centred on the main points of focus end reported in 8 deliverables: hydrogen production, hydrogen storage, low and high temperature fuel cells and fuel production [Fig.10].

- The improvement of alkaline electrolyser characterisation D8.1
- The extension of the metallic vessel embrittlement testing facility D8.2
- The development of in situ spectroscopy techniques D8.3
- The development of in situ visualization and verification of fluid characteristics in an operating fuel cell D8.4
- The development of a test facility for high power testing of fuel cells D8.5
- A report on degradation analysis methodologies D8.6
- The development of a test rig for steam reformer degradation analysis D8.7
- The development of a test rig for fuel quality and fuel type system testing D8.8



[Fig.10] Development or improved facilities for investigation components and systems alongside the hydrogen energy chain

The task entitled as "Improvement of Alkaline Electrolyser Installation in the Power Range of 0.5 to 5 kW" was first within the work package. A special problem of water electrolysis is the formation of bubbles at the triple point - the interface between liquid electrolyte, solid electrode surface and gas. These bubbles reduce the accessible cross-section for the ions through the electrolyte. The influence of bubbles can be reduced using a proper geometric design of the electrodes (Gdansky setup) and hydrophobic surface properties of the electrodes and diaphragm. The focus was set on the development of new diaphragms.

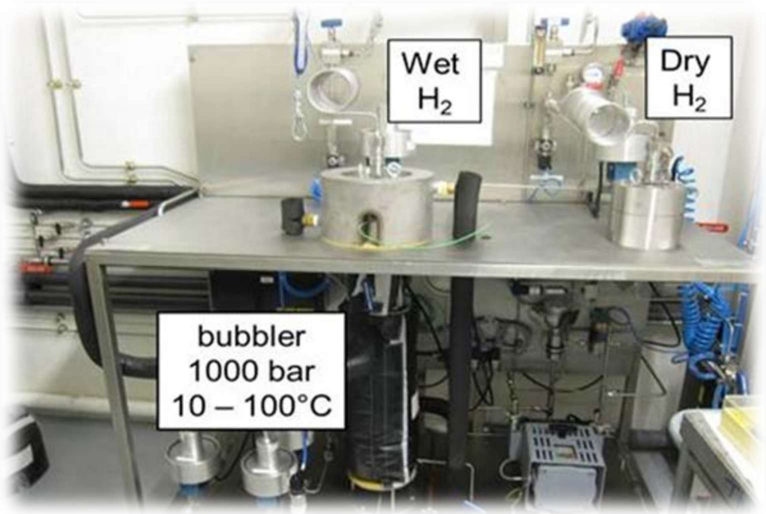
Flexible asbestos diaphragms are traditionally used in "zero-gap" electrolyzes, where the electrodes are in direct contact with the diaphragm. The health-related danger due to exposure to asbestos fibers brings, as well as the limited chemical stability of this material at temperatures above 100°C, triggered series of studies in order to find a substitute for asbestos in alkaline water electrolysis. The development of novel diaphragms' materials with promising properties has proven of not being sufficient to properly evaluate the ability of these materials for use as electrolysis diaphragms. Elaborate testing in prototype electrolyzer setups is a mandatory final step in the development of novel diaphragms for water electrolysis. The development of such prototype electrolyzer and appendant analysis methods was done. A single cell laboratory electrolyzer has been set up and equipped with a gas analyzer system and electrochemical characterization. The electrolyzer has a diameter of 50 mm and is operated at ambient conditions. In collaboration with an industry partner (IHT), an electrolyzer consisting of 8 cells with a diameter of 130 mm was developed, which is operated at technically relevant conditions of 30 bars and 80°C (current density of 200 mA/cm2). These important milestones are summarized in the following table:

	Target of the improvement – main technical specifications	Status of the improvement	Time schedule for complete achievement
Laboratory electrolyzer, P ~ 10 W	Single cell electrolyzer, 50 mm diameter, analysis	Developed, operational	02/2012

	methods		
IHT electrolyzer P ~300 W	8 cells stack, 130 mm diameter, technical conditions (30 bars, 80°C)	Developed, operational	06/2012
FHa Aragon Pilot electrolyzer P ~35 kW	8 cells stack, 1500 mm diameter, technical conditions (30 bars, 80°C)	Planning stage	Installation planned for 02/2013 Completed 11/2013

[Tab.1] Some specifications of the developed electrolysers

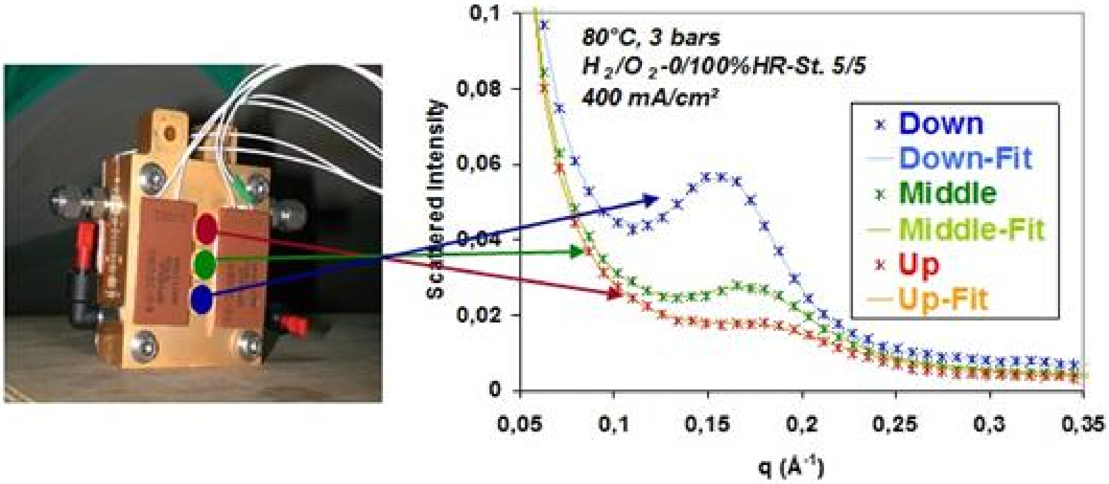
Within the next task "Extension of the Metallic Vessel Embrittlement Test Chamber to Moist Hydrogen" the extension of the operating conditions of the embrittlement test chamber PRETHY to moist hydrogen for rupture discs has been performed as shown [Fig.11]. The water vapor content is obtained by saturating hydrogen at a given pressure and temperature through a bubbler. Thus an additional cell dedicated to wet gas has been manufactured. This cell is connected to a water bubbler that withstands a pressure up to 1000 bar and a temperature ranging between 10 and 100°C.



[Fig.11] Developed PRETHY device

Since during a disc test, pressure is evolving, changing in turn the water vapor content, steps of several hours are performed at a given pressure and temperature, corresponding to a given vapor content, before launching the test leading to the disk rupture. First tests on ferritic steels have already been done in order to validate the device. This device allows to measure in situ the disk deformation when pressure is increasing. Moreover, it will allow fracture mechanics analysis using notched disks, the geometry of the notch being optimized by numerical simulations. It will then be possible to compare the local strain and stress fields to those obtained on CT or SENT specimens under hydrogen.

A further task "Facility and Measurement Improvements for in-situ Investigations of PEM Fuel Cells Materials and Components" is subdivided into subtasks. The first one is entitled as "In situ Spectroscopy Techniques with Enhanced Spatial Resolution and Enhanced Operation Conditions". The EDIP installation is based on the use of Small Angle Neutron Scattering (SANS) to visualize the water distribution across polymer membrane at different position in the cell under different operating conditions [Fig.13]. An analysis protocol was also developed to extract the water concentration profiles across the membrane thickness through SANS spectra reconstruction through the use of reference spectra recorded at swelling equilibrium. The EDIP installation is unique in the sense that the analysis is not perturbed, the experiments are performed in a representative fuel cell with state-of-art performance and under representative experimental conditions and water concentration profiles along the membrane thickness can be extracted with a high resolution.



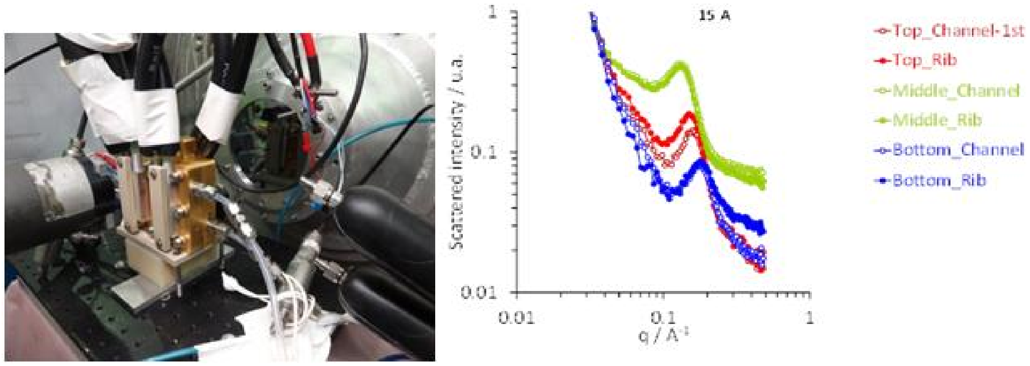
[Fig.12] Fuel cell transparent to neutrons (shown left side) and examples of experimental and fitted SANS spectra obtained at different positions in the cell under fuel cell operation (shown right side)

In the framework of the JRA activities, different series of experiments were conducted to improve the EDIP installation. The SANS experiments were previously conducted at the LLB (Laboratoire Léon Brillouin, Saclay, France) with a 1cm wide neutron beam and a count-time around several minutes per spectrum. A serpentine was dug in each end-plate for the gas distribution. Therefore the end-plate appears as alternating channels (0.8mm) distributing the gas on the MEA and ribs which collect the current (1.4mm). It follows that the SANS data integrated information over 5 ribs and channels. A new cell was designed that allow to mask part of analyzed area with cadmium foils and to study the membrane water content during operation in front of either only one channel or only one rib. However, the increase of the spatial resolution was obtained at the expense of the time resolution since the count time was increased by a factor 10. The High Flux Reactor at ILL (Institute Laue Langevin, Grenoble, France) was used benefiting from the high neutron flux to monitor a very small beam (0.5mmx2cm). The fuel cell was positioned to analyze separately the membrane content in front of one channel or one rib confirming the result with small count times (typically 30s).

A second major improvement achieved benefiting from the high neutron flux of the ILL was the possibility to study thinner membranes close to the state-of-art. Indeed, the previous experiments were mainly conducted with a thick Nafion membrane (Nafion 117, 175µm). We have demonstrated that the membrane water content can be determined with a Nafion 212 (50µm) based MEA. This important improvement open the EDIP installation to industrial partners developing new MEAs instead of being limited to the experimental validation of water distribution models.

In order to increase both the spatial and time resolution, a new cell was designed for a use of small-angle X-ray scattering on the synchrotron radiation. Two series of experiments were then conducted at the ESRF (European Synchrotron Radiation Facility, Grenoble, France) on the D2AM French CRG beamline and the ID2 international "High Brilliance" beamline allowing a submillimeter and sub-second resolution. Indeed, a 500x500µm^2 with a one second count time was first used on the D2AM

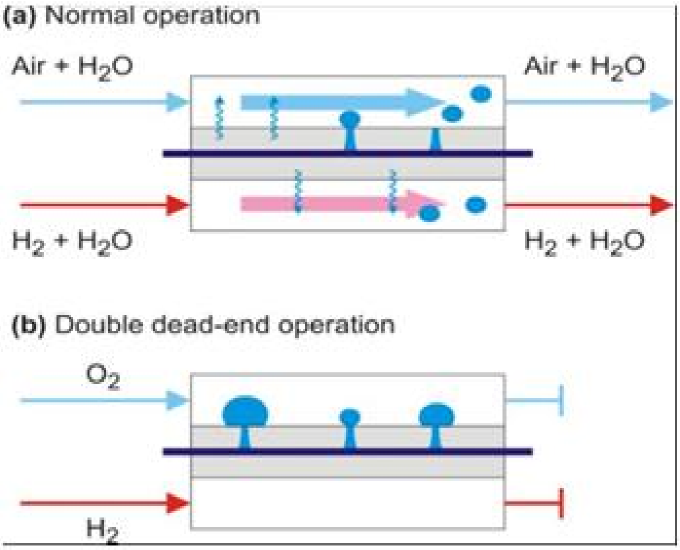
beamline and a 300x300µm2 with a 0.1 second count time was then used on the ID2 beamline allowing for the first time the real time determination the kinetics of water hydration at different positions in the cell under a call of current load or during fuel cell operation under cycling conditions.
The temperature range of operation was increased at both high and low temperatures. Most of the previous experiments have been performed at 80°C corresponding to the usual temperature of operation. However, it is very interesting to study the water management at sub-zero temperatures to understand the fuel cell behavior during cold start (fuel cell storage during winter times) and be able to investigate the water management at temperatures up to 120°C which represent one of the main targets for fuel cell development. Within the JRA of H2FC, series of experiments have been performed at sub-zero temperatures by SANS and at temperatures larger than 100°C by SAXS.
A new cell was designed and built (but not yet tested) with a smaller active area 2.5 cm^2 instead of the 25cm^2 currently used in the EDIP installation. While a large active area allow analyzing the heterogeneity of the water distribution within the cell depending on the operating conditions, a smaller active area will permit the obtaining of homogeneous conditions and so forth to be able to validate the water distribution models.
Finally, an ensemble of apparatus to control and measure precisely the humidity in the cell which is necessary to obtain quickly reliable references at defined relative humidity became designated. The necessary elements built the complete system and validated a protocol of operation.
The last scheduled improvement is to install the fuel cell on a laboratory SAXS camera. A laboratory camera implies long acquisition times but is well suited for experiments performed under stationary conditions. The improvements to EDIP installation permit now its use for the optimization of the fuel cell development, the experimental validation of water management models and the analysis of the behavior of some alternative membranes.



[Fig.13] New fuel cell transparent to neutrons at ILL (shown left side) and examples of SANS spectra recorded at different positions in front of ribs and channels under fuel cell operation (shown right side)

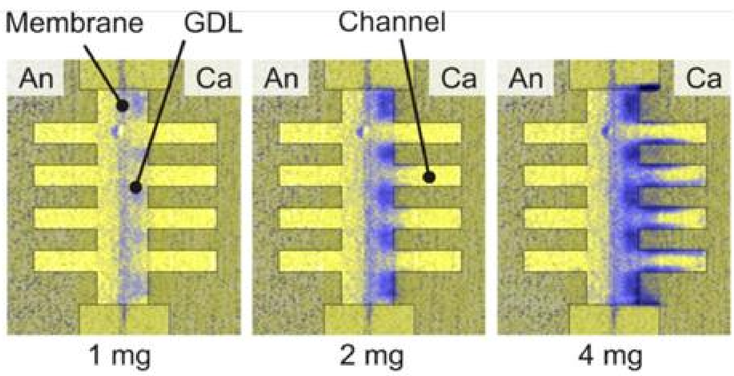
A new method was developed for assessing the accuracy of water quantification in fuel cells based on neutron imaging. First results conducted on a single fuel cell indicated reasonable agreement, though with a systematic bias of approximately 10%. For this purpose, the recently developed multi-cell setup is used to optimize the use of beam time at PSI.
In the recent years, an optimized imaging setup [1] combined with anisotropic enhancement [2] allowed a significant improvement in spatial resolution while keeping a good temporal resolution. The typical imaging setup for fuel cells has a pixel pitch of approx. 2.5 µm and an effective resolution (FWHM) of 20 µm for an exposure time of 10 seconds. A remaining open question is the accuracy of the water quantification based on neutron imaging. In this context, a methodology for assessing this accuracy was developed. A possibility would be to compare successive exposures in a given

stationary condition to obtain the standard deviation of the measured water quantity. However, such a measurement would only yield information about statistical variation, ignoring any systematic bias in the measurement. The method used in the frame of this work consisted in producing a well-defined quantity of water as a comparison basis.



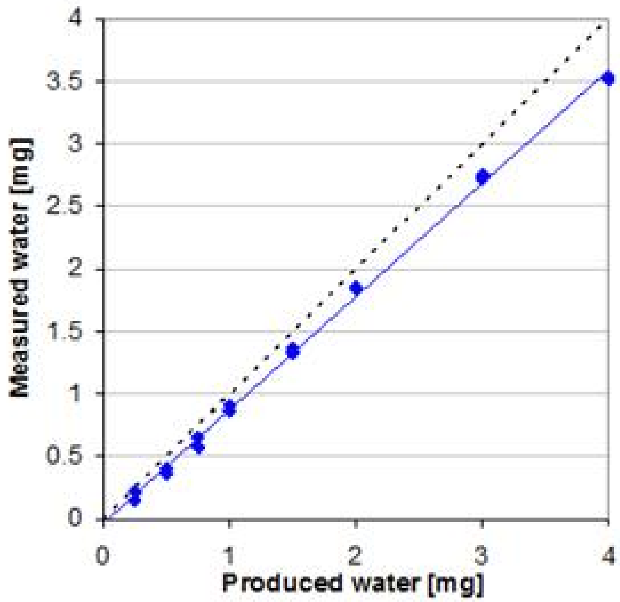
[Fig.14] Normal (a) and double dead-end (b) operation

In normal operation [Fig.14a] the quantity of water accumulated in the fuel cell is the result of a complex equilibrium between water brought into the cell by gas humidification, water produced by the electrochemical reaction and water removed by evaporation of as liquid droplets. For this reason, PSI used a special mode of operation called double dead end [Fig.14b]. In this mode, a constant inlet pressure is kept and the outlets are closed. When using dry gases at the inlet, water is neither entering nor leaving the cell, and the quantity of water accumulated in the cell can be calculated from the amount of water produced by the electrochemical reaction.
In the realized measurements, 8 different quantities of water up to 4 mg were produced. The experiment was performed twice with the same cell. The radiograms corresponding to 3 different quantities are reported [Fig.15]. Prior to the measurements, the imaging setup was calibrated to remove background contributions (e.g. due to scattered neutrons) and the effective attenuation coefficient of water for this setup was calibrated using a reference water scale.



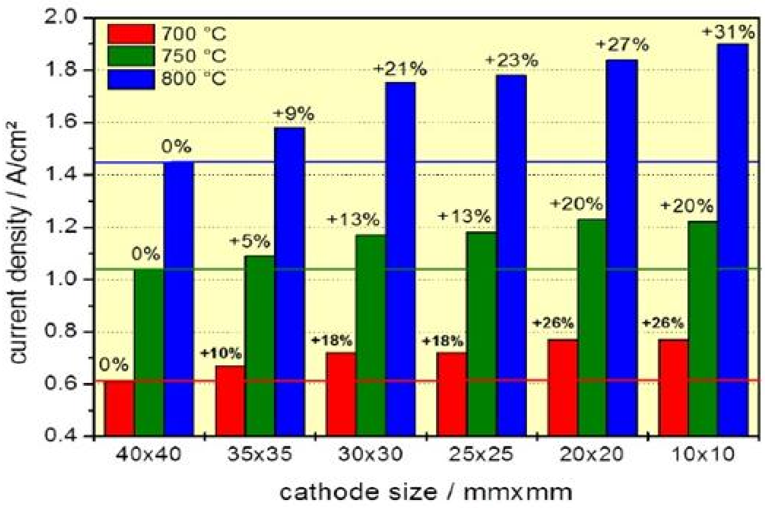
[Fig.15] Radiograms with different amounts of produced water (average over 5 minutes)

The water quantity from neutron imaging was computed as a difference between the quantities measured after the production and the initial water content. The comparison with the amount of water produced is reported in [Fig.15] for the 2 experimental series. The measured quantity is approximately 10% lower than the expected value. This deviation seems to impact all measurement points in a systematic way, as statistical errors are relatively low as shown by the comparison of the two experimental series. The reason for this discrepancy is not clear yet, and further research will be conducted to understand it.



[Fig.16] Comparison of the total water between measured with neutron imaging (------) with the produced water (doted blue curve)

Within the further task “Facility and Measurement Improvements for Investigations of high Temperature Fuel Cells Components and Systems”, single cell measurements were performed to predict the electrochemical behavior of the cell in a stack. The difference in electrochemically active area between stacks and single cell measurement set ups is often considerable. In stacks an electrochemical active area of up to 360 cm² can be found whereas the single cell experiments are frequently carried out on 1 cm² sized electrode surfaces. From experiments performed in the FZ Jülich a decrease in the electrical power density of 30 % is observed going from cells of 1 cm² to cells of 16 cm² sized cathodes produced from the same paste [Fig.17].



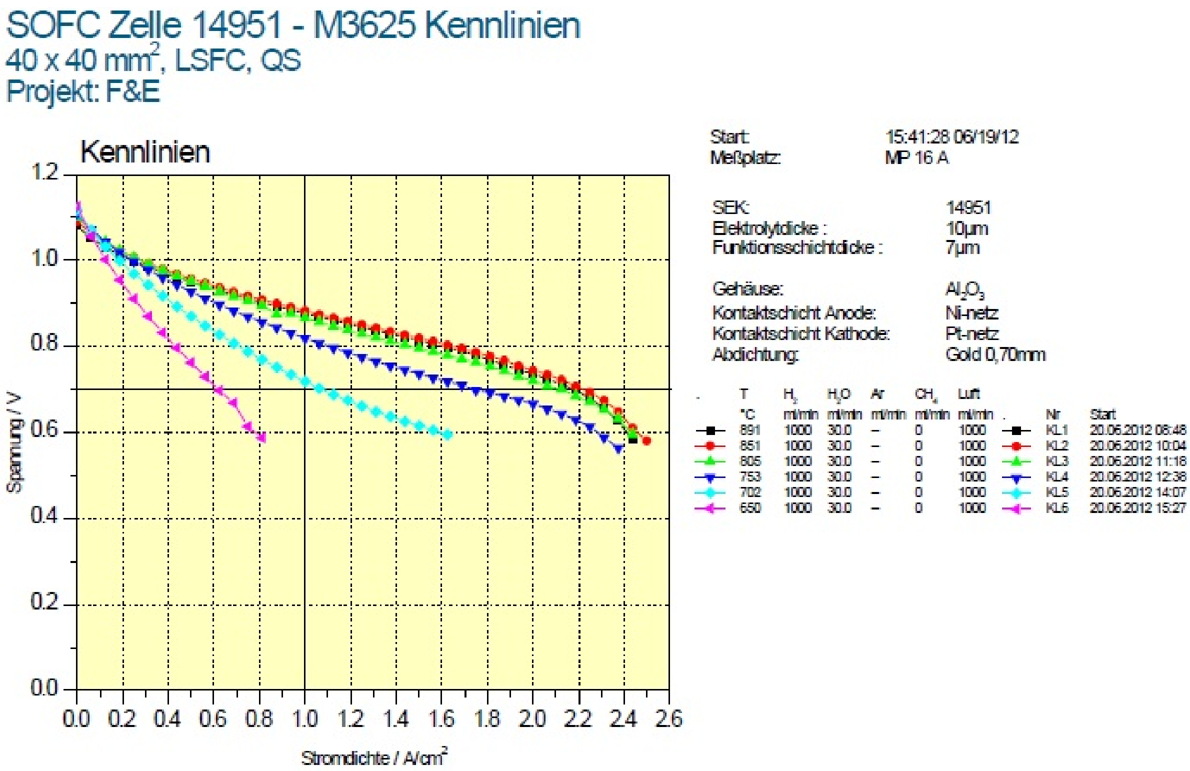
[Fig.17] Current density result depends on area of cathode

The reason for this decrease is probably caused by an increasing inhomogeneity of the contact between the cell and the current collectors. The larger cathodes also can give rise to a temperature gradient across the active area and a change in composition of the fuel and oxidant due to the electrochemical conversion. Further the resistance of the current collector (Pt or Au mesh) may play a role. These results suggest that when results from single cell measurements are to be comparable with stack results the data should be obtained on large cells.

- The improved electrochemical performance of the newest generations of cells causes an operation of stacks at increasing current densities
- Most test stands are however designed for relatively low current values
- The high performance of the cells combined with the need for large cells limits the current density in the current-voltage measurements
- At lower temperatures (T<700 °C) the measurements are still producing relevant information
- At higher temperatures the limitation to lower current densities the measured data have to be extrapolated to obtain the desired information. This extrapolation is however arbitrary and not based on a physical model

By increasing the maximum current at which a test stand can operate the need for extrapolation can be avoided and the electrochemical characteristics can be directly measured at high current densities. The adaptation of existing test stands to allow high current operation involves a larger number of modifications of these test stands.

Within the task “Test Facility for High Power Testing of Fuel Cells” an existing test rig was modified by upgrading the electrical load from 20 A to 40 A at FZ Jülich. One of the major problems associated with this upgrade is the Ohmic resistance in the current conducting circuit. At these high currents the voltage losses in this circuit exceed the maximum power output of the electronics. To lower the Ohmic resistance the wiring between the load and the furnace were adapted to the high current. The feed through into the furnace was changed from a simple wire to a massive steel rod of 6 mm. Inside the furnace the current is transported through 4 Platinum wires of 1 mm diameter. First measurements show that the test rig is capable of measuring up to the maximum current of 40 A [Fig.18].



[Fig.18] Current-voltage measurements on a standard Jülich anode substrate cell with LSFC cathode up to 40 A

From the results of these first measurements a problem with the gas and air supply of the cell housing becomes obvious. To solve these problems, new cell housing was designed and manufactured. The cell housing is constructed from Aluminum oxide. The sealing of the cell is a combination of a gold gasket and aluminum oxide felt. The current connectors are primarily constructed of nickel and gold meshes. The aluminum oxide flow fields in the cell housing can be exchanged for flow fields of other materials e.g. Crofer22APU. This new cell housing comprises CFD optimized manifolds. A fuel bypass present in the old housings was minimized as was the dead volume in the fuel compartment.

At KIT a 16 cm² SOFC test bench was modified to allow an operation of the single cells at currents of up to 50 A (3.125 A/cm²). The Al2O3-flowfield on the anode was exchanged by a Ni-flow-field acting as a low resistance current collector. The former bilayer Ni-mesh acting as contact and current collector was exchanged by a single layer contact mesh to provide a good contact between anode and Ni-flow-field. The disadvantage of the Ni-flow-field is its high catalytic activity. For in-situ gas conversions measurements by µGC, the Ni-flow-field have to be exchanged with a flow-field manufactured from a SoA interconnect material (i.e. Crofer APU). The gold mesh on the cathode was reinforced by welding the formerly used fine gold mesh onto a coarse gold mesh and additional gold wires, resulting in a significant reduction of the in-plane resistance. The electronics in the test bench were modified to enable current of up to 50 A and a 50 A load was integrated. Tests were performed to prove the reliability of the above mentioned modifications. For this task, VTT has improved two single cell test and four stack test. The results so far are that cell and stack testing facilities can be used for normal operation, life-time and degradation studies by changing operating conditions like current, temperature, fuel and air utilization rate, fuel composition, additional impurities etc. In addition stack testing facilities have been equipped with oxygen and humidity sensors to detect possible changes in leakages and utilization rates.

The further task “New Characterisation Concepts for Fuel Cell Degradation” focused on long term stability of fuel cell operation. Long term stable operation of Solid Oxide Fuel Cells (SOFC) is a basic requirement for introducing this technology to the stationary power market. The continuous degradation of fuel cell voltage commonly observed has to be reduced such that the loss of power remains within acceptable limits during the lifetime. The project aimed at a better understanding of the degradation phenomena as a tool for mitigating these effects and as a first step towards developing accelerated testing methods. It follows a systematic approach to analyze some of the most important degradation mechanisms. It concentrated on the 'continuous' (baseline) degradation phenomena determining stack behavior in the long term. By deconstructing the SOFC stack into isolated elements and interfaces, these are exposed to the physical conditions found in typical SOFC system operation (and beyond). At regular intervals, specimens were taken from the experiments and thus a time series of gradual development of degradation effects became recorded. This time-lapse photography type approach is designed specifically to allow the modeling of physical changes over time.

Exposures tests of Ni-YSZ cermet substrates (ASC matrix) and Ni-CGO cermet layers (ESC matrix) and contact resistance measurements on Ni-mesh/Crofer-steel joints were continued at selected conditions for durations of 300, 1000 and 3000 hours. The tests were extended with including the CFY steel material (ESC matrix) and including anode substrate samples sandwiched between the Ni-mesh/steel joint. For each case 'zero' hour exposure test were conducted as well, in order to obtain 'zero' hour reference values and samples. Ni-YSZ anode substrates exposed at 800° C in hydrogen show an increase in resistivity of close to 24% after 3000 h. The time evolution of the resistivity could be described with a second-order exponential decay. This decay shows to be faster at high humidity (80% steam) in comparison to the case with low steam content (3%), but the relative increase is similar for both cases after 3000 h. Similar observations were also made during investigation of the influence of current passing through the samples during the exposure tests. During the total 2000 h of exposure no differences could be observed in the relative increase of resistivity for samples exposed to 0.7 A/cm² and samples not exposed to current flow. As opposed to the data obtained at 800° C surprising difference in degradation behavior of the samples exposed for 1000 h at 700° C is seen for 97%H2+3%H2O and 20%H2+80%H2O atmospheres: 25.7. 3% water content in the gas and only 2.6 unexpected because so far high water content in the gas was considered by many researchers as the main reason of Ni-anode degradation. Nevertheless there is no doubt that degradation of all samples exposed at 700° C in 20%H2+80%H2O atmosphere is very low.

The investigations on the Ni-mesh/Crofer22APU and Ni-mesh/Crofer22H joints showed that during long term exposure austenitic grains form in the steel adjacent to the contact area. Ni diffuses from the wire-mesh into the steel whereas Fe, Cr and Mn diffuse from the steel into the Ni-mesh. Monitoring the resistivity of the Ni-mesh/steel joints during exposure did however not reveal a direct influence of the formation of the austenitic grains on the resistance. Over 2000 h of exposure at 800° C the resistivity of the sandwiches showed in general a steadily decrease, except for those samples, which showed during post-test analysis oxide formation on the wires of the Ni-mesh.

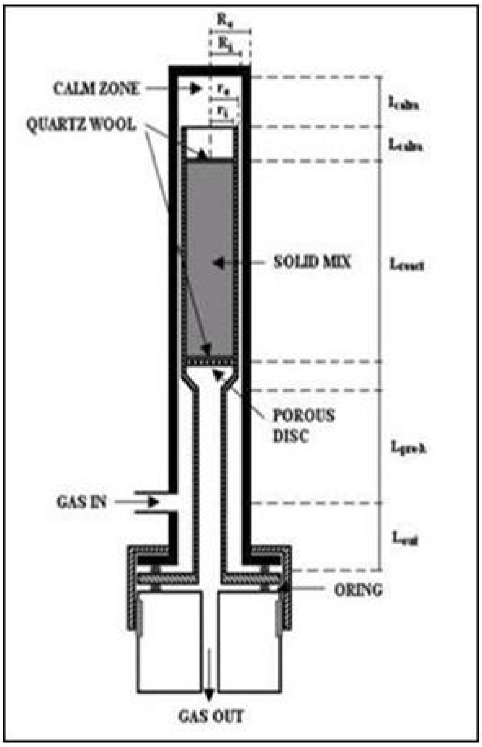
Exposure tests of LSM-YSZ composite cathode layers on YSZ (ESC matrix) and LSCF cathode layers on CGO on YSZ (ASC matrix) and contact resistance measurements on Crofer-steel/(Mn, Fe)-oxide coating/LSM contact layer joints (ESC matrix) were continued at selected conditions for durations of

300, 1000 and 3000 hours. Also here for each case 'zero' hour exposure test were conducted as well, in order to obtain 'zero' hour reference values and samples. The conductivity of LSM-YSZ composite cathode layers on YSZ exposed at 900 °C in air with 4.4% humidity increases non-linear over time during the total period of 3000 h. The increase in conductivity amounts to over a factor of 2 to 2.5. In dry atmospheres the conductivity increases linearly at a lower pace. Lowering the temperature of exposure to 800° C hardly any degradation is observed any more in dry atmosphere. Post-test examination of the microstructure of the LSM-YSZ composites showed that the length of the triple phase boundary (TPB) at 900 °C is approximately 16% lower compared to the 800° C case. No clear change over the 3000 h exposure was observed. Contact resistance measurements conducted on Crofer-steel/(Mn, Fe)-oxide coating/LSM contact layer joints at 850° C in air show a marked difference in the behavior between Crofer22H and Crofer22APU samples over 2000 h of exposure. For the Crofer22APU the resistance decreases, whereas for Crofer22H the resistance increases. The latter increase can be described using a parabolic law. Similar parabolic behavior is observed for Cr5Fe1Y2O3 steel samples with the same (Mn, Fe) Ox coating and LSM contacts exposed at 900° C in air.

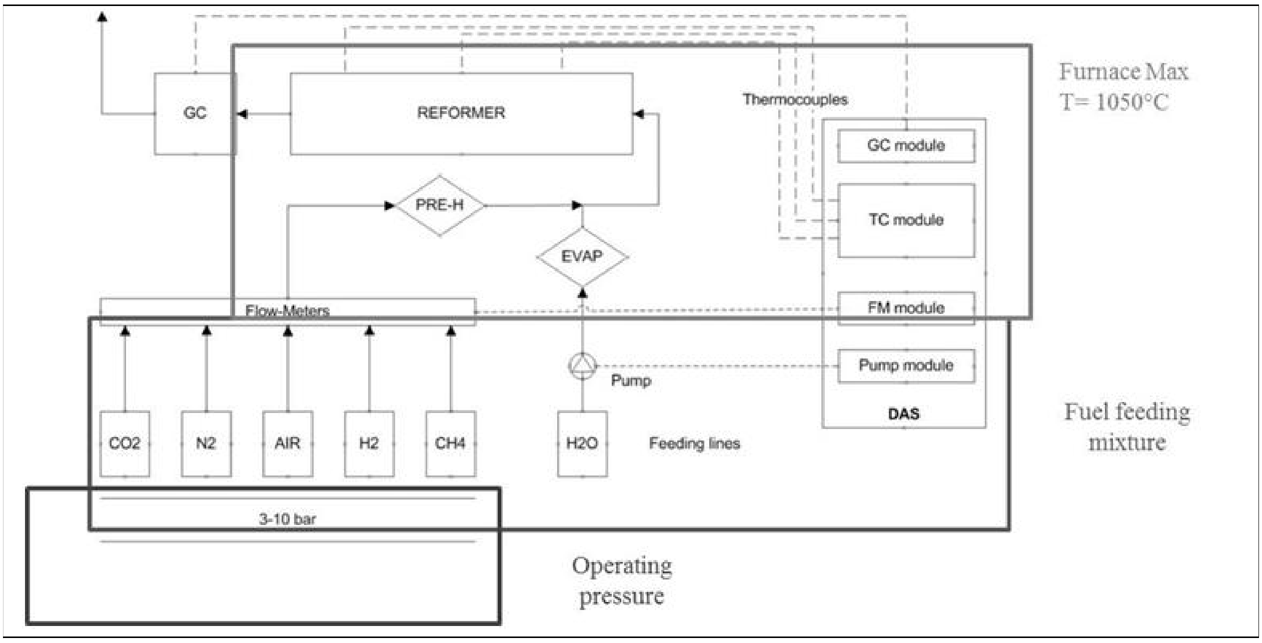
From this first series of investigations with a newly designed segmented SRU test bench, it appears that the main degraded process was the anode charge transfer reaction. However, the probable source of degradation was most likely the edge sealing (hence an ‘external’ source, that can be corrected, and not an ‘intrinsic’ one related to the cells themselves, known to be sufficiently stable (<1%/1000h)). No degradation of the cathode was detected. Progress has been made in the development of numerical models to link the results of the exposure tests conducted in the work packages 1 and 2 with the time lapse evolution of the microstructure as determined during post-test analysis. Finally, a first comparison of the ASR degradation data of components accumulated in the SOFC-life project so far and of relevant stack tests under (as far as possible) similar test conditions was made. First remarkable observation comparing stack and component results is that ASR degradation rates are significantly higher for stacks than for the IC (fuel side) and anode material component tests D8.6.

“Improvement of Test Facilities for Measuring the Impact of Fuel Gas Treatment on System Degradation”, subtask “Test Facilities for Steam Reforming”.

Design of the test bench for the execution of the SE-SMR process to the aim of the evaluation of the hydrogen production efficiency, in function of the temperature and pressure operating conditions, the feeding gases mixture and the catalyst/sorbent weight ratio, beyond that their typology. The layout of the test bench, which must guarantee operative conditions variable within 5-10 bar and 500-900°C, constituted of four main sections: gas feeding, water-vapor feeding, reactor, gas analysis. CO2 (max 0.21 NL/min), N2 (max 1.26 NL/min), Aria (max 1.26 NL/min), H2 (max 1.26 NL/min), CH4 (0.21-0.42 NL/min) for reactor feeding will be obtained from high purity gas cylinders, stored outside laboratory in a specific cylinders package, through suitable flow-meters interfaced with the data acquisition (DAQ) system. Flow rate of steam to the reformer is variable in the range 0.42-0.84 NL /min. Liquid water will be fed using a gear pump and evaporated by a boiler. It will be possible to vary the operational system pressure in the range 1-10 atm. The variation range of the water flow has been determined (regulation by means of a water flow rate control module interfaced to the DAQ system). Components to be incorporated in the test bench were the vaporizer and the deionized pressurization device. Pressure indicators, interfaced with the data acquisition system became installed at the reactor inlet and outlet to monitor the system pressure; moreover a pressure relief valve will be placed to protect reactor from excessive pressure. Reactor temperature will be maintained by a split-tube furnace with integrated regulation (with the possibility to preset temperature ramps; the furnace temperature control module is interfaced to the DAQ system). Such a device can assure a constant (±5°C) temperature until 1200° C along the reactor length (heated length equal to the reaction zone of the reactor; compatible with maximum external reactor diameter of 38mm).



[Fig.19] SE-SMR Reactor



[Fig.20] Test bench *(Furnace, Fuel feeding mixture and operating pressure)*

For the execution of SE-SMR tests, a suitable procedure has been determined. Such a procedure includes, for each test, 4 main steps: pre-calcination of the sorbent material, catalyst activation, hydrogen production process, sorbent regeneration.

Relative to the materials typology, the solution with both Ni-based catalyst and CaO sorbent incorporated into inert material that acts as structural support has been chosen. In particular, as inert materials SiO2, Al3O3 and TiO2 have been selected. Moreover a material obtained through incorporation of only Ni-based catalyst into calcium aluminate will be investigated.

Task "Test Facilities for HT FC Multi Fuel Feeding and Poisoning" aimed to develop a facility able to realize different type of test, measuring the cell performance in terms of main cell characteristics: voltage, current and temperature. In addition, a useful test rig has to guarantee the correct operation of the cell as described in the start-up procedure. This usually requires a specific ramp rate to reach operative temperature, a "safety" flow mix, mainly nitrogen based, and a mechanical load on the cell to guarantee the continuous contact between the cell and the system. With the aim of having all functions required, the rig approach was functionally divided in 6 subsystems: cell housing, thermal management, temperature and voltage measurement, gas control, mechanical load and current control. The compounds were tested separately so no cross influences were studied. The duration of the exposure of the SOFC cells to the contaminant varied. In [Tab.2], the studied components and the concentration in the fuel gas are listed.

Unsaturated Hydrocarbons				
C2H4	7 ppm	100 h	950 °C	ESC
Gaseous				
NH3	4800 ppm	101 h	950 °C	ESC
HCN	5 ppm	525 h	800 °C	ASC
	10 ppm	650 h	800 °C	ASC
	20 ppm	856 h	800 °C	ASC
	200 ppm	130 h	950 °C	ESC
HCl	5 ppm	50 h	800 °C	
H2S	1 ppm	292 h	950 °C	ESC
	4 ppm	121 h	950 °C	ESC
	8.7 ppm	142 h	950 °C	ESC
	30 ppm	varied	800 °C	ASC
	60 ppm	varied	800 °C	ASC
	150 ppm	varied	800 °C	ASC
Tar				
Toluene	25 ppm	500 h	800 °C	ASC
	50 ppm	482 h	800 °C	ASC
	100 ppm	785 h	800 °C	ASC
	550 ppm	100 h	950 °C	ESC

[Tab.2] Contaminant concentrations in the fuel gas

The measurements were performed on both electrolyte supported (ESC) and anode supported cells (ASC). All cells had an electrochemical active are of 16 cm². Both types of cells feature a nickel/8YSZ anode though of different composition and micro structure. The cells are measured in all alumina housing with platinum cathode contacts and nickel anode contacts. The cell is sealed using gold gaskets. The concentration of the contaminants but for toluene and hydrogen chloride were controlled by adding mixtures of the contaminant in nitrogen to the main fuel feed. Toluene and hydrogen chloride were added by saturating an additional nitrogen flow. The saturation was accomplished by controlling the gas temperature after passing the nitrogen through the liquid toluene or saturated hydrogen chloride solution in water. The experiments with the ESC were performed at 950° C and a current density of 150 mA/cm². The experiments with the ASC were performed at 800° C and at a current density of 500 mA/cm².

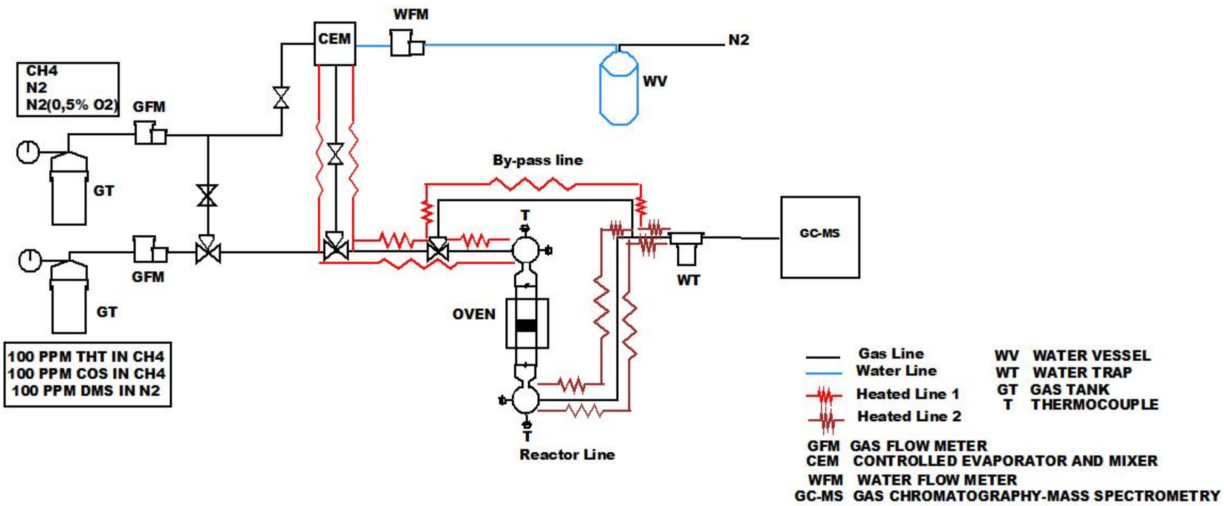
For most of the contaminants tested there was no measurable influence on the performance of the cells. The results for hydrogen chloride are to be considered with some caution because of difficulties with the test rig. During the course of the experiment no effect could be observed. The only contaminant with a noticeable effect was hydrogen sulphide both for ESC and ASC. For low concentrations of 1 ppm in the experiments using ESC there is no noticeable effect in the short term experiments. At higher concentrations a drop in the cell voltage can be observed shortly after the adding of the contaminant. At 4 ppm this effect seemed to be reversible. At 8.7 ppm the cell voltage increases after the removal of the contaminant but does not reach the voltage from before the measurement. Measurements on ASC at 800° C under higher H2S concentrations show a similar drop in cell voltage after addition of the contaminant to the fuel feed. During operation the cells failed without any noticeable warning. Also the time till failure could not be correlated to the amount of H2S in the fuel feed. The data obtained in our laboratory indicate that the electrochemistry of the anode of the SOFC is insensitive to most fuel contaminants. The only real problem is posed by Sulphur containing compounds. At higher concentrations the anode is irreversible damaged. Unfortunately, there is no correlation between the concentration of the H2S and the life time of the cell. There is also no indication in the data announcing the failure of the cell.

ENEA contributed by enlarging and further accessorizing their set-ups for biogas and natural gas clean-up. The selected clean-up technique is adsorption by activated carbon, being the most cost-effective at current standards of technology and regulations.

[Fig.21] Test bench (Gas clean-up rig for constant humidity shown in left image and gas clean-up rig for variable humidity shown in the right image)

Two facilities dedicated to biogas clean-up experiments were built; they are shown in [Fig.20], the clean-up facility 1 (CUF1) on the left [Fig.21], the CUF2 on the right [Fig.21]. The two facilities are essentially equivalent except for the relative humidity of the gas to be cleaned, fixed in CFU1, as the gas relative humidity is achieved by flowing the gas in a water bottle, and variable in CFU2, in which a CEM (Controlled Evaporation Mixer) sets the gas humidity within a wide possible range, allowing to investigate the capacities for purifying both water-saturated fuels such as biogas and dry fuels such as natural gas, and any mixtures thereof. This is important as the adsorption by activated carbons is strongly influenced by water content. To ensure precise and reliable measurements, the gas lines in the test facilities have all been assembled made of Sulfinert®, a trademark tubing which is coated with a layer that is inert to the adsorption of sulphur compounds. Since sulphur is a highly reactive species, and since the concentrations of concern in fuel cell applications are extremely low (<1-2 ppm), it is crucial to avoid the influence of the test rig on the measurements obtained. To this effect, the main reactor housing the test samples of several activated carbon types is made of quartz, a highly heat and stress resistant glass, which allowed also to investigate adsorptive capacities at temperatures above ambient.

The contaminant volumetric content of the matrix gas can be adjusted in the 5-500 ppm range, thereby simulating most realistic applications, by mixing the gas coming from a tank at calibrated contaminant content with a dilution second gas stream. The scheme of the testing apparatus is shown [Fig.22].



[Fig.22] Test bench ENEA CFU2 Clean-up Facility scheme

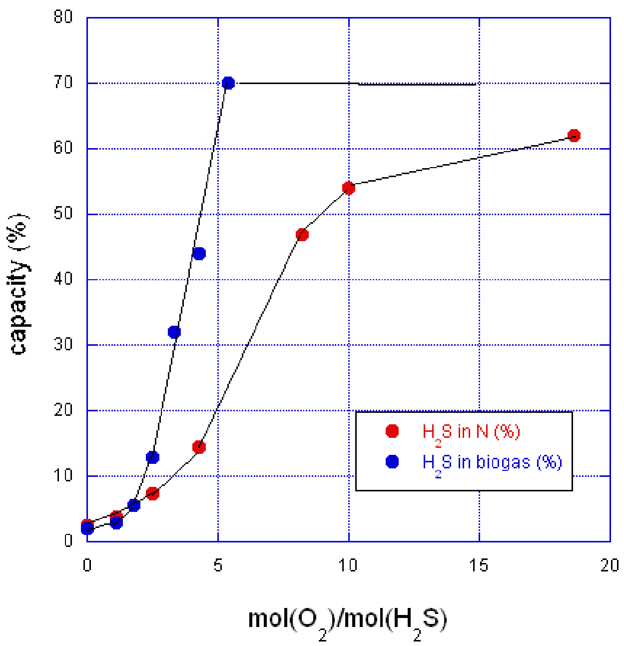
Three sulphur compounds, always present in biogas at concentration similar to the testing conditions, have been tested as pollutants: H_2S (hydrogen sulphide), COS (carbonyl sulphide) and DMS (dimethyl sulphide). RGM3 activated carbon by NORIT was selected as adsorption powder for three contaminants as it was experimented to be effective in H_2S removal. The RGM3 superficial area surface was determined by BET measurements: 963+/-1% m^2/g, 684m^2/g of which is surface internal to the pores, about 21 micron diameters, the remaining is external to the pores. Activation metals: Cu, Fe. The presence of Cu and Fe atoms was detected by EDX (energy-dispersive X-ray spectroscopy) measurements. The carbon was ground and sifts to get 250-350 micron mesh powder.

The polluted gas is made to flow at constant mass flow rate (100mL/min) through an activated carbon bed, placed over a porous septum in the 10mm diameter quartz cylindrical reactor, kept at constant temperature by a PID thermo-controller. The gas leaving the reactor is analysed by a Perkin

Elmer Clarus 580 Gas Chromatograph-Mass Spectrometer detector to determine its pollutant concentration, achieving quantifiable detections down to less than 0.1 ppm. The H_2S presence is uniquely determined by the mass 34, mass 33 and mass 32 peaks; the DMS presence by the mass 62, mass 47, mass 35 and mass 27 peaks; the COS presence by the mass 60, mass 44 and mass 28 peak; their concentration can be determined by the main peak area. The signal MS is calibrated before each test by switching the inlet (at fixed concentration) directly to the GC-MS. The pollutant concentration curve vs time (breakthrough curve) allows the breakthrough time t_{BT} (at 2ppm concentration) determination. The capacity (pollutant mass versus activated carbon mass) is then calculated by: C=mg POL/mg AC = Flow*POL conc*POL density* t_{BT}/AC mass

The capacity of the carbon in contaminant up-taking was measured at different operating reactor temperature: 30, 80 and 120°C, with different gas matrix: pure nitrogen, nitrogen with different oxygen content, simulated biogas (65% CH_4+35% CO_2 mixing) and at different gas hour space velocity (3800-20000 h^{-1}).

While H_2S up-taking resulted being a co-process, involving both physical adsorption over AC surface and chemical reaction, namely H_2S partial oxidation to elemental Sulphur, the DMS and COS retention is a purely physical adsorption. RGM3 capacity vs H_2S therefore increases with temperature: we set the optimum temperature condition at 120°C, at which Sulphur melts and easily wet the carbon surface; the reaction is catalyzed by functionalizing metal (Fe, Cu) and the bonds between S and AC are quite strong. Moreover, water vapor in gas matrix severely depletes AC capacity; oxygen was demonstrated to be necessary for partial oxidation reaction occurrence, as shown in [Fig.23] where RGM3 capacities are plotted vs oxygen content, both with H_2S in nitrogen matrix and in simulated biogas (65% CH_4, 35% CO_2) matrix. Fig.3 results show that the AC capacities are sensitively higher with biogas matrix, indicating that CO_2 is not competitive with H_2S up-taking, on the contrary, facilitates the process.



[Fig.23] RGM3 AC capacities in H2S up-taking; red dots: N2 matrix, blue dots: simulated biogas matrix

Very high capacities, higher than 70%, can be attained by the NORIT RGM3 AC at optimised operating conditions (dry gas, 120°C reactor temperature, nitrogen matrix, 500ppm H_2S conc, 20% molar oxygen over H_2S ratio). The presence of oxygen and reactor temperature affected the adsorption differently in the case of DMS and COS. In the former case a little amount of Oxygen increase the adsorption capacity and the optimum reaction temperature is 30°C. In the case of COS, the optimum reactor temperature is 120 °C, and the presence of a small amount of oxygen showed a negative effect on the adsorption capacity. Norit RGM3 capacities values for COS and DMS are anyway much lower than for H_2S. A summarization of the results regarding H_2S, DMS and COS tests respectively are shown in tables [Tab.3] [Tab.4] [Tab.5].

Sample	**Treatt (°C)**	**gas Matrix**	**H_2S concentr (ppm)**	**Oxygen (%)**	**GHSV (h^{-1})**	**Capacity (mg H_2S/mg AC) %**
A3	30	biogas	400	0.1	3800	2.8
A4	30	biogas	500	0	3800	1.2
A6	120	biogas	400	0.1	3800	12.3
A12	120	biogas	400	0.1	3800	13
A16	20	biogas	400	0.1	7600	3.8
A18	20	N2	400	0.1	3800	3.5
A19	120	N2	400	0.1	3800	7.5
A20	120	N2	200	0.1	3800	21.7
A23	120	N2	400	0.1	3800	5.2
A25	120	N2	400	0.1	3800	7.0
A27	120	N2	500	0	3800	2.3
A28	120	N2	400	0.1	3800	7.3
A29	120	N2	250	0.25	3800	54
A32	120	N2	180	0,32	3800	62
A33	120	biogas	500	0	3800	2.0
A34	120	N2	450	0.05	3800	3.8
A35	120	N2	350	0.15	3800	14.4
A36	120	N2	200	0.1	3800	19.1
A37	120	biogas	450	0,05	3800	2.9
A38	120	biogas	325	0.175	3800	70
A39	120	biogas	425	0.075	3800	5.5
A40	120	N2	275	0.225	3800	43
A41	120	biogas	350	0.15	3800	48
A42	120	biogas	375	0.125	3800	32

[Tab.3] Norit RGM3 capacity in H_2S up-taking; mass sample: 600mg; biogas: 65% CH_4, 35% CO_2

Sample	**T_{reatt} (°C)**	**Gas Matrix**	**DMS concentration (ppm)**	**Capacity (%)**
D1	30	pure N_2	100	2.87
D2	120	pure N_2	100	0.25
D3	120	pure N_2	50	0.6
D4	80	Pure N_2	100	0.9
D8	30	N_2 (0.5% O_2)	50	2.3
D10	30	N_2 (O_2)	20	1.6
D11	30	N_2 (O_2)	80	2.8
D12	30	50% DMS in N_2 50% CH_4(65%)+CO_2(35%)	50	1.35
D13	30	50% DMS in N_2 50% CH_4	50	1.44

D14	30	50% DMS in N_2 50% CO_2	50	1.47
D15	30	pure N_2	100	2.9

[Tab.4] Norit RGM3 capacity in DMS up-taking; DMS in N2: 100ppm; mass sample: 600mg

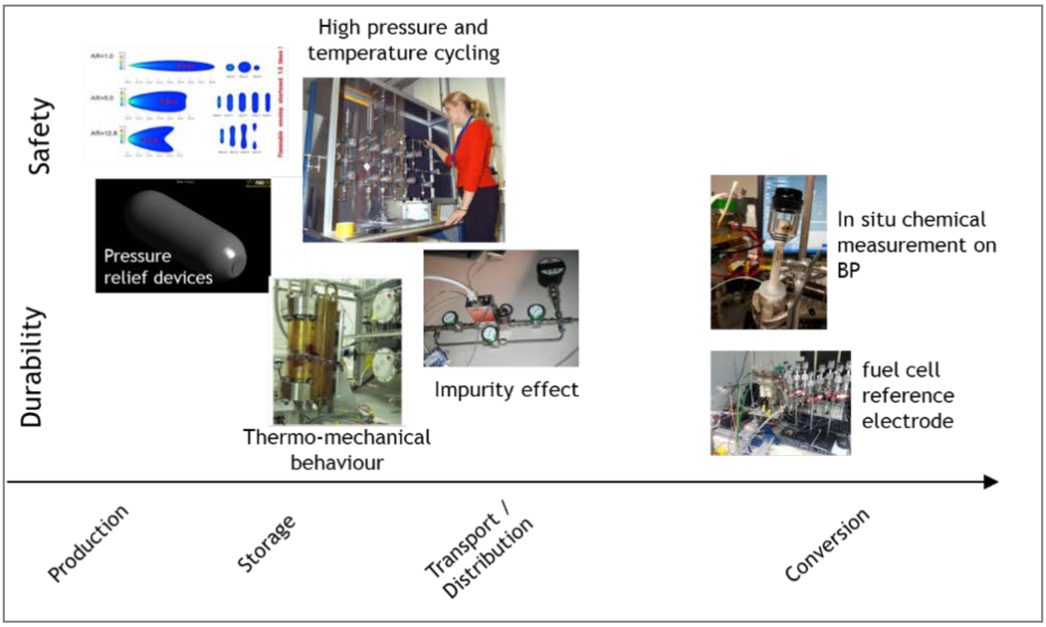
Sample	Treatt (°C)	COS conc (ppm)	Flow composition (mL/min)	t_{BT} (min) (2ppm)	Capacity %
C1	30	50	50mL/min COS in CH_4 50mL/min N_2+O_2	132	0.3
C2	120	50	50mL/min COS in CH_4 50mL/min N_2+O_2	700	1.6
C3	120	100	100mL/min COS in CH_4	920	4.0
C4	120	50	50mL/min COS in CH_4 50mL/min pure N_2	1450	3.3
C5	120	75	75mL/min COS in CH_4 25mL/min pure N_2	1140	3.7
C6	120	50	50mL/min COS in CH_4 50mL/min CO_2	880	2.0

[Tab.5] Norit RGM3 capacity in COS up-taking; COS in CH4: 100ppm COS in CH4; N2+O2: 0.5% O2 in N2; sample mass: 600mg

3.2.3 Development of Methods, Protocols and Benchmarking Exercises

This third joint research activity was centred on the "development of methods, protocols and benchmarking exercises". The general aim was the definition and dissemination of good testing practices among the European hydrogen and fuel cell community especially regarding on the one hand safety and risk assessment and on the other hand performance and durability. The work package was organised in four work tasks that consider the harmonisation of test methods, the definition of test protocols and the benchmarking exercises:

- Fire resistance of on-board pressurized hydrogen storage
- Hydrogen solid storage materials and components behaviour and properties
- Fuel cell components degradation mechanisms
- Fuel quality measurements



[Fig.24] Development of protocols for investigating components and systems of the hydrogen energy chain

Within the first task of work package a survey of available technologies and data evaluation has been achieved concerning the production of defined gradient mixtures with hydrogen. It is shown that the pressure load effect of accidental combustion of released hydrogen inventories depends mainly on the effective flame speed. Flame acceleration (FA), even reaching detonations (deflagration to detonation transition, DDT), is widely studied using close combustion tubes filled with homogeneous H2/air/O2 mixtures while in reality, inhomogeneous mixtures prevail. Consequently FA and DDT studies for real accident scenarios are required. Since it is very difficult to produce mixtures with pre-defined concentration gradients and to measure gradients in such mixtures, this work task has given a survey of available technologies and has collected the data of related experiments to extend the scope of the established σ- and λ-criteria with respect to the influence of mixture non-uniformity on critical values σ- and λ-criteria. Also, several advanced measuring techniques and experimental technologies to create prescribed hydrogen concentration gradients are presented and became reported D9.1. Additionally such non-uniform hydrogen-air mixtures at differently scaled facilities were used to evaluate the predictive capabilities of σ- and λ-criteria and to fill possible gaps as well as to assess the applicability and strategies to introduce the validated criterions in CFD codes.

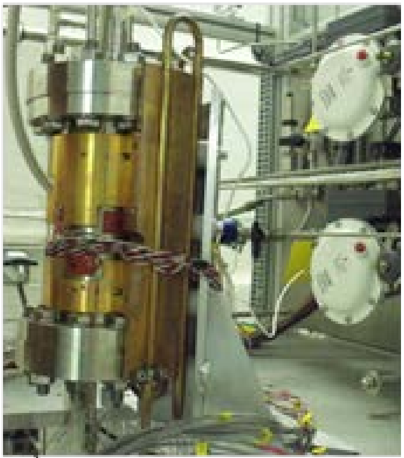
The second task was organized into two subtasks in order to tackle in an integrated way the:

- Controversy over measured storage capacities on different types of materials, opening the way to improved understanding of H_2 storage mechanisms (e.g. role of dopants/additives in composite materials, role if impurities, pollutants, etc.)

- Lack of reliable safety and performance (life cycle) assessment of solid-state storage materials and components.

Controversial issues in the hydrides properties measurements have been clearly identified D9.2 and shared by the partners for a wide range of model hydrogen storage materials. To overcome these controversial issues, the partners have constructed new measurement equipment or improved already existing facilities. It concerns 3 installations at CEA [Fig.25], KIT and JRC.

- The device COMEDHY at CEA, which is open for transnational access, has been improved in terms on precision of the measure of the quantity of hydrogen absorbed by the material while keeping its thermo-mechanical sensors to control and monitor the hydride behaviour. The safety of hydride containers is strongly linked to the manner hydrides are integrated into tanks and to the thermal management foreseen. Upon hydrogen adsorption and desorption the "breathing" of the hydride material occurs that is not extensively documented in the literature. In particular, predictive laws in order to ensure the container integrity are missing. The equipment has been improved in terms of cycle speed and accuracy of the volume of hydrogen absorbed and desorbed.
- The KIT device aims at studying the safety issues that may arise through chemical reactions between hydrogen storage materials and impurity gases present within the hydrogen, such as O2, H2O, NH3, COx etc. Indeed, in the most severe cases, these reactions may lead to the inflammation or even deflagration of the metal hydride/hydrogen/impurity mixture. However, this is rarely the case, and mostly the surface chemistry is altered, affecting significantly the hydrogenation/dehydrogenation kinetics as well as the capacity of the material. The reactor built allows easy control of the hydride bed temperature thanks to a thermal bath that is constantly monitored. After reaction, the hydrogen leaves the apparatus through a mass flow meter that allows both its analysis and the quantification of the absorbed /desorbed amount of hydrogen.



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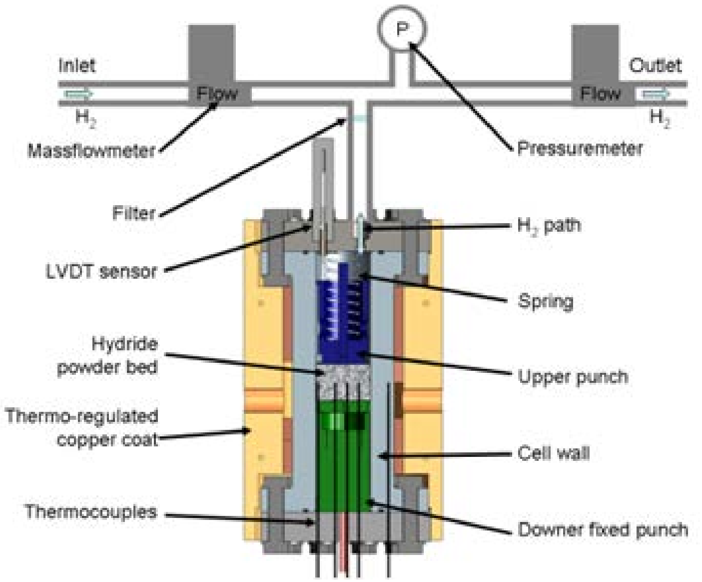


[Fig.25] Image of the test cell COMEDHY mounted on the NEW DESHY test bench (to the left) and detailed sectional view of the cell (to the right)

- The KIT device aims at studying the safety issues that may arise through chemical reactions between hydrogen storage materials and impurity gases present within the hydrogen, such as O2, H2O, NH3, COx etc. Indeed, in the most severe cases, these reactions may lead to the inflammation or even deflagration of the metal hydride/hydrogen/impurity mixture. However, this is rarely the case, and mostly the surface chemistry is altered, affecting significantly the hydrogenation/dehydrogenation kinetics as well as the capacity of the material. The reactor built allows easy control of the hydride bed temperature thanks to a thermal bath that is constantly monitored. After reaction, the hydrogen leaves the apparatus through a mass flow meter that

allows both its analysis and the quantification of the absorbed /desorbed amount of hydrogen.

- At JRC the focus has been put on the characterisation of the performance of hydrogen storage materials under long term cycling and on the analysis of its ageing and degradations in term of storage capacity and sorption kinetics. For that purpose JRC had designed and constructed a Sievert-type apparatus able to execute thousands of absorption-desorption cycles on materials quantities up to few hundred grams. The original IVOR has already been used successfully, but its temperature and pressure range were limited to 300°C and 5 MPa. The upgrade of the IVOR device allows it to operate in the full practical range usual for hydrogen storage materials (up to 500°C, 20 MPa and 1000 pressure cycles), including full quantitative measurements of the hydrogen quantities.

After improving or developing testing facilities, round robin test exercise (RRT) using MgH_2 was performed, which would pave the way towards a harmonized and clear recommendation for material characterization procedures. This RRT exercise focused on the evaluation of the precision of the measurement of thermodynamic properties of a metal hydride by means of Differential Scanning Calorimetry. To be able to link the results of this exercise to those of a previous RRT executed with Sievert's apparatus, the material selected is a magnesium hydride. The selected magnesium hydride (MgH_2) is a commercial material containing additives, provided by the company McPhy. The two principal properties to be measured are the enthalpy of reaction and the energy of activation. This RRT exercise has been designed for laboratories having DSC and/or a high pressure DSC (HPDSC).

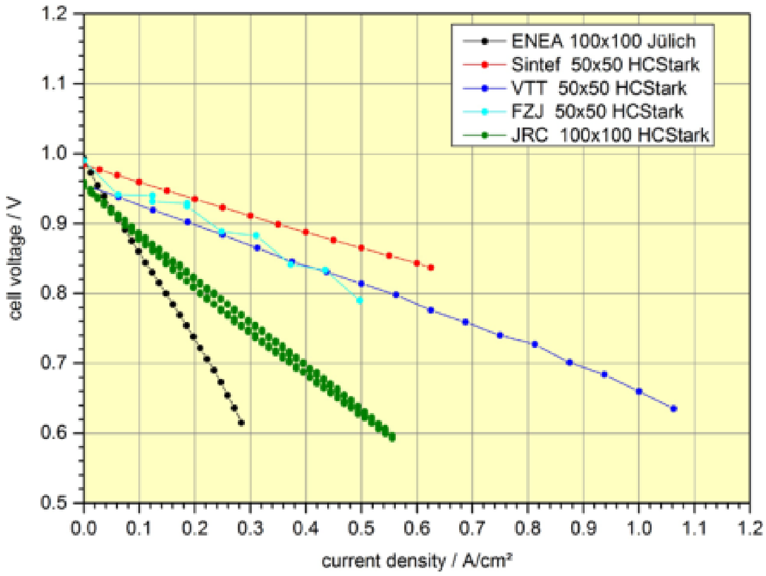
The first objective of the exercise was the quantitative evaluation of the precision of the DSC measurements of thermodynamic and kinetic properties. Magnesium hydride was selected as storage material in order to be able to link the present results to those of a previous RRT executed with Sievert's apparatus. The two major properties to be measured are the enthalpy of reaction and the energy of activation. A second objective of the RRT exercise was the analysis of the source of errors, to identify improvements potential and feed these in a measurement best practice. The RRT was not fully completed at the end of the project (some participants still had to deliver results). Nevertheless the results have already allowed for the formulation of a measurement protocol, to be refined later with the final conclusions from the RRT exercise. In the second part, protocols and/or operational recommendations were elaborated for the following methods: Thermogravimetry /Differential Scanning Calorimetry coupled with Mass Spectrometry (TG-DSC-MS), thermogravimetry coupled with Raman spectroscopy, portable volumetric measurements coupled with neutron diffraction, and gas sorption coupled with IR spectroscopy.

The third task focused on fuel cell components degradation mechanisms. The aim of the work conducted during the third period was to develop an instrumented single cell polymer electrolyte membrane fuel cell (PEMFC) for the study of carbon corrosion during start-up and shut-down, consisting of an array of reference electrodes for mapping of the potential distribution across the active area of the cell and an infrared sensor for CO_2 measurement at the cathode outlet. A new PEMFC with 9 reference electrodes was build and tested. An infrared analysis was also implemented to measure the CO_2 emission in the exhaust gases to identify the carbon corrosion. A protocol was optimized to follow the PEMFC transient response to start-up and stop down operation modes. Most attention is given to PEMFC fuel cell membrane electrode assemblies (MEAs) whereas bipolar plates comprise approximately 80% of the weight and 25% of the cost of a typical fuel cell stack. They ensure electrical current collection and reactant gases feeding. As such they are critical components for fuel cell competitiveness. During the period 2 special emphases has been given to test protocol harmonisation for durability testing of bipolar plates. In deliverable D9.6 in situ measurements of pH, corrosion potential and fluoride ion concentration at the surface of an uncoated 316L stainless steel bipolar plate are presented that are achieved during operation of a single PEMFC cell. The development of novel in situ measurement techniques in this work is shown to facilitate identification of the appropriate conditions for ex situ testing. A key observation was that the degradation mode is more akin to atmospheric corrosion in relatively dilute thin liquid layers, in contrast to the fully immersed conditions employed in conventional ex situ screening tests. Another issue not usually taken into account is the transient spike in cathode potential encountered during start-up and shut-down of PEMFCs due to the presence of a fuel/air boundary at the anode, which can reach as high as 1.6 V (SHE).

There was organised a workshop for interested parties on towards harmonisation of test protocols for qualification testing of metallic bipolar plates to discuss the issues highlighted in D9.6. Major international players will be invited from the research community (e.g. Los Alamos National Laboratory, Oak Ridge National Laboratory, NREL, University of Birmingham) and bipolar plate manufacturers (e.g. Elring Klinger, Borit), along with appropriate representatives from the entire fuel cell supply chain. The aim of the workshop was to reach a consensus on appropriate test methods for metallic bipolar plate materials, which form the basis of pre-normative test protocol development work under international standards committee IEC TC 105. The long term goal will be the establishment of international standards for material qualification, which will have a significant impact on the required cost reductions in bipolar plate manufacture and supply.

As a continuation of the report on SOFC Degradation Analysis Methodologies D8.6, a collective comparative exercise was executed by some partners. The main objective of the exercise was to evaluate on selected “reference” single cells the robustness of a common SOFC testing protocol including harsh continuous conditions and cycling. The exercise is positioned as a complement to the work done in SOFC-Life (more basic), in Design (focused on degradation signatures) and in FCTestQA (focused on mild stationary conditions).

The last task focused on both the harmonization of test procedures to study SOFC degradation. The first harmonisation of test protocols was dedicated to SOFS durability testing through a Round Robin Test (RRT) based on the use of the same cells (HC Stark supplier). The results are gathered in the D9.7. The RRT included first an elevation of the electrochemical performance followed by a long term ageing test (500h). The main results are that despite harmonization of the test protocols very large discrepancies were observed between the partners and varying the size of the cell (100x100 or 50x50).

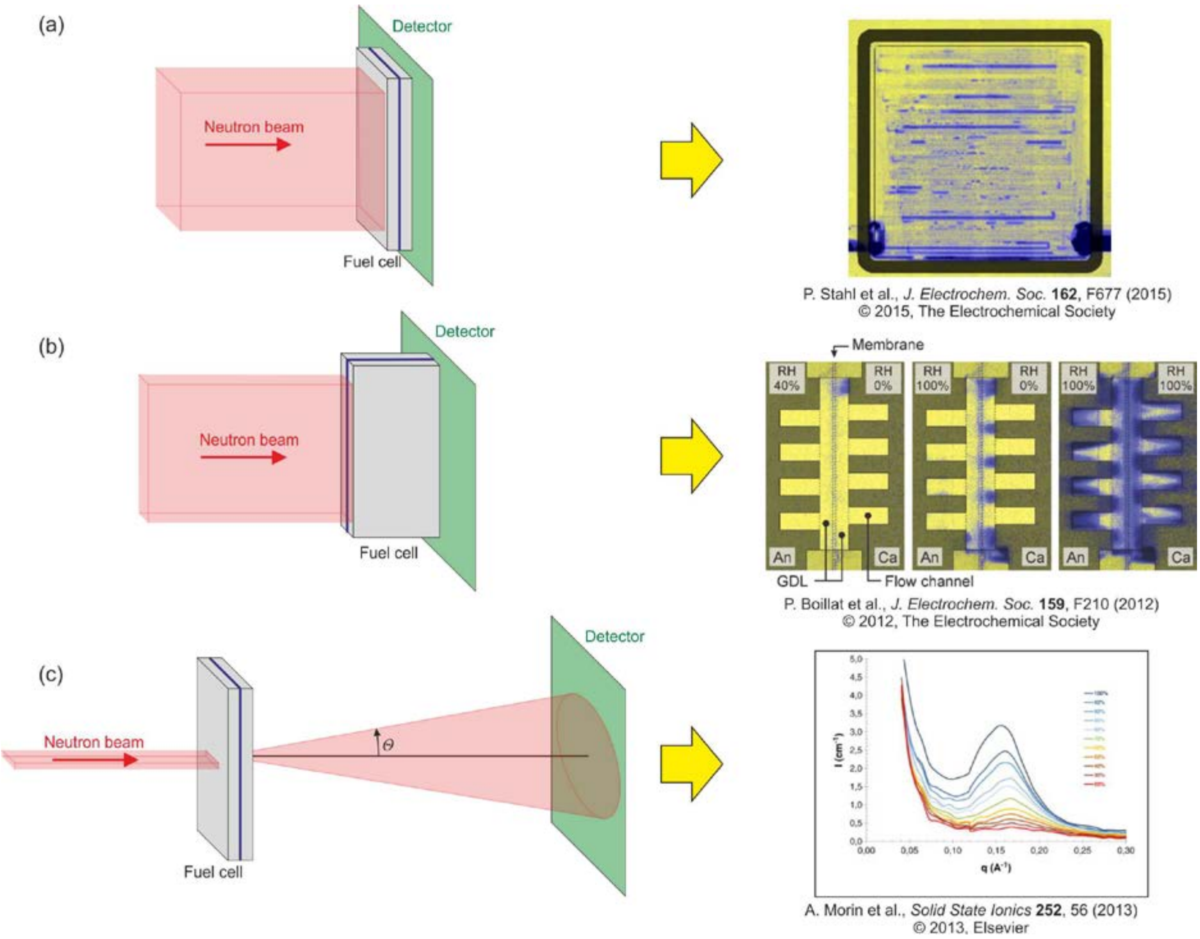


[Fig.26] Harmonisation test procedure (comparison of measurement results)

As expected based on the comparison of the electrochemical analyses, the degradation study over 500h also exhibit discrepancies.

The second aim was devoted to a "round-robin exercise of fuel quality measurements"; namely the analysis of a model gas mixture with low levels of CO, CO_2, CH_4, SO_2, O_2 and N_2 in hydrogen using the analysis methods available by the participating partners. Indicatively the nominal contaminant levels were known to be of between 5-15 ppm. The objective of this this joint research was to rationalize the approach in terms of pollutants, techniques and calibration protocols. The gas analyses were conducted by mass spectrometry and FT-IR spectroscopy. Thanks to calibration curves established with model gases, the partners were able to estimate the uncertainties.

CEA and PSI have developed the use of neutrons for the study of water management in PEMFCs (Small-angle neutron scattering (SANS) for CEA and neutron imaging for PSI). It was then decided to combine the two different techniques in a case study. The protocol and results will allow for the first time to combine the information of the in-plane and through-plane liquid water spatial distribution in the PEMFC with a local determination of the membrane water content under operation as a function of the gas distribution geometry.



[Fig.27] Small-angle neutron scattering (SANS) for CEA and neutron imaging for PSI as a case study

3.2.4 Cyber Laboratory

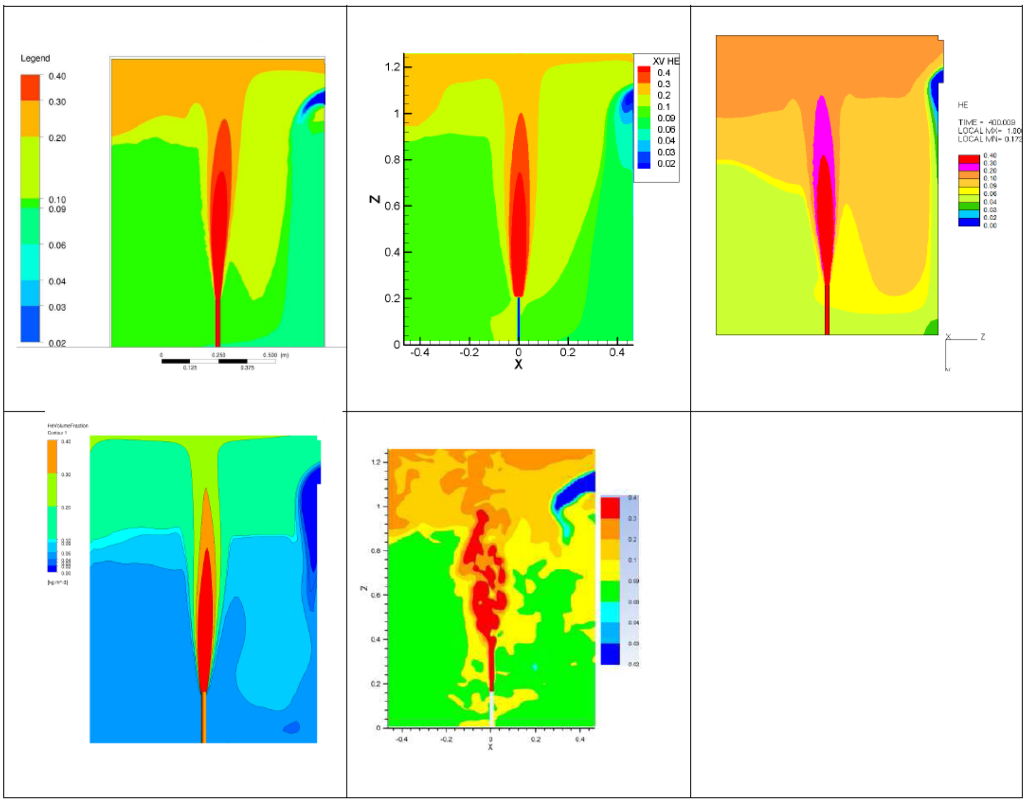
The strategic goal of Cyber-Laboratory is defragmentation and improvement of European e-infrastructure for hydrogen and fuel cell research. Complementarities and synergies between numerical and experimental research is expected to greatly assist in closing knowledge gaps, development of innovative technologies, design and testing of prototypes. Several models and codes lack experimental validation even for simple situations like hydrogen release and dispersion. Indeed, despite recent efforts in comparing and assessing results from different codes (e.g. within NoE HySafe), a systematic, comprehensive validation effort covering a wide range of cases, conditions, etc. is not available to H2FC community. Thus the work package aimed at developing a specially-tailored software suite for users of the H2FC European Infrastructure liable to contribute to Europe's leadership and competitiveness is the field focusing the objectives:

- Identification of best existing physical models and numerical codes available for describing the key phenomena relevant to hydrogen storage, safety and fuel cell performance
- To identify the remaining bottlenecks and deficiencies in building up the European H2FC e-Infrastructure and to propose a roadmap for addressing these bottlenecks via a program of interconnected experiments and numerical tests
- Undertake model inter-comparison exercises through round robin tests
- Approaches and models for not yet fully understood phenomena
- Create a validated software suite for the assessment of hydrogen and fuel cell systems key performance parameters for use by European researchers and stakeholders

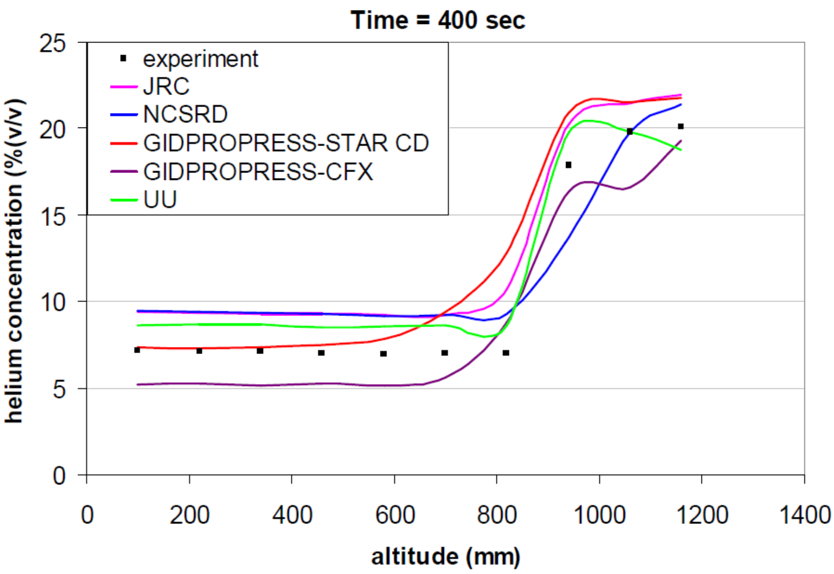
One of the first tasks within this work package a model ranking exercise was completed which identified existing physical models and numerical codes in the key areas of fuel cells, safety and storage. The applicability and suitability of models to various scenarios was assessed and remaining bottlenecks and deficiencies in software were identified. Finally, a detailed model evaluation approach was developed. Under the light of the former task, a database of high quality experimental reference data for model validation became developed. This database includes a total number of 41 reviewed papers reporting on experiments consisting of Dispersion (11), Ignition (1), Deflagration (18), DDT (8) and Detonation (3) scenarios which can get taken as reference data.

The database was taken to test model and simulation according verification of models in two benchmarking exercises. To compare results arising from modelling and simulation by different software, a specific benchmarking exercise on the Gamelan Experiment was selected and executed [Fig.28]. The results between the participants became compared to get incorporated in a harmonised test protocol [Fig.29].

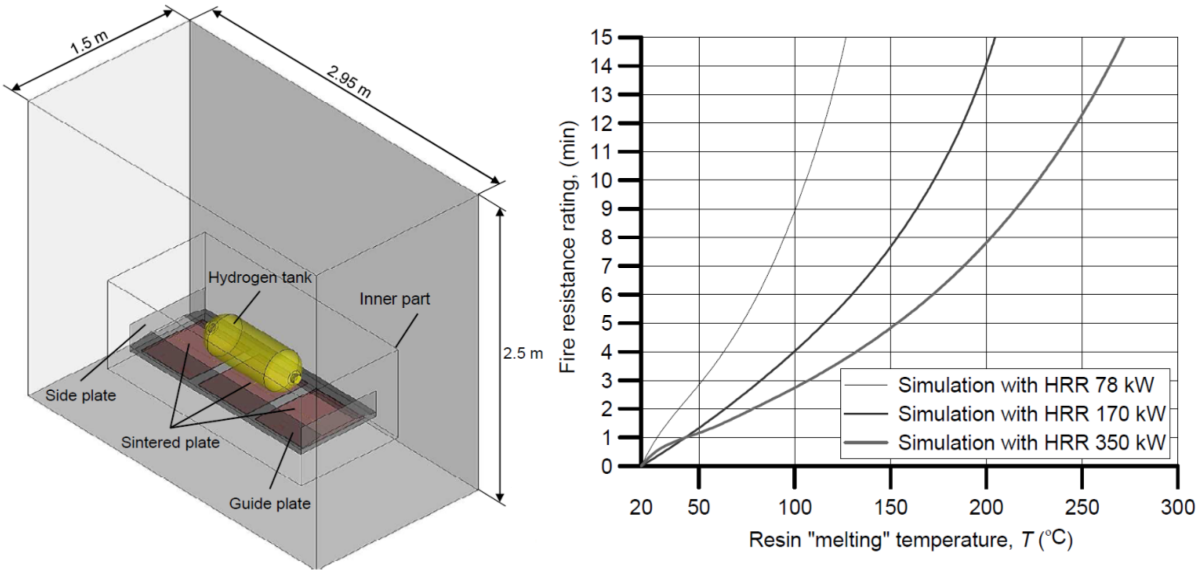
Apart from the round robin testing a number of pre-test simulations were performed to support the joint research activities experimental programme D10.10. The pre-test simulations undertaken into the fire resistance of on-board storage tanks highlighted that the safety concepts implemented in the current Global Technical Regulations (GTR) do not address the clear hazards to car passengers, first responders and the general public which stems from the current safety strategy of venting the contents of the hydrogen tank to avoid rupture [Fig.30] [Fig.31]. These pre-test simulations were used as a basis to harmonise bonfire test methods, within the definition of test protocols and during benchmarking. The lessons learned from the numerical study of indoor jet fires undertaken [Fig.32] provide key information in order to maximise the data obtained from planned future experimental programmes. Finally the software suite for hydrogen and fuel cell systems has been built on and expanded to include not only safety but also fuel cells and storage engineering tools and CFD models D10.11 and D10.12.



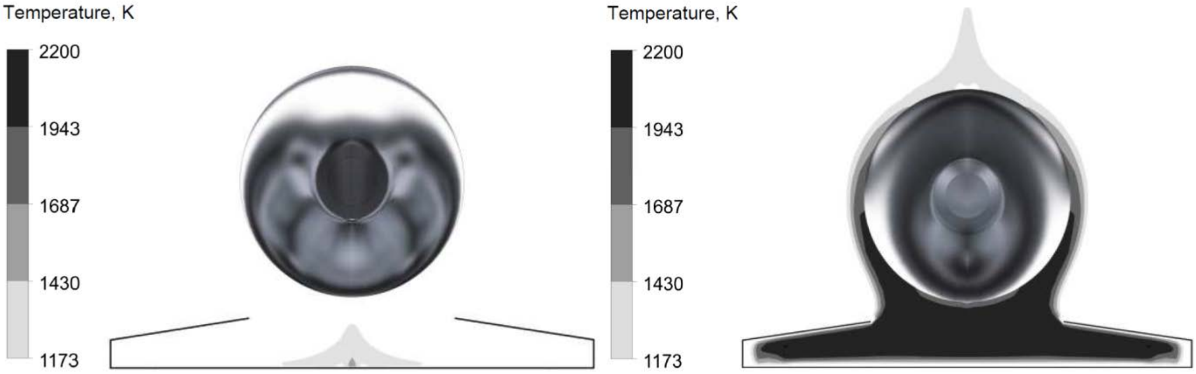
[Fig.28] Gamelan experiment round robin test: Predicted contours at steady state



[Fig.29] Gamelan experiment round robin test: Experimental vs. Numerical concentration profiles at steady state



[Fig.30] Fire resistance of on-board storage tanks: Schematic of numerical bonfire test (to the left); FRR vs. resin melting temperature dependence for changing HRR (to the right)

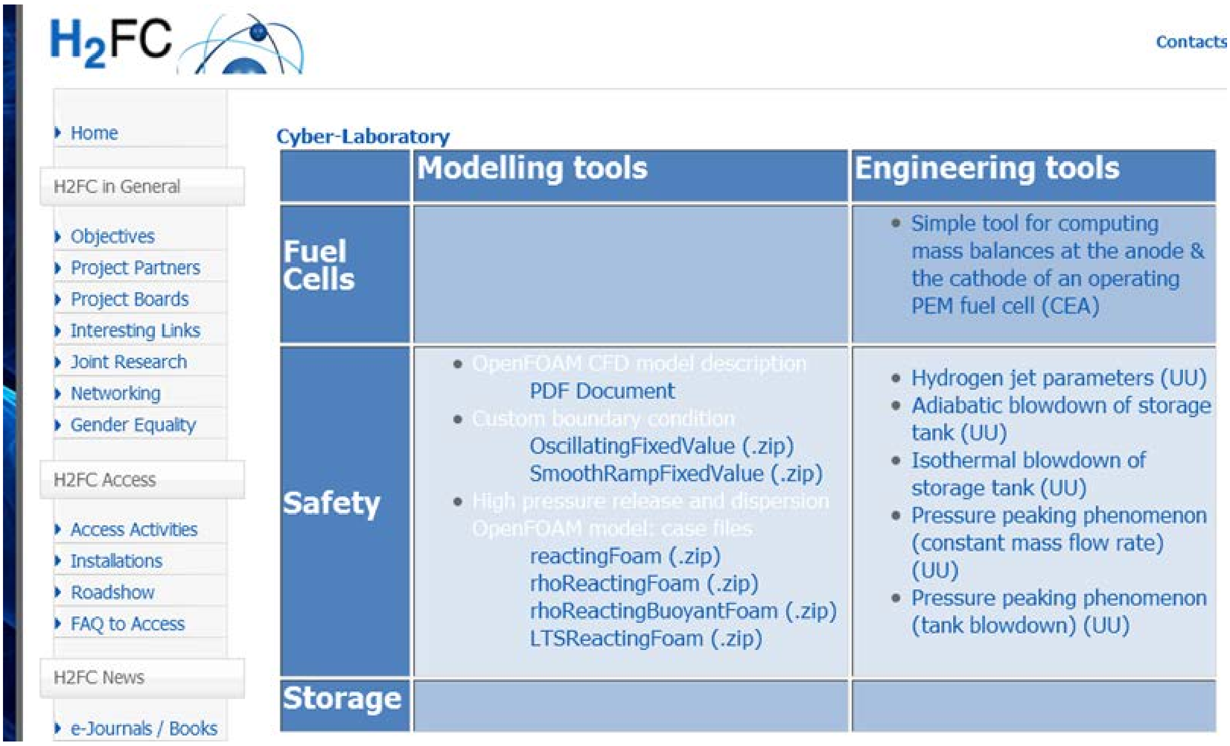


[Fig.31] Fire resistance of on-board storage tanks: Flame temperature distribution at HRR 78 kW (to the left); Flame temperature distribution at HRR 370 kW (to the right)

The H2FC European Cyber-Laboratory was developed to include engineering and modelling tools for operations and education [Fig.32].

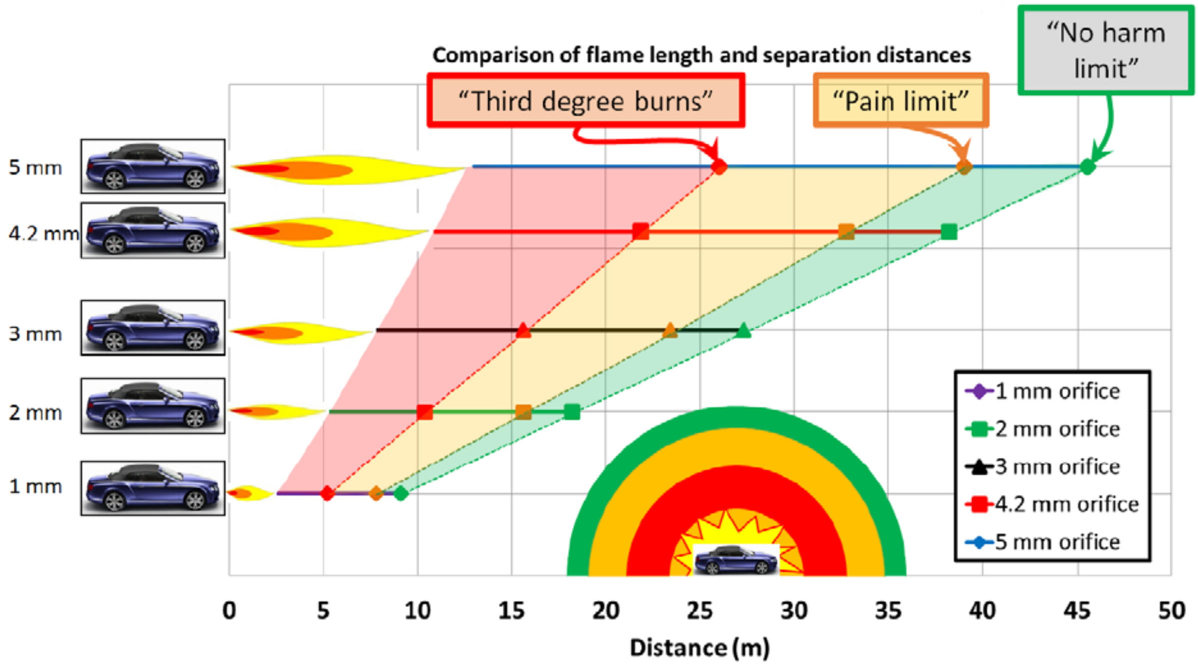
- A fuel-cells engineering tool for computing mass balances at the anode and the cathode of a PEM fuel cell has been made available for use on the H2FC European Cyber-Laboratory
- A total of eleven safety related engineering tools have been developed and made available, including a hydrogen jet parameters tools, pressure peaking phenomenon tools, blowdown tools, flame length and separation distance tool and a tool to calculate distance to a particular concentration in unignited jets
- Three storage cases have been formulated (including the issue of thermal coupling of fuel cells and storage tanks). Available simulators and open-source codes were considered, in order to study the presence and inclusion of H2 gas guests in different hydrate structures and novel framework materials like MOF's

- o In addition to the engineering tools made available, open source and fully customisable CFD models based on the Open-FOAM CFD toolbox have been included on the H2FC European Cyber-Laboratory. Descriptive documents, user guides and where appropriate tutorials and source code examples have been included to facilitate the user to manipulate the models made available in order to complete their own particular research and also for educational purposes

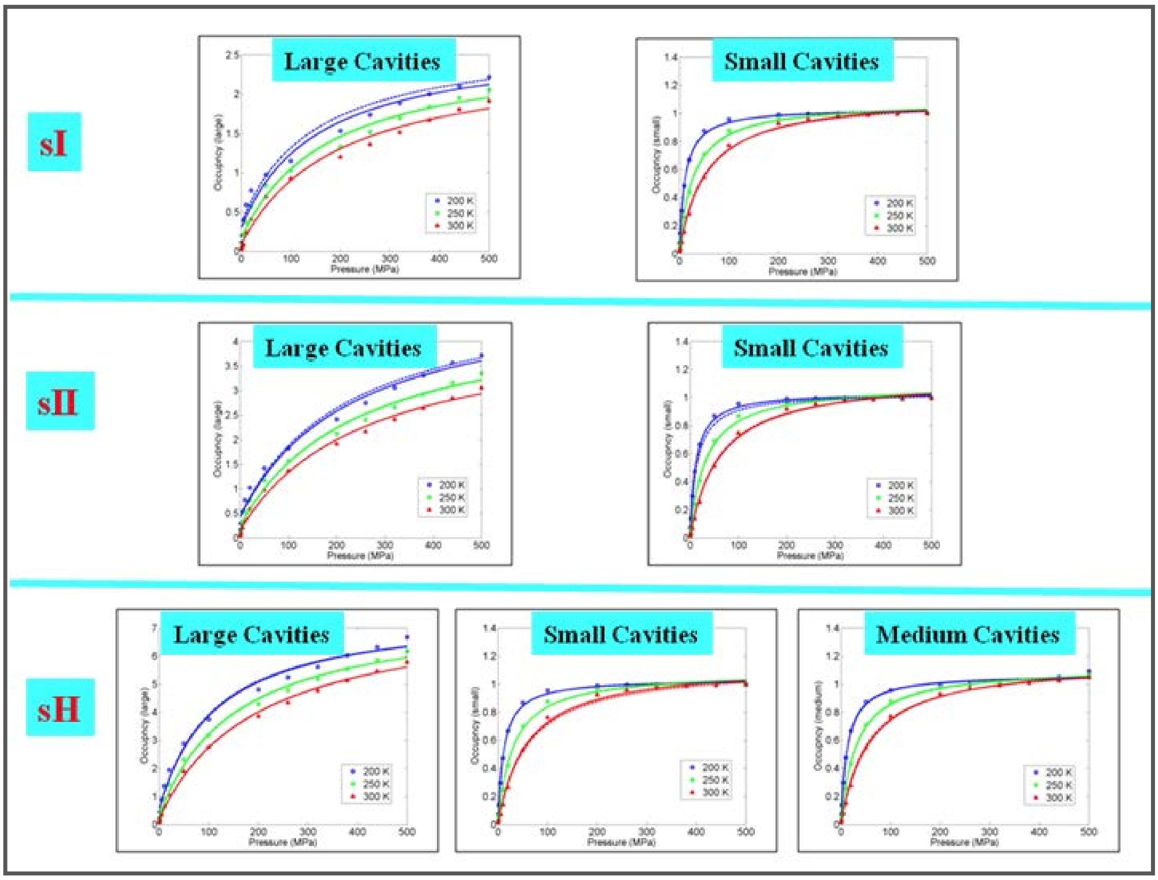


[Fig.32] Screen shot of project website providing modelling and engineering tools

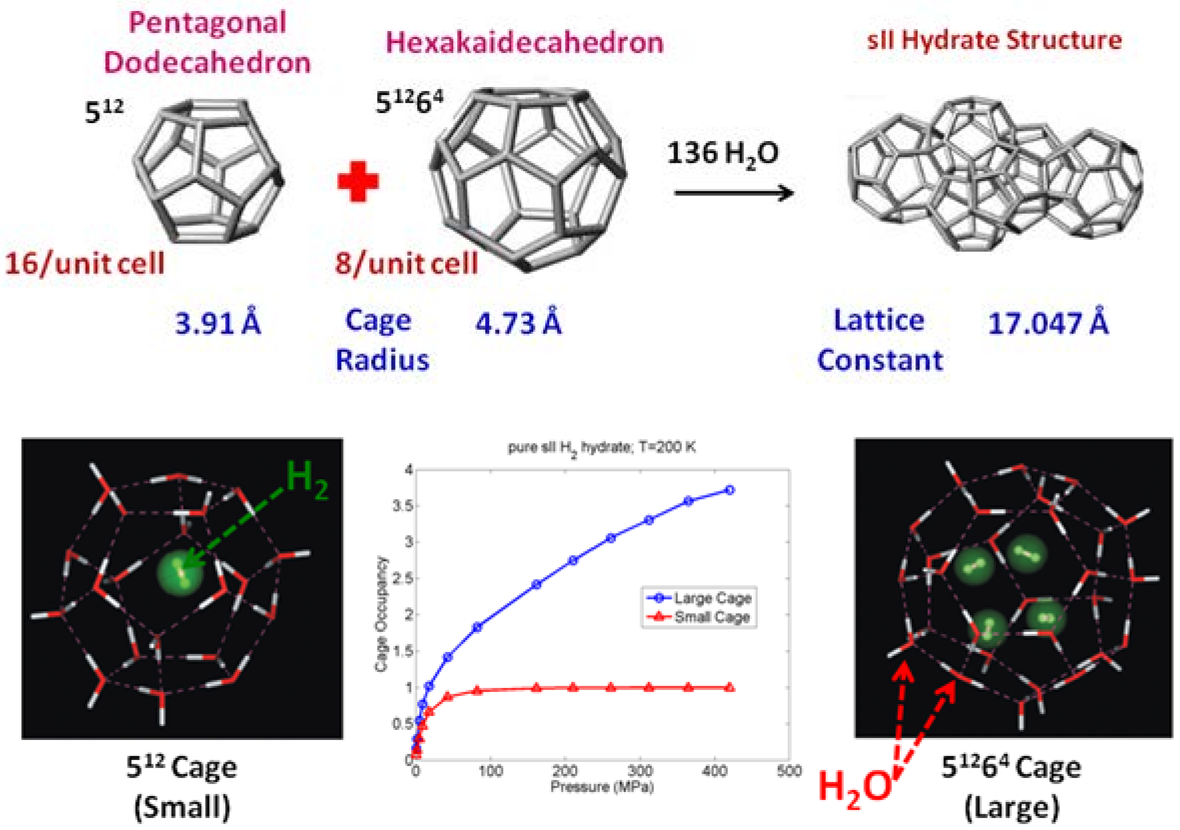
The H2FC Cyber-Laboratory can therefore be considered as the first significant step towards the defragmentation and improvement of European e-Infrastructure for hydrogen and fuel cell research. Ultimately it will be expanded to create a 'one-stop-shop' for the whole FCH community and include not only modelling and engineering tools but also facilitate networking, data exploration, research, interfaces and open web services and education through a 'virtual knowledge centre'. This undertaking will thereby provide open access to FCH digital resources, tools and services, leading to more effective collaboration between researchers, and higher efficiency, creativity and productivity of research [Fig.33] [Fig.34] [Fig.35] [Fig.36].



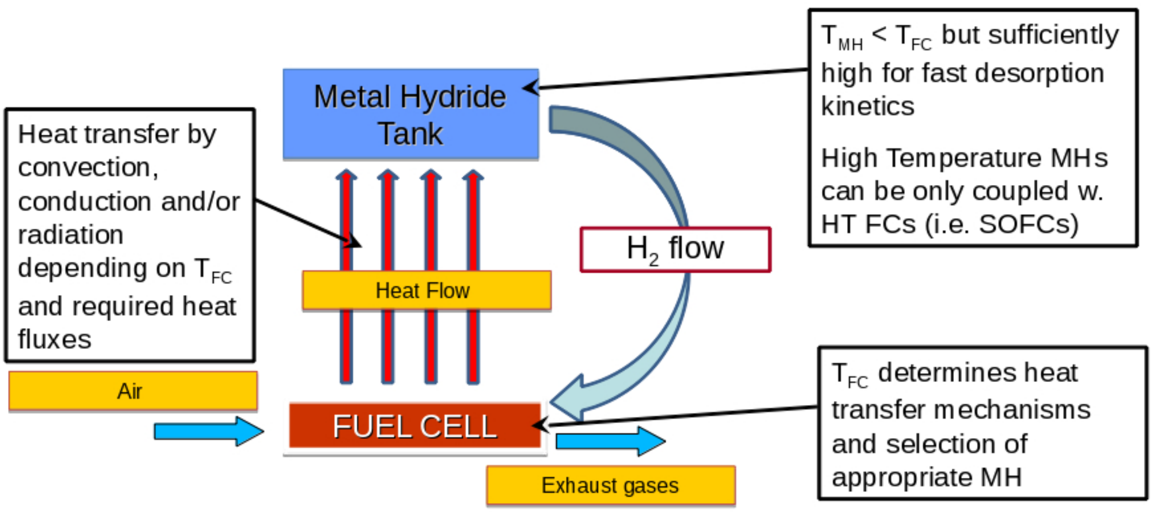
[Fig.33] Typical Engineering tool implemented in the cyber laboratory (overview of change in separation distance with changing TPRD diameter, using "Safety" engineering tool)



[Fig.34] GCMC results of cavity hydrogen occupancies for the three hydrate structures considered



[Fig.35] Hydrogen Storage in Hydrates: From the Molecular to the Continuum Scale and Beyond: Stabilization of hydrate cages by hydrogen molecules



[Fig.36] Design of Thermally coupled Hydrogen Storage and Fuel Cell Systems

3.3 Introduction to the Joint Research Activities

Networking activities enhanced the services provided by **H_2FC**European Infrastructure in many ways. They fostered a culture of cooperation between the participants and the scientific communities benefiting from the results achieved during the lifetime and use of the state-of-the-art facilities of project partners through:

- Joint participation in annual meetings of European Panel on Hydrogen and Fuel Cells to identify and prioritise bottlenecks in basic and applied research in the field, as well as solution mining
- Participation of both partners and users in the proceedings of the technical school, including work-in-progress sessions, round-table discussions, advanced research workshops, instrumentation workshops, CFD seminars, etc.
- Information exchange and coordination of national (regional), European and international research activities, projects and organizations (FCH-JU, IPHE, IEA HIA, DoE), including shaping of European and global research agenda in the field, through different NA activities where stakeholders from outside the project take an active part
- Establishing and working together in editorial boards for publishing journals and handbooks in the field during the project and beyond 2015 thus building together the future of the ***H_2FC****European Infrastructure* etc.

3.4 Major Achievements to the Networking Activities

3.4.1 Technical Schools and Researchers Exchange Programme

Starting with the technical school, this measure has been the major networking activity within the project. Four technical schools were organised – year 2012, 2013, 2014, and 2015. Location of all four schools was Crete (Greece). The school programmes were designed as outlined in the description of work and addressed specifically the theme of hydrogen safety, storage, production and fuel cells. The programme was composed of topical lectures, instrumentation workshop, cyber laboratory (addressing scientific bottlenecks through modelling and simulations), the advanced research workshop, specific poster sessions and the session on transnational access (TS2013, TS2014, TS2015). The technical school 2015 also included section on e-Infrastructure for hydrogen safety, storage and fuel cells with hands-on training session for use of the cyber-laboratory during days 3-5.

Details of the schools organisation including location selection, programme structure and content, selection of attendees and registration fees, financial details as well as feedback analysis were reported:

D3.4 First Technical School - TS2012 (24^{th}–29^{th} September 2012, Aquis Arina Sand hotel, Crete)
D3.5 Second Technical School - TS2013 (23^{rd} -27^{th} September 2013, Agapi Beach, Heraklion, Crete)
D3.6 Third Technical School - TS2014 (23^{rd} -28^{th} June 2014, Sentido hotels, Crete)
D3.10 Fourth Technical School - TS2015 (22^{nd} – 26^{th} June 2015, Aquis Arina Sand hotel, Crete)

Content	TS2012	TS2013	TS2014	TS2015
Topical lectures	4	5	9	14
Instrumentation workshop and TA	16	14	14	15
Cyber Laboratory	3	7	10	-
e-Infrastructure	-	-	-	16

Hands-on training session	-	-	-	5
ARW	13	22	12	-
WIP	16	-	-	-
Poster	-	10	10	24
Total	**52**	**58** (48+10)	**55** (45+10)	**74** (50+24)

[Tab.6] Technical programme and content of the schools

	TS2012	**TS2013**	**TS2014**	**TS2015**
Partners	37 (62%)	35 (59%)	26 (37%)	33 (35%)
Externals	23 (38%)	24 (41%)	45 (63%)	61 (65%)
Females	8 (13%)	9 (16%)	10 (14%)	22 (23%)
Countries	17	18	19	31
PhD+ESR	N/A	N/A	22 (31%)	49 (52%)
Total	**60**	**59**	**71**	**94**

[Tab.7] Analysis of the school audience structure is summarised

The experience of the technical school attendees' was gauged using a questionnaire distributed at each school. Overwhelmingly positive feedback was obtained on the school organisation and travel arrangements; location and facilities; technical programme, school structure and speakers; etc. Majority of school participants would like to attend the school in future or to recommend it to others. Feedback summary and analysis from TS2012, TS2013, TS2014 and TS2015 is given in respective deliverables.

[Fig.37] Group photo attendees to the technical school

The project offered a researchers exchange programme for internal and external participation. A group of students from Sofia Bulgarian Academy of Science visited the research facilities at University Perugia and ENEA and some single external PhD students visited technical school and other research facilities. External partners practised an exchange in concerns of developing the cyber-laboratory and exchange of expertise regarding modelling and simulation. Generally there was minor motivation of external participants to use the researchers exchange program.

3.4.2 Key Scientific Bottlenecks and Mapping Research Infrastructures

An overview of key scientific bottlenecks were extracted and compiled from a selection of reports (issued through the European Commission, Fuel Cell and Hydrogen Joint Undertaking and U.S. Department of Energy) and from all the partners of the H2FC consortium who, as experts in the field, have provided specific information on different technologies. This is all presented in deliverable report D4.1.

From this study it is evident that the barriers against a hydrogen-based economy are not limited to only a few central issues for further hydrogen and fuel cells research. Depending on the maturity of the different technologies from hydrogen production to end-use, there are different ways and requirements to focus on harmonizing test protocols, safety standards, develop modelling in addition to further improvements on scientific areas, before large scale commercialization is possible. Mature technologies such as hydrogen production from natural gas reforming, pressurized hydrogen storage and PEMFC as end-use experience challenges more on economical and institutional level rather than technical. For less mature technologies such as electrolysis for hydrogen production, solid storage and SOFC as end-use, challenges are still more scientific, as these technologies require more research and development before potentially being ready for market entry.

The need for better understanding of materials and systems, for advanced characterisation methods including in situ characterisations, and for concerted modelling is evident. Moreover, harmonised approaches stand as facilitating vector for increasing the technology readiness level of all technologies. Safety is also specially highlighted within the H_2FC consortium, where modelling in general as well as safety related regulations, codes and standards for the various technologies and use of hydrogen in general is defined as bottlenecks. One of the most challenging safety issues is a low fire resistance of on-board hydrogen storage and consequences of accidental leaks from vehicles outdoors and indoors.

The analysis of the Scientific Bottlenecks for Commercialization of H_2 & FC Technologies confirms that the H_2FC European infrastructure project is positioned on these key issues:

- Test harmonisation and protocols
- Accelerated tests development
- Mechanisms understanding and modelling thanks to advanced characterisation means including in situ characterisation
- Safety
- Other cross cutting issues such as public demonstration and awareness

The partners involved, with the coordination of KIT and the University of Perugia, have drawn up an informative list or mapping of the existing laboratories, universities, industries and associations in the area of “hydrogen and fuel cells” all over Europe. This mapping became already improved according the basic structure and was restructured in 2015 as a “yellow page”.

It is worth to mention that the inventory doesn't mean to be exhaustive: as such, it will get updated continuously. The mapping of existing infrastructures is summarized in deliverable report D4.4 Inventory on European Research Infrastructure facilities, which was updated as more input was supplied. The inventory is presented online through the H2FC website. It is a dynamical tool intended to facilitate expansion of the existing mapping by adding more and more activities to the mapping.

3.4.3 Tracking Achievements in an European Progress Review

This work package was combined with the execution of a series of expert workshops enhancing the exchange of knowledge. The first European annual progress review was arranged in Rome, Italy, 16-17 October 2013 in collaboration with EERA. Following this first European Annual Progress Review, arranged in Rome, Italy, 16-17 October 2013 in collaboration with EERA, the corresponding deliverable D4.5 was updated to include all the details regarding the event.

In order to achieve to overcome the existing knowledge gaps and technological bottlenecks a survey was prepared and circulated to national experts in Europe. Based on their responses a first compilation of input and main findings from the survey was presented in deliverable report D4.7.

For the second H2FC progress review workshop it was also agreed to merge the event with a similar "European Progress Review" meeting on "Hydrogen and fuel cell science and engineering – national status" held by EERA. The second progress review meeting was hence arranged in Brussels April 27th 2015, with invited experts in the field of hydrogen and fuel cells. The merge with the EERA events were natural as H2FC and EERA share a lot as far as the general objectives are concerned as well as partners representing the different activities.

This second Progress Review was reported on in deliverable report D4.6, and the outcome of the aforementioned survey D4.7 was presented at the workshop by Anders Ødegård (SINTEF) and thoroughly discussed with the participants. The fruitful discussions gave rise to suggested modifications and additional points to be added to the report to complete the European overview. Extensive input was provided during the Progress Review and it was agreed with the EERA partners to also include documentation from available implementation plans/road maps on hydrogen and fuel cells published or under development by EERA. The process for developing the present report is illustrated [Fig.38].

[Fig.38] Flow scheme for the development of European Progress Review

As for previous report D4.7, the modified, updated report D4.8 summarize existing activities and progress, as well as recommendations for further focus areas and required infrastructure to overcome the existing knowledge gaps and technological bottlenecks, for 4 main topics:

- Hydrogen production (including purification)

- Hydrogen Storage and Distribution
- Hydrogen end use
- Hydrogen safety

The report provides valuable input for all 4 topics on the achievements and infrastructure, which implications these have on the further development and prioritization within the hydrogen and fuel cell area, e.g. as input to FCH2 JU and relevant Horizon2020 topics. A development plan for a European H2 and fuel cell research infrastructure was developed.

Based on the output from other tasks a summary of the transnational access installations and research activities of the H2FC infrastructure was prepared and this has been presented in deliverable report D4.9. The outcome is compared with the research demand as anticipated by stakeholders of society, i.e., scientific bottlenecks as defined by international experts, European policy documents, as well as some recommendations from industry. Any new technology runs through a peak of inflated expectations, which is mostly fired by new exciting discoveries in basic research. The net cash flow is often positive, because this research is regularly funded by the public sector, or privately on the basis of these high expectations. With time, the investments of particular the private sector increases. The net cash flow is negative, and refunded, when the revenue growth of the final product has found its market ("valley of death"). The nearer to the market, the deeper will be the valley of death, and the investments' pay back can only come in the future. As argued in section 2, the market entry barriers for new technologies in the energy sector are particularly high because of the huge investments needed.

3.4.4 Long Term Perspectives

Concerning the long term perspective this work package became subdivided in three major topics.

- Master Curriculum (hydrogen technology)
- E-Newsletter
- FCH Reference Handbook
- E-Infrastructure

Regarding the first major topic a course curriculum on a master degree level was developed as modules comprising fuel cells and hydrogen technologies based on "hydrogen as energy carrier" and/or "resource technologies". The scope represents a closed contour of the teaching content. It was offered to KIT and DHBW to add 2-3 compulsory optional subjects to an already existing and accredited master course in mechanical engineering. These compulsory optional subjects are:

- Fuel Cells
- Hydrogen Technology
- Safety Aspects of Hydrogen Technology (Simulation and Modelling)

The second major topic was an H2FC Newsletter with a tentative title 'Progress in hydrogen and fuel cell technologies' is dissemination of research findings in the field of hydrogen and fuel cell technologies, including but not limited to safety, storage, production, and fuel cells. The e-Newsletter was developed and four issues circulated to more than 50.000 stakeholders: 1st issue-December 2014, 2nd issue-February 2015, 3rd issue-May 2015, 4th issue-August 2015. The editorial board for the H2FC Newsletter includes executive members and a representative from each partner. Executive members are composed of co-editors (Vladimir Molkov; Olaf Jedicke; Thomas Jordan), design and production (Anke Veser; Chiara Barchiesi). The e-Newsletter is hosted at the specially designed newsletter page of the project website www.h2fc.eu.

[Fig.39] Cover page of H2FC e-newsletter

The e-newsletter gets distributed by the content of e-communication list. All following issues will get only announced by Email and will be available at project website under H2FC Newsletter: e-Journals / Books

The reference handbook gets internally reworked and as far finished to be presented to the listed authors. It was decided that KIT act as self-publishers first and to arrange a second issue which shall address publishers like: Springer Verlag, because having already a series of books dedicated to renewable energies and energy technologies and IOP publishing. Both publishers act international but have different stakeholders. Meanwhile the book will get published by Elsevier after getting reworked and actualised second time.

This task is mainly connected to the “cyber laboratory” work package 10 (JRA 4). Digital education and digital research (modelling and simulation) grow extremely, not only in hydrogen and fuel cell technology.

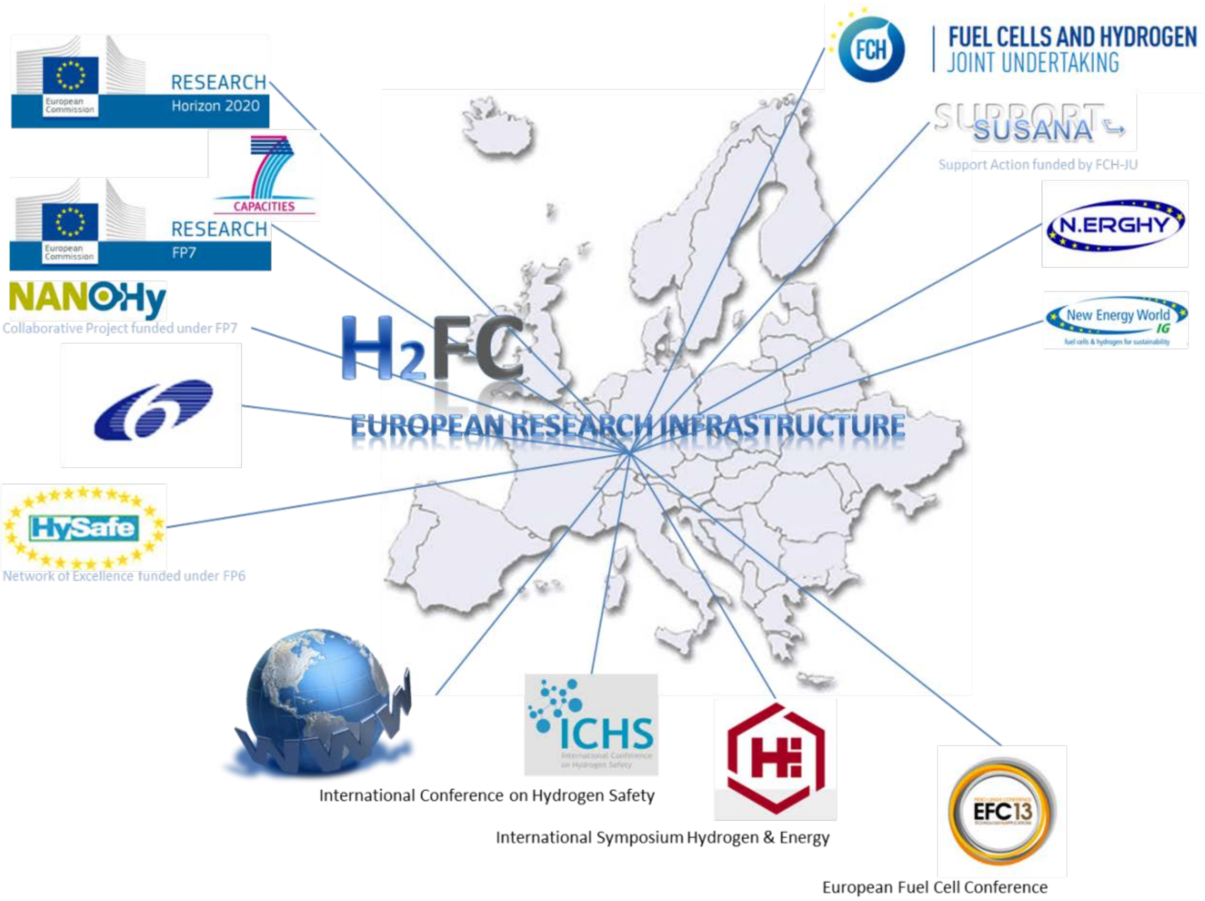
The cyber laboratory gets developed in concerns of “safety”, “hydrogen behaviour” and some basics to “fuel cells”. The cyber laboratory was used for the technical schools as well as on external events and education, mostly done by University of Ulster and KIT. Due to the novel idea to generate and develop a cyber laboratory for common work and education, and due to the success also in concerns of not much input as expected, the cyber laboratory became transferred to another project to be main objective there and to get further developed as an educational platform running e-education and e-laboratory.

Ultimately this will be further added to and expanded into a ‘one-stop-shop’ for the whole FCH community thereby providing open access to FCH digital resources, tools and services, leading to more effective collaboration between researchers, and higher efficiency, creativity and productivity of research.

4 Potential Impact and main Dissemination Activities

4.1 Potential Impact

The main impact of H2FC European Infrastructure can be mirrored clearly in the graphic below, as nearly the whole project consortium can be found integrated as active parts in boards or committees to the FCH Joint Undertaking 2.0 meanwhile, and additionally in several national and international associations and organizations, e.g. HySafe Association, EERA and notable conferences like WHEC or WHTC, ICHS, EFC etc. [Fig.40]. Not mentioned are the creations of further research and demonstration projects based on developed H2FC content and results; Means, that most of H2FC partners continue meanwhile with the H2FC project targets in other projects, like NET-Tools, TechHy, PRESLHy, HyResponse, etc.



[Fig.40] International collaborations and inclusion of H2FC to events, authorities and project collaborations

In principle, numerous publications were done, more than 277 publications, based on the received results of project activities and reflect an impressive dimension of the main project scope and also its complexity. Worth to be mentioned, that the number of publications done does not include publications to the transnational access activities and its project results. Several activities on the H2FC European Infrastructure objectives didn't end with the project; also all fixed targets were fulfilled and results achieved and reported ordinary by 118 deliverables. Meanwhile some of the targets became overtaken for further processing and development beyond the project, due to their attractiveness and importance related to the scientific content but also incorporated of novel ideas.

However, facing the joint research activities, which main target were to improve and modify existing research infrastructures and technical installations, several targets achieved didn't end up only in a technical manner (improvement of research infrastructures and technical installations), but furthermore to guidelines, instructions, new measurement techniques and methodologies. Though, the range of themes covered by the joint research activities was enormous. It started at safety issues, including jet fires, deflagration, detonation, etc. followed by fuel cells including PEM and SOFC, facing test methods for single fuel cells and stacks, water content and its distribution, investigation and development of electrodes and membranes, further electrolyzer, material science (hydrogen embrittlement), hydrogen purity, clean up methods and investigation of purity, digital science, modelling and simulation concerning fuel cells and safety issues and so on.

The done benchmarking and comparison of measurement techniques leads to several protocols and guidelines useable by the whole FCH community. A lot of installations became improved and can provide today as a kind of measurement techniques and methods in forefront means, measurement techniques which were not available before (higher resolution, new test methods and methodologies, expanding of dimensions from 2D to 3D, etc.). Due to that the technical development and market readiness of FCH devices in Europe will be fostered by the new methods, methodologies and techniques.

The benchmarking activities under joint research led to useable protocols and further improvements in applying several measurement technologies and evaluation methods. Also from these activities it follows that several existing methods should get reviewed in order to get improved the achievement of trustable results and data. As a secondary effect several guidelines became developed or started to be developed in future concerning the harmonization of measurements and comparability of test data and experimental results.

The outstanding development of an e-laboratory has its major impact in getting developed and proved first time as a novel instrument for scientific cooperation which works without physical meeting and thus over distances. The e-laboratory demonstrates formidable its fruitful usability related to education and training of students, technicians, engineers etc. on the respective FCH themes. The positive reverberation was somehow astonishing, that some partners rethought the strategy of the e-laboratory to get it incorporated in specific proposal like NET-Tools. There the e-laboratory will get developed further to an e-platform including more than only e-tools for engineering. Definitely, the impact of this action is not only a scientific one useable for scientists and engineers, but also for education and training and opens thus a wide spread activity and additional novel ideas and development. Especially the e-laboratory can get taken as a novel pattern for further activities not only concerning fuel cells and hydrogen themes. The inclusion of a so called digital collaboration on scientific themes appears as novel that way.

In concerns to the networking activities the execution of the four technical schools has the major impact also in a sustainable manner. Not provided and processed in a conventional manner and wider scope, the technical schools became notable all over Europe and worldwide. The concept meanwhile gets taken to other summer and winter schools, but at least cannot get copied easily due to missing interconnections and network of stakeholders. Especially the interconnections and network is something particular of H2FC network. Education and training were offered to a broad audience including a wide scientific scope. The direct contact to the lectures and leading scientists and also politicians appeared as most promising to the attendees of technical schools.

Also related to education and training, the development of a master course curriculum has a major impact at some Universities. A further activity became developed which ended in a project facing the harmonization of course curricula on university level all over Europe and is coordinated by University Birmingham entitled as TecHy in corporation with NET-Tools. This will help at least to harmonize the education content and requirements in the FCH themes further and to make exams considerably more comparable all over Europe.

The focus on the bottlenecks and knowledge gaps has a great impact on the further development of technical infrastructures and drafting of proposal content. The knowledge was transported to EERA and will get there discussed further also with experts arising from the H2FC project consortium. Concerning the knowledge gaps and bottlenecks in safety related issues, FCH-JU perceived the opportunity to install a safety panel consisting out of members of H2FC project. Thus the benefit is guaranteed also in safety related concerns.

It should not get forgotten that major impact appeared according the execution of user projects within the transnational access activities of the project. Around 100 user proposals received and around 68 user project became executed by H2FC consortium and finished by useable results. Especially from transnational access, industry, universities and others profits by getting executed experiments which were otherwise not financeable for those users. Some of the access activities get executed further beyond the project due to common interest and/or collaboration. Especially this activity supported industrial research and development in a meaningful and sustaining manner. This activity became independent meanwhile and still H2FC European Infrastructure receives applications or gets directly asked to continue the activity (but also technical schools, review on bottlenecks and expert workshops). Each user project can get seen as small research project targeting on specific problems and ideas. Due to the fact that all user projects became reported and achieved results disseminated the impact by spreading knowledge in this concern, is likewise enormous.

Apart from activities described in description of work, one target ranked on higher level was to team the different communities; the safety community, the fuel cell community and the community working on material science and technological development. This target was achieved and has its benefit in further collaboration by overcoming hurdles. The people involve were notable and influence their community respectively forward to be one community facing on installing and promoting “hydrogen as an energy carrier”. Last but not least, the community increased continuously and thus the collaboration of former separated experts. This has also an influence on the society (recognizing the community as a common and bigger one), public awareness and politicians, who knows meanwhile whom to ask about hydrogen and fuel cell technology, its status quo, further development and future prospects.

4.2 Dissemination Activities

Already at the starting of H2FCEuropean Infrastructure a road show was developed to draw the attention of potential European customers on the possibilities of free transnational access to research facilities. The road show was implemented in the H2FCEuropean Infrastructure project website and continuous presented at various events and conferences. In particular, the road show is still available at http://h2fc.eu/roadshow.

4 thematic workshops became organised and executed alone standing or in collaboration with conferences to address especially key bottlenecks and provide breakthroughs in H2FC research

[Tab.8]. Attendees to the workshops were individual researchers in the complete hydrogen chain, from hydrogen production to the applications in fuel cells. The "specification of key scientific bottlenecks" had a fundamental role within the identification of the key workshop's issues.

	Title / Object	**Where**	**When**
1	Integrating Numerical and Experimental Approaches for the Design of Next Generation Fuel Cells	ENEA Headquarters *Rome, Italy*	10th December 2013
2	H2FC Materials Workshop	Parque Tecnológico de San Sebastián (Tecnalia) *Donostia-San Sebastián – Gipuzkoa, Spain*	18th March 2014
3	Integrating Safety Strategies and Engineering Solutions	EMPA Emmetten, Switzerland	29th January 2015
4	Integrating Safety Strategies and Engineering Solutions	ENEA / H_2FC	29th January 2015

[Tab.8] List and schedule of planned and executed workshops

The European Technical Schools on Hydrogen and Fuel Cells 2011-2015 in Crete were almost used to publish the achieved results from joint research activities and access projects.

H_2FCEuropean Infrastructure project was reported completely to the FCH Joint Undertaking and once at the Programme Review Days regarding Joint Undertaking. This event was arranged in Brussels, Belgium, 28-29 November 2012 (http://www.fch-ju.eu/prpage/programme-review-2012) and an attempt of coordinating the first European Annual Progress Review event of the H_2FCEuropean Infrastructure alongside with this event was made.

The main focus was to organize at least four special sessions and/or parallel events within renowned international conferences throughout the whole project durations, one during the first project months in order to promote its launch, the others in years 2-4 following the Review Panel meeting to address key bottlenecks and provide breakthroughs in H2F research. These special sessions should focus on broad area of hydrogen and fuel cells so to gather the H2FC community, investigate bottlenecks and chances within the field, promote H2FC project activities and opportunities. The aim was to attract at least 100 participants at each conference.

In accordance to the task, the following conferences have been organized:

	TITLE / OBJECT	**WHERE**	**WHEN**	**WEB**
1	European Fuel Cell Technology & Applications Piero Lunghi Conference – EFC11	Rome, Italy	December 14-16, 2011	www.europeanfuelcell.it
2	International Conference on Hydrogen Safety - ICHS 2013	Brussels, Belgium	September 9-11, 2013	www.ichs2013.org
3	EMRS Fall Meeting	Warsaw, Poland	September 16-20, 2013	www.emrs-strasbourg.com/index.php?option=com_ content&task=view&id=572&Itemid=1584
4	Piero Lunghi Conference EFC13	Rome, Italy	December 11-13, 2013	www.europeanfuelcell.it
5	9th Symposium Hydrogen and	Emmetten,	January 25 – 30,	http://hesymposiu

	Energy	Switzerland	2015	m.ch/
6	International Conference on Hydrogen Safety - ICHS 2015	Yokohama, Japan	October, 19-21 2015	http://www.ichs2015.com/
7	Piero Lunghi Conference EFC15	Naples, Italy	December 15-18, 2015	www.europeanfuelcell.it

[Tab.9] List of renowned conferences H2FC collaborated by own sessions and series of presentations (examples to the dimension given in [Fig.41] and [Fig.42])

[Fig.41] Attendees, group photo taken at the international ICHS Conference 2013 located in Brussels (the conference was attended by over 200 participants, including 183 registered participants)

The European Materials Research Society (E-MRS) was founded in 1983 through the initiative of individual European Materials scientists and has now more than 3,200 members from industry, government, academia and research laboratories, who meet regularly to debate recent technological developments of functional materials.

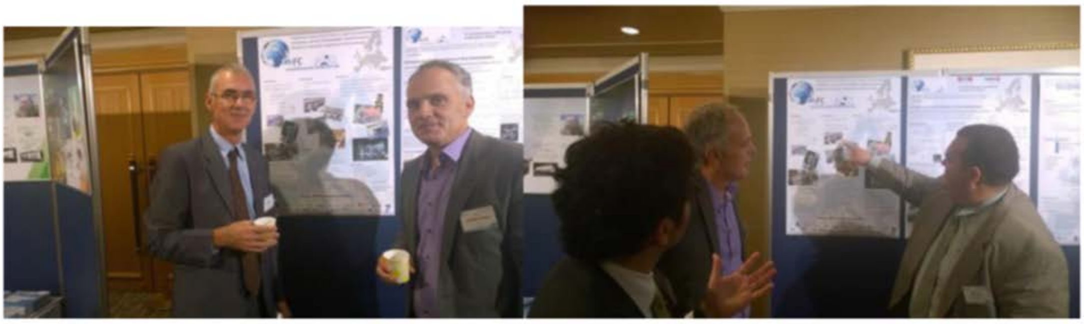
Most of the problems facing the world such as energy supply and health will be solved only by breakthroughs in materials science. 2013 marks the 30th Anniversary of E-MRS and the Fall Meeting provided the opportunity to exchange ideas and knowledge. The Fall Meeting was hold in Poland at the Central Campus of the Warsaw University of Technology, from 16th to 20th September 2013. The meeting included 14 parallel symposia, plenary sessions and some training activities for young researchers and scientists wishing to extend their expertise to new fields. The conference attracted more than 730 participants coming from 53 different countries.

Among the 14 parallel Symposia the Symposium M: Research Infrastructures at the frontier of innovation- cutting edge technologies for knowledge based applications, was organized by the FP7 European Infrastructure projects EUMINAfab, the H2FC European Research Infrastructure and the Central European project Nanoforce.

[Fig.42] EMRS Fall Meeting 2013 16-20 September 2013

In order to support the dissemination of the access activities the H2FC European Infrastructure organised several poster sessions to conferences on which users became invited to present their achievements to the community [Fig.43] [Fig.44].

[Fig.43] H2FC Poster sessions concerning done access projects at ICHS 2013, EMRS Fall Meeting 2013, ICHS 2015, EMPA Symposium Emmetten



[Fig.44] H2FC Poster sessions concerning done access projects at ICHS 2015 (Japan)

4.3 List of done Publications

Publications done 2011

[1] Safety distances: comparison of the methodologies for their determination, Matteo Vanuzzo, Marco Carcassi, **4^{th} International Conference on Hydrogen Safety (4^{th} ICHS)**, 12- 14^{th} September 2011, San Francisco (California USA) Oral Presentation

[2] Development of an Italian fire prevention technical rule for hydrogen pipelines; Nicola Mattei; Carcassi M.N., Ciannelli N., Pilo F.; **4^{th} International Conference on Hydrogen Safety (4^{th} ICHS)**; 12- 14^{th} September 2011; San Francisco (California USA) Oral Presentation

[3] H2FC European Infrastructure Project Integrating European Infrastructure to support science and development of Hydrogen- and Fuel Cell Technologies towards European Strategy for Sustainable, Competitive and Secure Energy; Olaf Jedicke; Thomas Jordan; **4^{th} International Conference on Hydrogen Safety (4^{th} ICHS);** 12- 14^{th} September 2011; San Francisco (California USA) Opening Plenary Session (Oral Presentation)

[4] Hydrogen-methane mixtures: dispersion and stratification studies; Alessia Marangon; Marco Carcassi; **4^{th} International Conference on Hydrogen Safety (4^{th} ICHS)**; 12- 14^{th} September 2011; San Francisco (California USA) Oral Presentation

[5] Safety aspects in the Production and Separation of Hydrogen from Biomass; Susana Perez; Iñaki Azkarate; **4^{th} International Conference on Hydrogen Safety (ICHS 2011)**; 12- 14^{th} September 2011; San Francisco (California USA) Oral Presentation

[6] **H2FC** European Infrastructure Project Integrating European Infrastructure to support science and development of Hydrogen- and Fuel Cell Technologies towards European Strategy for Sustainable, Competitive and Secure Energy; Olaf Jedicke; Thomas Jordan, Chiara Barchiesi, Vanessa Rossi; **International Hydrogen and Fuel Cell Conference (Zing Conference); Occidential Grand Xcaret (Mexico)**; 1 – 6^{th} December 2011; Occidential Grand Xcaret (Mexico); Oral Presentation

[7] The H2FC project "Integrating European Infrastructure to support science and development of Hydrogen- and Fuel Cell Technologies towards European Strategy for Sustainable, Competitive and Secure Energy"; Olaf Jedicke, Chiara Barchiesi, Marco Carcassi, **European Fuel Cell Technology & Applications Piero Lunghi Conference (EFC11),** published within the "Book of proceedings" of EFC11, ref. EFC11222, 14 - 16^{th} December 2011, ENEA Frascati Research Center (Italy)

Publications done 2012

[8] Perspectives of H Storage and Battery Materials, Maximilian Fichtner, **MCARE 2012**, Clearwater/FL, USA, 27^{th} February 2012, Oral Presentation

[9] H2FC European Infrastructure, Pierre Boillat, **9^{th} Symposium on Fuel Cell and Battery Modeling and Experimental Validation (MODVAL9)**, 2^{nd} – 4^{th} April 2012, Sursee, Switzerland, Poster Presentation as general presentation of the H2FC project

[10] Opportunities for fuel cell modelling validation through the H2FC transnational access activities, Pierre Boillat, **10th Symposium on Fuel Cell and Battery Modeling and Experimental Validation (MODVAL10), 2nd – 4th April 2012**, Bad Boll, Germany, Poster Presentation of the H2FC project with a focus on the potential of transitional access in the frame of modelling validation studies.

[11] H2FC European Infrastructure alongside the hydrogen chain, Olaf Jedicke, Thomas Jordan, **World Hydrogen Energy Conference 2012 International Conference and Exhibition,** 3 – 7th June 2012, Toronto Centre Sheraton, Toronto, Oral Presentation

[12] TITEL FEHLT, Iñaki Azkarate, **Master en energías renovables, pilas de combvuestible e hidrógeno. Universidad Internacional Menendez Pelayo,** 12th June 2012, Madrid, Oral Presentation

[13] Synthesis and Characterization of Hydrogen Storage Materials at KIT-INT, Ulrich Ulmer, Maximilian Fichtner, **2nd Technical School on Hydrogen and Fuel Cells 2013,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral Presentation (2013??? Reihe obendrüber)

[14] Taking into account hydride breathing in an integrated heat exchanger of a hydrogen storage vessel, Benoit Charlas, Pierre Doremus, Didier Imbault, Albin Chaise, Manon Elie, Thierry Portra, Patrick Mayoussier, Olivier Gillia, **European Technical School on Hydrogen and Fuel Cells 2012**, Crete, Greece, 24-28 September 2012, Oral Presentation

[15] Instrumented facility for hydrogen solid storage characterization around the COMEDHY facility, Benoit Charlas, Marko Feldic, Albin Chaise, Olivier Gillia, **European Technical School on Hydrogen and Fuel Cells 2012,** Crete, Greece, 24-28 September 2012, Oral Presentation

[16] Challenges with neutron diffraction under high hydrogen pressure, Magnus H. Sørby, **2st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[17] Neutron Scattering Instrumentation at IFE, Magnus H. Sørby, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[18] Structure and property investigations of hydrogen storage materials, Magnus H. Sørby, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[19] Membrane and Fuel Cell testing at low to high temperatures, Paul Inge Dahl,

1st Technical School on Hydrogen and Fuel Cells 2012, Arina Sands Hotel, Heraklion, Crete (Greece), 24 – 28th September 2012, Oral presentation

[20] H2FC European Infrastructure Project Integrating European Infrastructure, Olaf Jedicke, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[21] The influence of experimental data on the regulation "Italian Technical Rule for Hydrogen Pipelines", Marco Carcassi, Nicola Mattei, **1st Technical School on Hydrogen and Fuel Cells 2012,** Arina Sands Hotel, Heraklion, Crete (Greece), 24- 28th September 2012, Oral presentation

[22] 'In-situ and in-operando methods for hydrogen related research', Arndt Remhof, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[23] Innovative materials testing for Sorption enhanced steam reforming, Federico Gallorini, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[24] Methods and test rig for HT FC performance analysis, Giovanni Cinti, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[25] Safety issues of hydrogen-powered vehicles, Vladimir Molkov, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Oral presentation

[26] Ground breaking research at UU: PLANE HYDROGEN JETS, Dmitriy Makarov, Vladimir Molkov, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[27] Comparison of different Pd doped carbon foam/carbon nanoparticles composites for hydrogen storage, Thanos Stubos, **Euro-mediterranean Hydrogen Technologies Conference - EmHyTeC 2012**, 11-14 September 2012, Hammamet (Tunisie), Oral presentation

[28] Instrumentation and research methods at NSCRD: Capacity, kinetics, thermodynamics and cycle life measurements of hydrogen storage materials, Theodore Steriotis, **1st Technical School on Hydrogen and Fuel Cells 2012**, 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[29] Simulations for thermal design of hydrogen storage systems, Thanos Stubos, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[30] Ground breaking research at NCSRD: LES modelling of hydrogen dispersion and combustion using the ADREA-HF code, Alexandros Venetsanos, **1st Technical School on Hydrogen and Fuel Cells 2012**, 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[32] Instrumentation and research methods at University of Pisa, Hydrogen and Hydrogen-Methane mixture concentration measurements and gas chromatography, Marco Carcassi, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[33] Membrane and Fuel Cell testing at low to high temperatures, Paul Inge Dahl, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[34] Ground breaking research at Pro-Science Hydrogen combustion and detonation in narrow tubes, Joachim Grune, **1st Technical School on Hydrogen and Fuel Cells 2012**, 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[35] Hydrogen, from powders to power, S.J. McPhail (ENEA), **1st European Technical School on Hydrogen and Fuel Cells**, Crete, Greece, Oral presentation

[36] BAM – a generalist in terms of safety research and technonogy, Ulrich Schmidtchen, **1st Technical School on Hydrogen and Fuel Cells 2012,** Arina Sands Hotel, Heraklion, Crete (Greece), 24 – 28th September 2012, Oral presentation

[37] A new safe method for the high pressure storage of hydrogen gas, Ulrich Schmidtchen, Kai Holtappels, Dan Eliezer, **1st Technical School on Hydrogen and Fuel Cells 2012,** Arina Sands Hotel, Heraklion, Crete (Greece), 24 – 28th September 2012, Oral presentation

[38] Develpment of Low-cost BCC Hydrogen Storage Alloys, Ulrich Ulmer, Maximilian Fichtner, **2nd Technical School on Hydrogen and Fuel Cells 2013,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[39] Synthesis and Characterization of Complex Hydrides for Hydrogen Storage, Ulrich Ulmer, Elisa Gil Bardaji, Maximilian Fichtner, **1st Technical School on Hydrogen and Fuel Cells 2012** , 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[40] Instrumentation & Research method at JRC: GasTeF and SenTeF, Pietro Moretto, B. Acosta-Iborra, L. Boon-Brett, V. Palmisano, C. Bonato, F. Harskamp, **1st Technical School on Hydrogen and Fuel Cells 2012**, 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[41] Analytical study of hydrogen release and dispersion in an enclosure with vents, Volodymyr Shentsov, Sile Brennan, Vladimir Molkov, **1st Technical School on Hydrogen and Fuel Cells 2012**, 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[42] Performance validation of commercially available sensors, Valerio Palmisano, Lois Boon-Brett, Pietro Moretto, **1st Technical School on Hydrogen and Fuel Cells 2012,** 24 – 28th September 2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[43] On-board Compressed Hydrogen Storage: Fast Filling Experiments and Simulations, Pietro Moretto, B. Acosta, D. Baraldi, E. Weidner, D. Melideo, N. De Miguel, **1st Technical School on Hydrogen and Fuel Cells 2012**, 25/09/2012, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[44] Instrumentation and research at PSI: Imaging of liquid water in operating polymer electrolyte fuel cells, Pierre Oberholzer (PSI), **1st European Technical School on Hydrogen and Fuel Cells**, 24 - 28.10.2012, Heraklion, Greece, Access to slides to participants, Presentation of the methods available for transnational access, Oral Presentation

[45] Ground breaking research at PSI: Neutron imaging combined with helox pulse analysis in fuel cells, Pierre Oberholzer (PSI), **1st European Technical School on Hydrogen and Fuel Cells**, 24 - 28.10.2012, Heraklion, Greece, Access to slides to participants, Presentation of the methods available for transnational access, Oral Presentation

[46] Hydrogen storage and energy related materials, Magnus H. Sørby, Christoph Frommen, Stefano Deledda, Bjørn Hauback, **The European Powder Diffraction Conference (EPDIC 13)**, 28 - 31st October 2012, Grenoble (France), Oral Presentation

[47] Hydrogen as an energy carrier: Challenges and Prospects, Thanos Stubos, **Workshop organised by the University of Cyprus,** 25 October 2012, Nicosia (Cyprus), Oral presentation

[48] H2FC: plenty of opportunities for you!, Giovanni Cinti, Chiara Barchiesi, **Workshop on CO2 capture and storage**, Rome (Italy), 14th November 2012, Power point presentation, poster, flyers, book of access

[49] **H2FC** European Infrastructure Project, Science and Development alongside the Technological Hydrogen Chain, Olaf Jedicke, **Fuel Cells and Hydrogen and Joint Undertaking's Programme Review Days 2012,** 28 – 29th November 2012, Brussels (Belgium), Oral presentation

Publications done 2013

[50] H2FC: plenty of opportunities for you!, Chiara Barchiesi, Giovanni Cinti, Meeting for presentation of H2FC opportunities (mainly access and technical schools) to be highlighted with dissemination purpose, Marostica (Italy), 09 January 2013, Power point presentation, poster, flyers, book of access

[51] Modelling the thermomechanical behaviour of the breathing hydride powders threatening the integrity of their containers, B. Charlas, O. Gillia, P. Doremus, D. Imbault, A. Chaise, **7th International Symposium on Hydrogen Energy**, Stoos, Switzerland, 21 - 25 January 2013, Oral Presentation

[52] The Energy Density of Hydrogen Storage Systems, Andreas Züttel, **7th International Symposium on Hydrogen and Energy (Swiss)**, 21 – 25th January 2013, Stoos (Swiss), Poster presentation

[53] 'Sorption Enhanced Reactions for Renewable Synfuels', Andreas Borgschulte, **7th International Symposium on Hydrogen and Energy (Swiss)**, 21 – 25th January 2013, Stoos (Swiss), Oral presentation

[54] **H2FC** European Infrastructure Project, Science and Development alongside the Technological Hydrogen Chain, Olaf Jedicke, **7th International Symposium on Hydrogen and Energy (Swiss)**, 21 – 25th January 2013, Stoos (Swiss), Oral presentation

[55] Self-Igniting Catalytic Hydrogen Burner with Zero Emission, Uli Vogt, **7th International Symposium on Hydrogen and Energy (Swiss)**, 21 – 25th January 2013, Stoos (Swiss), Poster presentation

[56] H2FC: plenty of opportunities for you!, Chiara Barchiesi, Giovanni Cinti, **Meeting at Vimar** for presentation of H2FC opportunities (mainly access and technical schools) to be highlighted with dissemination purpose, Vimar (Italy), 9th January 2013, Power point presentation, poster, flyers, book of access

[57] Membranes for fuel cells: from structure and transport properties to new concepts, Gérard Gebel, **Advances in materials for proton exchange membrane fuel cells systems**, 17 – 20th February 2013, Asilomar, Pacific Grove, California, USA, Oral presentation: Plenary Lecture

[58] Porous carbons as sorbents, substrates and scaffolds for hydrogen storage applications, Thanos Stubos, **Task 32 IEA HIA "Hydrogen based Energy Storage", Expert kick-off meeting**, 21 – 25th April 2013, Heraklion, Crete (Greece), Oral presentation

[59] H2FC: plenty of opportunities for you!, Chiara Barchiesi, Giovanni Cinti, **Meeting at Fraunhofer IKTS** for presentation of H2FC opportunities (mainly access and technical schools) to be highlighted with dissemination purpose, Dresden (Germany), 24 - 26th April 2013, Power point presentation, poster, flyers, book of access

[60] A Novel Correlation for Vented Hydrogen-Air Deflagrations, Vladimir Molkov, Bragin Maxim, **7th International Seminar on Fire and Explosion Hazards**, 5 - 10 May 2013, Providence, (R.I., USA), Oral presentation, 689-698, ISBN: 978-981-07-5940-7

[61] Numerical Simulation of 10% Hydrogen-Air Vented Deflagration in a 120 m^3 Enclosure, Dmitriy Makarov, Vladimir Molkov, **7th International Seminar on Fire and Explosion Hazards**, 5 - 10 May 2013, Providence, (R.I., USA), Oral presentation, 975-984, ISBN: 978-981-07-5940-7

[62] Towards the Implementation of Rayleigh-Taylor Instability into the Multi-Phenomena Deflagration Model, James Keenan, Dmitriy Makarov, Vladimir Molkov, **7th International Seminar on Fire and Explosion Hazards,** 5 - 10 May 2013, Providence, (R.I., USA), Oral presentation, 932-941, ISBN: 978-981-07-5940-7

[63] Sustained Hydrogen Leak Concentration in Enclosure with One Vent, Vladimir Molkov, Volodymyr Shentsov, James Quintiere, **7th International Seminar on Fire and Explosion Hazards**, 5-10 May 2013, Providence, (R.I., USA), Oral presentation, 903-912, ISBN: 978-981-07-5940-7

[64] Dynamics of Hydrogen Flame Self-Extinction in a Vented Enclosure, Vladimir Molkov, Volodymyr Shentsov, Sile Brennan, Dmitriy Makarov, **7th International Seminar on Fire and Explosion Hazards**, 5 - 10 May 2013, Providence, (R.I., USA), Oral presentation, 922-931, ISBN:978-981-07-5940-7

[65] H2FC: plenty of opportunities for you!, Chiara Barchiesi, Giovanni Cinti, **Meeting at Thyssenkrupp** for presentation of H2FC opportunities (mainly access and technical schools) to be highlighted with dissemination purpose, Terni (Italy), 6th May 2013, Power point presentation, poster, flyers, book of access

[66] The use of scattering techniques to investigate structure and transport properties in electrolytes, Sandrine Lyonnard, **Diffusion In Solids and Liquids, Session Alternative Energies**, 24 – 28th June 2013, Madrid, Spain, Oral presentation

[67] Experimental Study of Vented Hydrogen Deflagration with Ignition Inside and Outside the Vented Volume, Martino Schiavetti, Marco Carcassi, **5th International Conference on Hydrogen Safety (5th ICHS)**, 9 - 11 September 2013, Brussels (Belgium), Oral presentation

[68] Simulation of hydrogen dispersion under cryogenic release conditions, Alexandros Venetsanos, S.G. Giannissi, N. Markatos, D.B. Willoughby, M. Royle, **5th International Conference on Hydrogen Safety**, Brussels, Belgium, 9 - 11 September 2013, Oral presentation / Abstract

[69] Modelling and effect of Rayleigh-Taylor instability on coherent deflagrations, Dmitriy Makarov, Vladimir Molkov, **5th International Conference on Hydrogen Safety (5th ICHS)**, 9- 11 September 2013, Brussels (Belgium), Oral presentation

[70] Hydrogen-air deflagrations: vent sizing correlation for low-strength equipement and buildings, Vladimir Molkov, Bragin Maxim, **5th International Conference on Hydrogen Safety (5th ICHS)**, 9 - 11 September 2013, Brussels (Belgium), Oral presentation

[71] Numerical simulations of hydrogen non-premixed combustion and self-extinction in an enclosure, Vladimir Molkov, Volodymyr Shentsov, Sile Brennan, Dmitriy Makarov, **5th International Conference on Hydrogen Safety (5th ICHS)**, 9 - 11 September 2013, Brussels (Belgium), Oral presentation

[72] Passive ventilation of a sustained gaseous release in an enclosure with one vent, Vladimir Molkov, Volodymyr Shentsov, James Quintiere, **5th International Conference on Hydrogen Safety (5th ICHS)**, 9 - 11 September 2013, Brussels (Belgium), Oral presentation

[73] Experimental investigation of flame and pressure dynamics after spontaneous ignition in tube geometry, Joachim Grune, K. Sempert, M. Kuznetsov, T. Jordan, **5th International Conference on Hydrogen Safety (ICHS 2013)**, 9-11 September 2013, Brussels (Belgium), Oral presentation

[74] Vented hydrogen-air deflagrations in low strength equipment and buildings, Vladimir Molkov, Maxim Bragin, **5th International Conference on Hydrogen Safety (5th ICHS)**, 9-11 September 2013, Brussels (Belgium), Oral presentation

[75] Modelling and simulation of lean hydrogen-air deflagrations, Dmitriy Makarov, Vladimir Molkov, **5th International Conference on Hydrogen Safety (5th ICHS)**, 9 -11 September 2013, Brussels (Belgium), Oral presentation

[76] Rayleigh-Taylor instability: modelling and effect on coherent deflagrations, James Keenan, Dmitriy Makarov, Vladimir Molkov, **5th International Conference on Hydrogen Safety (5th ICHS)**, 9- 11 September 2013, Brussels (Belgium), Oral presentation

[77] Modelling and Simulation Supporting the Application of Hydrogen Technologies, A. Stubos, A. Venetsanos, M. Kainourgiakis, Th. Steriotis, G. Charalambopoulou, E. Stamatakis, **E-MRS 2013 FALL MEETING - Symposium M: Research Infrastructures at the frontier of innovation – cutting edge technologies for knowledge based applications**, Warsaw (Poland), 17/9/2013, Oral presentation / Abstract

[78] Safety of hydrogen use indoors: recent progress at Ulster, Vladimir Molkov, **European Technical School on Hydrogen and Fuel Cells 2013**, 23-27 September 2013, Heraklion (Crete),

[79] Recent results on modelling the breathing of hydrides while absorbing desorbing hydrogen, B. Charlas, O. Gillia, P. Doremus, D. Imbault, A. Chaise, **EMRS Conference 2013, Symposium C**, Warsaw, Poland, 16 - 20 September 2013, Oral presentation

[80] Structure/transport interplay in electrolyte membranes, Sandrine Lyonnard, **European Material Research Society, Session Proton Conductors**, 16 – 20th September 2013, Warsaw, Pologne, Invited Oral presentation

[81] Hydrogen Sensor Application of Palladium based Catalyst Systems, Bernhard RIEGEL (HOPPEKE), Eduardo CATTANEO (HOPPEKE), Christian HUNKER (HOPPEKE), Lois Brett (JRC), Valerio PALMISANO (JRC), **EMRS Fall Meeting 2013**, 16 - 20/09/2013, Warsaw, Oral presentation, Results of the H2FC TNA project 2005

[82] Safety of hydrogen use indoors: recent progress at Ulster, Vladimir Molkov, Volodymyr Shentsov, James Quintiere, Dmirtiy Makarov, Sile Brennan, Maxim Bragin, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 22nd – 28th September 2013, Agapi Beach Hotel, Heraklion, Crete (Greece), Oral presentation

[83] Numerical Simulation of Gas Releases in Enclosed Space, Boris Chernyavsky, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 22nd – 28th September 2013, Agapi Beach Hotel, Heraklion, Crete (Greece), Oral presentation

[84] Numerical simulation of helium release and dispersion in an enclosure, Volodymyr Shentsov, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 22nd – 28th September 2013, Agapi Beach Hotel, Heraklion, Crete (Greece), Poster

[85] Bonfire test protocols for on-board hydrogen storage systems, Svetlana Tretsiakova-McNally, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 22nd – 28th September 2013, Agapi Beach Hotel, Heraklion, Crete (Greece), Poster

[86] Characteristics of under-expanded planar hydrogen diffusion flames, David Yates, Dmitriy Makarov, Vladimir Molkov, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 22nd – 28th September 2013, Agapi Beach Hotel, Heraklion, Crete (Greece), Poster

[87] Investigation of hydride powder bed breathing during cycling under hydrogen for different compressive stresses, Benoit Charlas, Marko Feldic, Albin Chaise, Vasile Iosub, Olivier Gillia, **European Technical School on Hydrogen and Fuel Cells 2013**, Crete, Greece, 23-27 September 2013, Oral presentation

[88] Rayleigh-Taylor instability modelling, James Keenan, **European Technical School on Hydrogen and Fuel Cells 2013**, 23 - 27 September 2013, Crete (Greece), Oral presentation

[89] Modelling and simulations for integrated hydrogen storage - fuel cell systems, G. Charalambopoulou, A. Stubos, T.A. Steriotis, M. Kainourgiakis, A. Yiotis, **2nd H2FC Technical School**, Heraklion, Crete – Greece, 23-27 September, 2013, Oral presentation / Abstract

[90] Neutron imaging of liquid water in fuel cells, Pierre Boillat (PSI), **2nd European Technical School on Hydrogen and Fuel Cells**, 23 - 27.9.2013, Heraklion, Greece, Oral Presentation, Access to slides to participants, Presentation of the methods available for transnational access

[91] Combining imaging with advanced electrochemical methods, Pierre Boillat (PSI), **2nd European Technical School on Hydrogen and Fuel Cells**, 23 - 27.9.2013, Heraklion, Greece, Oral Presentation, Access to slides to participants, Presentation of the methods available for transnational access

[92] Physical adsorption characterisation of hydrogen sorbents, Th. Steriotis, G. Charalambopoulou, A. Stubos, A. Gotzias, **2nd H2FC Technical School**, Heraklion, Crete – Greece, 23 - 27 September, 2013, Oral presentation / Abstract

[93] Combustion modelling using the ADREA-HF code, A. Venetsanos, **2nd H2FC Technical School**, Heraklion, Crete – Greece, 23 - 27 September, 2013, Oral presentation / Abstract

[94] User guidance and demonstration of UU numerical modelling tools available on Cyber Laboratory software suite, James Keenan, **European Technical School on Hydrogen and Fuel Cells 2013,** 23 - 27 September 2013, Crete (Greece), Oral presentation

[94] Bonfire Test Protocols for on-board hydrogen storage, Svetlana Tretsiakova-McNally, **European Technical School on Hydrogen and Fuel Cells 2013**, 23-27 September 2013, Crete (Greece), Poster presentation

[95] Structural Health Monitoring techniques for damage detection in Hydrogen pressure vessels, Juan Carlos Sánchez, Iñaki Azkarate, **5th International Conference on Hydrogen Safety. ICHS 2013**, 9 - 11th September 2013, Brussels, Poster

[96] Friction Experiments in liquid hydrogen – how to set up a laboratory, Ulrich Schmidtchen, Thomas Gradt, **European Technical School on Hydrogen and Fuel Cells 2013**, 23 - 27 September 2013, Crete (Greece), Oral presentation

[97] Investigation of glasses as hydrogen storage material, Peter Ried, Ralf Müller, Martin Gaber, Ulrich Schmidtchen, **European Technical School on Hydrogen and Fuel Cells 2013**, 23-27 September 2013, Crete (Greece), Oral presentation

[98] Recent experimental results from the JRC-IET high pressure gas tanks testing facility, Nerea De Miguel, R. Ortiz, B. Acosta, P. Moretto, F. Harskamp, C. Bonato, **2nd European Technical School on Hydrogen and Fuel Cells 2013**, 23-27 September 2013, Crete (Greece), Oral presentation

[99] Methods and results of MCFC test for CCS, Giovanni Cinti, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 22 - 28/9/2013, Agapi Beach Hotel, Crete (Greece), Oral presentation

[100] Hydrogen for transport from renewable energy in Mid-Norway, Paul Inge Dahl, Steffen Møller-Holst, Steve Völler, Magnus Korpås, Ulrich Bünger, **2nd Technical School on Hydrogen and Fuel Cells 2012**, 22nd – 28th September 2013, Heraklion, Crete (Greece), Oral presentation

[101] Experimental test of innovative materials based on calcium aluminates for SE-SR, Federico Gallorini, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 22 - 28/9/2013, Agapi Beach Hotel, Crete (Greece), Oral presentation

[102] Measurement instrumentation at the KIT HyKa facilities, Andreas Friedrich, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 23 – 27 September 2013, Agapi Beach Hotel, Heraklion, Crete (Greece), Oral presentation

[103] High temperature membranes for hydrogen separation processes, Paul Inge Dahl, Thijs Peters, Marit Stange, Yngve Larring, Marie-Laure Fontaine, Partow P. Henriksen, Rune Bredesen, **2nd Technical School on Hydrogen and Fuel Cells 2013**, 22nd – 28th September 2013, Heraklion, Crete (Greece), Oral presentation

[104] Advanced materials research in ENEA, S.J. McPhail (ENEA), **2nd European Technical School on Hydrogen and Fuel Cells,** Crete, Greece, 25/09/2013, Oral presentation

[105] From research to industrial deployment - activities in ENEA on H2 and HTFC, S.J. McPhail (ENEA), **2nd European Technical School on Hydrogen and Fuel Cells**, Crete, Greece, 24/09/2013, Oral presentation

[106] Thin palladium membranes for hydrogen separation, Margot Llosa, Iñaki Azkarate, **Hydrogen and fuel cell science and engineering. National Status**, 16 - 17th October 2013, Roma, Oral presentation

[107] From water sorption to water management: X-ray and neutron scattering studies, Gérard Gebel, **Water Phenomena in PEM**, Trondheim, Norway, 3 – 4th October 2013, Invited Oral presentation

[108] Fuel cells & H2-production – Norway, Anders Ødegård, **H2FC European Fuel Cells and Hydrogen Progress Review,** 16th – 17th October 2013 Rome, Italy, Oral Presentation

[109] Solid-state hydrogen storage materials in Norway – research activities at IFE, bottlenecks and outlook, Stefano Deledda, Christoph Frommen, Magnus, H. Sørby, and Bjørn C. Hauback, **H2FC European Fuel Cells and Hydrogen Progress Review**, 16th – 17th October 2013, Rome, Italy, Oral Presentation

[110] A ten years' time travel through the research on hydrogen storage, Borgschulte, Andreas, **Final meeting of the ACTS Hydrogen program**, Ede, NL, 25/11/2013, Oral presentation

[111] H2FC: opportunities of free access at the best European Installations, Chiara Barchiesi, Giovanni Cinti, Angelo Moreno, Stephen McPhail, **European Fuel Cell Technology & Applications Piero Lunghi Conference EFC13**, Poster presentation – poster displayed within the "Dissemination of EU projects" session; Talk about the H2FC opportunities within the special EU networking cocktail, Poster session: Rome, Italy, 11-13 December 2013, Networking cocktail: Rome, Italy, 12 December 2013

[112] Thermal transients modelling of a reformer unit for diagnostic analysis of SOFC-based systems, Linda Barelli, G. Cinti, U. Desideri, A. Ottaviano, Proceedings of EFC2013, **5th edition of the "European Fuel Cell Technology & Applications Piero Lunghi Conference"** Rome, Italy, 11-13 December 2013, Abstract, code EFC13148 Oral Presentation, Special Issue of the International Journal of Hydrogen Energy, ISBN 978-88-8286-297-8

[113] Modelling and analysis of SOFC BoP thermal transients for diagnostic scopes, Giovanni Cinti, U. Desideri, L. Barelli, A. Ottaviano, D. Penchini, **Submitted within the 5th edition of the "European Fuel Cell Technology & Applications Piero Lunghi Conference" EFC13**, Rome, Italy on 11-13 December 2013, Abstract, code EFC13149, Oral Presentation, Special Issue of the International Journal of Hydrogen Energy, ISBN 978-88-8286-297-8

[114] H2FC: plenty of opportunities for you!, Chiara Barchiesi, Giovanni Cinti, **European Fuel Cell Technology & Applications Piero Lunghi Conference EFC13**, Display of H2FC flyers and installations book, Rome, Italy, 11-13 December 2013

Publications done 2014

[115] Towards the H2FC 2-infrastructure roadmap-Overview & UU proposals, James Keenan, **H2FC WP10 Meeting**, 22 January 2014, Karlsruhe (Germany), Oral presentation

[116] Rayleigh-Taylor instability: modelling and effect on coherent deflagrations, Vladimir Molkov, **Explosion phenomena seminar**, 8 February 2014, Yamagata University, Japan, Oral presentation

[117] Rethinking high-pressure X-ray photoelectron spectroscopy for the study of hydride-forming materials, Renaud Dellement, Callini Elsa, Stadie Nicholas, Hosoglu Fadime, Borgschulte Andreas, Züttel Andreas, **8th international symposium on hydrogen and energy 2014**, 2014-02-16, Zioquang (China), Oral Presentation

[118] Development and characterization of gas separation membranes for alkaline water electrolysis, Vogt, Ulrich, Schlupp Meike, Burnat Dariusz, Züttel Andreas, **8th international symposium on hydrogen and energy 2014**, 2014-02-16, Zioquang (China), Oral Presentation

[119] Materials compatibility with Hydrogen, Iñaki Azkarate, **HYSAFE training course**, 11th March 2014, Sevilla (Spain), Oral presentation

[120] Innovative fabrication routes and materials for proton conducting fuel cells, Maria Parco, Iñaki Azkarate, **Workshop on Materials for Hydrogen Applications**, 18th March 2014, San Sebastian (Spain), Oral presentation

[121] Metallic Hydrides for Hydrogen Storage, Miguel Angel Lagos, Iñaki Azkarate, **Workshop on Materials for Hydrogen Applications,** 18th March 2014, San Sebastian (Spain), Oral presentation

[122] Hydrogen embrittlement of steels, Jean Baptiste Jorcin, Iñaki Azkarate, **Workshop on Materials for Hydrogen Applications**, 18th March 2014, San Sebastian (Spain), Oral presentation

[123] Materials for PEMFC, Alberto Garcia, Iñaki Azkarate, **Workshop on Materials for Hydrogen Applications,** 18th March 2014, San Sebastian (Spain), Oral presentation

[124] Investigation of the liquid water distribution in a 50 cm2 PEM Fuel Cell: effects of reactants relative humidity, oxygen/air feed, and load changes, Alfredo Iranzo (AICIA), Pierre Boillat (PSI), Johannes Biesdorf (PSI), Antonio Salva (AICIA), Felipe Rosa (Universidad Sevilla), **EHEC 2014 (European Hydrogen Energy Conference)**, 12.3.2014, Sevilla, Spain, Oral presentation, September 2014 (proceedings in IJHE), Access to slides for EHEC participants only, paper published in the International Journal of Hydrogen Energy (IJHE), Presentation of results from user project 2008

[125] Investigation on liquid water distribution patterns featuring anode/cathode interference in a Polymer Exchange Membrane Fuel Cell with Neutron Imaging, Alfredo Iranzo (AICIA), Pierre Boillat (PSI), Johannes Biesdorf (PSI), Antonio Salva (AICIA), Felipe Rosa (Universidad Sevilla), EHEC 2014 (European Hydrogen Energy Conference), Sevilla, Spain, 12.3.2014, Poster presentation, September 2014 (proceedings in IJHE), Access to slides for EHEC participants only, paper published in the International Journal of Hydrogen Energy (IJHE), Presentation of results from user project 2008

[126] Investigation of PEMFC start-up/shut-down degradation using reference electrode array, Gareth Hinds, Edward Brightman, **H2FC Materials Workshop**, 18th March 2014, Tecnalia, San Sebastian, (Spain), Oral presentation

[127] Materials for SOFC: decreasing the operating temperature, Izaak Vinke, **3rd General**, San Sebastian (Spain), 18/03/2014, Assembly, Oral Presentation

[128] In situ mapping of potential transients during start-up and shut-down of a polymer electrolyte membrane fuel cell, Edward Brightman, Gareth Hinds, **Fuel Cell Advances 2014**, 3rd – 4th April 2014, Amsterdam, Netherlands, Poster presentation

[129] Imaging and quantifying water in fuel cells with neutrons: latest methodological improvements, Johannes Biesdorf (PSI), **3rd European Technical School on Hydrogen and Fuel Cells**, 23-27.6.2014, Rethymnon, Greece, Oral Presentation, Access to slides to participants, Presentation of the methods available for transnational access

[130] H2FC Summer school, Züttel, Andreas, **H2FC Summer School**, Crete, 26/06/2014, Oral presentation

[131] Overview of engineering tools for Cyber Laboratory, James Keenan, Klaus Bittner, Manuelle Quinaud, **European Technical School on Hydrogen and Fuel Cells 2014**, 23 - 27 June 2014, Crete (Greece), Oral presentation

[132] Hands-on training of engineering tools for Cyber Laboratory, James Keenan, Klaus Bittner, Manuelle Quinaud, **European Technical School on Hydrogen and Fuel Cells 2014**, 23-27 June 2014, Crete (Greece), Oral presentation

[133] Hydrogen powered transport: safety issues and future safety strategies, Vladimir Molkov, **European Technical School on Hydrogen and Fuel Cells 2014,** 23-27 June 2014, Crete (Greece), Oral presentation

[134] Prediction of overpressure during vented deflagrations of localized mixtures, Dmitriy Makarov, **European Technical School on Hydrogen and Fuel Cells 2014**, 23 - 27 June 2014, Crete (Greece), Oral presentation

[135] Thermally coupled storage tank-fuel cell systems, A. Yiotis, G. Charalambopoulou, M. Kainourgiakis, A. Stubos, **3rd H2FC Technical School**, Heraklion, Crete –(Greece), 23 - 27 June, 2014, Oral presentation / Abstract

[136] Scientific methodology improvement from access results at University of Perugia. Experimental test of innovative sorbents based on calcium aluminates for SE-SR, Gabriele Discepoli, **3rd Technical School on Hydrogen and Fuel Cells 2014**, 22 - 28/6/2014, Agapi Beach Hotel, Crete (Greece), Oral presentation

[137] Transnational Access at KIT HyKa, Andreas Friedrich, **3rd Technical School on Hydrogen and Fuel Cells 2014**, 23 - 27 June 2014, Sentido Hotels, Rethymnon, Crete (Greece), Oral presentation

[138] Towards a more representative corrosion test method for metallic PEFC bipolar plates, Gareth Hinds, Edward Brightman, **3rd Technical School on Hydrogen and Fuel Cells 2014,** 23 – 27th June 2014, Aegean Pearl Hotel, Rethymnon, Crete (Greece), Oral presentation

[139] Improved high-power test rig facility, Izaak Vinke, Josef Mertens, **3nd H2FC Technical School**, Rethymnon (Greece), 23-27.06.2014, Oral presentation

[140] H2FC Summer school, Züttel, Andreas, H2FC Summer School, Crete, 26/06/2014, Oral presentation

[141] Water in fuel cells, Sandrine Lyonnard, **Water Conference,** 12 – 14th June 2014, Zaragoza, Spain, Invited Oral presentation

[142] Enabling low-cost fuel cell deployment, S.J. McPhail (ENEA), **3rd European Technical School on Hydrogen and Fuel Cells**, Crete, Greece, 25/06/2014, Oral presentation

[143] Testing SOFCs at high Current Densities, André Weber, Ellen Ivers-Tiffée, **11th European SOFC & SOE Forum**, European Fuel Cell Forum AG, Lucerne (Switzerland), 03.07.2014, Poster, 192- 201, No, just conference proceedings

[144] Measure of the hydride breathing while cyclically absorbing and desorbing hydrogen, A. Chaise, B. Salque, V. Iosub, O. Gillia, B. Charlas, C. Dupuis, L. Guenoux, **MH2014, 14th International Symposium on Metal-Hydrogen Systems: Fundamentals and applications (ThOH-139),** 20-25 July 2014, Salford, Manchester, United Kingdom, Oral presentation, ThOH-139

[145] Hydrogen Storage Properties of Pd-doped Thermally Oxidized Single Wall Carbon Nanohorns, Ch. Tampaxis, D. Giasafaki, G. Charalambopoulou, D. Mirabile Gattia, A. Montone, G. Barucca, Th. Steriotis, **14th International Symposium on metal-Hydrogen Systems**, Salford- Manchester (UK), 20 - 25 July 2014, Poster presentation / Abstract

[146] Hydrogen Storage Properties of Pd-doped Thermally Oxidized Single Wall Carbon Nanohorns, Ch. Tampaxis, D. Giasafaki, G. Charalambopoulou, D. Mirabile Gattia, A. Montone, G. Barucca, Th. Steriotis, **14th International Symposium on metal-Hydrogen Systems (MH 2014)**, Salford- Manchester (UK), 20 - 25 July 2014, Poster presentation / Abstract

[146] Hydrogen in Metals / Metalhydrides, Züttel, Andreas, Hydrogen in materials: Fundamentals and Applications, **University of Salford Summer school**, Manchester (UK), 17/07/2014, Oral presentation

[147] Hydrogen in materials: Fundamentals and Applications, Züttel, Andreas, Hydrogen in materials: Fundamentals and Applications, **University of Salford Summer school**, Manchester (UK), 17/07/2014, Oral presentation

[148] Raman and Infrared Spectroscopy Studies of Metal Hydrides, Borgschulte, Andreas, Hydrogen in materials: Fundamentals and Applications, **University of Salford Summer school**, Manchester (UK), 19/07/2014, Oral presentation

[149] Femtosecond Spectroscopy on Complex Hydrides, Borgschulte, Andreas, **14th International Symposium on Metal-Hydrogen Systems in Manchester**, Manchester, 20/07/2014, Oral presentation

[150] Spontaneous Dehydrogenation reactions, Callini, Elsa, Zilágyi, Petra; Paskevicius, Mark; Stadie, Nicholas; Rehault ,Julien ; Buckley, Craig; Jena, Puru; Ramirez-Cuesta, A.J.; Borgschulte, Andreas; Züttel, Andreas, **14th International Symposium on Metal-Hydrogen Systems in Manchester**, Manchester (UK), 20/07/2014, Oral presentation

[151] Alkaline Membrane Fuel cells and the Challenge of Water Management, Miles Page (Cellera Technologies Ltd.), Pierre Boillat (PSI), Shimshon Gottesfeld (Cellera Technologies Ltd.), **Fuel Cells Gordon Research Conference**, 5.8.2014, Smithfield, RI, USA, Oral presentation, Presentation of results from user project 2014

[152] Scientific and Organizing Committees, Iñaki Azkarate, **5th International Conference on Hydrogen Safety (5ICHS)**, 9 - 11th September 2014, ICHS, Brussels (Belgium)

[153] Structure and Transport in fuel cell membranes probed at microscopic scales, Sandrine Lyonnard, **Solid State Proton Conductors**, 14 – 19th September 2014, Seoul, Korea, Oral presentation: Plenary Lecture

[154] H2FC Plenty of opportunities!, Giovanni Cinti, **Dissemination meeting focused on access opportunities**, 20.09. 2014, University of Manchester (UK), Oral presentation, flyers, book of access

[155] Cost reduction strategies for quality assurance of hydrogen for fuel cell applications, Arul Murugan, Andrew Brown, **Hydrogen Fuel Cell Quality Assurance for PEM Fuel Cells**, 30th September 2014, European Commission, Brussels, Oral presentation

[156] H2FC Plenty of opportunities!, Giovanni Cinti, Dissemination meeting focused on access opportunities, Hosting of Mr. Milewski for discussing about access opportunities, September 2014, University of Perugia (Italy), Oral presentation

[157] Hydrogen storage capacity of different nanoporous carbon adsorbents, N. Kostoglou, C. Rebholz, V. Tzitzios, C. Tampaxis, T.A. Steriotis, K. Giannakopoulos, G.C. Charalambopoulou, K. Polychronopoulou, Y. Li, K. Liao, **30th Panhellenic Conference on Solid-State Physics and Materials Science**, Heraklion, Crete – Greece, 21 - 24 September, 2014, Oral Presentation / Abstract

[158] Opportunities for fuel cell modelling validation through the H2FC transnational access activities, Pierre Boillat (PSI), **10th World Conference on Neutron Radiography (WCNR-10)**, 8.10.2014, Grindelwald, Switzerland, Poster Presentation, Presentation of the H2FC project with a focus on the potential of transitional access in the frame of modelling validation studies.

[159] Instrumentation and research at PSI: Imaging of liquid water in operating polymer electrolyte fuel cells, Pierre Oberholzer (PSI), **1st European Technical School on Hydrogen and Fuel Cells**, 8.10.2014, Heraklion, Greece, Oral Presentation, Access to slides to participants, Presentation of the methods available for transnational access

[160] Accuracy and reproducibility of water quantification in fuel cells by neutron imaging, Pierre Boillat (PSI), Pierre Oberholzer (PSI), Johannes Biesdorf (PSI), **10th World Conference on Neutron Radiography (WCNR-10)**, 8.10.2014, Grindelwald, Switzerland, Expected 2016, Access to slides to participants / Paper to be published, Presentation of results from the work realized within WP8 (JRA 2.3.1), Oral Presentation

[161] Structure and Dynamics of Novel Energy Materials, Remhod, Arndt, **Colloquium, Deptartment of Chemistry, University Aarhus**, Aarhus, (Denmark), 23/10/2014, Oral Presentation

[162] Status of research activities on hydrogen production, storage and conversion in France – focus on durability and thermo-mechanics, Thierry Priem, Olivier Gillia, Sandrine Lyonnard, **Annual meeting of the French Laboratory Association on Hydrogen, fuel cells and systems,** 17-20 November 2014, Poitiers (France), Oral presentation: Plenary Lecture

[163] Synthesis, characterization and hydrogen storage capacity of nanoporous graphene-based adsorbents, N. Kostoglou, V. Tzitzios, Ch. Tampaxis, G. Charalambopoulou, Th. Steriotis, K. Giannakopoulos, A. Kontos, Y. Li, K. Liao, K. Polychronopoulou, C. Rebholz, **AVS 61st International Symposium & Exhibition**, Baltimore(USA), 9-14 November 2014, Poster presentation / Abstract

[164] Development of a Web-Based Performance Assessment Tool for H2 Storage in Clathrate Hydrates, A. Stubos, S.N. Karozis, N.I. Papadimitriou, G. Charalambopoulou, I.G. Economou, I.N. Tsimpanogiannis, **Euro-mediterranean Hydrogen Technologies Conference (EmHyTeC2014)**, Taormina(Italy), 9 - 12 December 2014, Oral presentation / Abstract

[165] Hydrogen storage in solids with the use of nanoporous carbon supports and scaffolds, Th. Stubos, A. Ampoumogli, D. Giasafaki, Ch. Tampaxis, G. Charalambopoulou, Th. Steriotis, **Euro-Mediterranean Hydrogen Technologies Conference - EmHyTeC2014**, Taormina, Italy, 9 - 12 December 2014, Plenary invited lecture / Abstract

[166] Development of a Web-Based Performance Assessment Tool for H2 Storage in Clathrate Hydrates, Th. Stubos, S.N. Karozis, N.I. Papadimitriou, G. Charalambopoulou, I.G. Economou, A.K. Stubos, I.N. Tsimpanogiannis, **Euro-Mediterranean Hydrogen Technologies Conference - EmHyTeC2014**, Taormina, Italy, 9-12 December 2014, Oral presentation / Abstract

[167] Fuel cell metrology – supporting the transition to a low carbon economy, Gareth Hinds, Edward Brightman, **CED Seminar**, 17th December 2014, University of Surrey, Guildford (United Kingdom), Oral presentation

Publications done 2015

[168] Quality assurance of hydrogen for fuel cell vehicles, Arul Murugan, **Hydrogen London**, 13th January 2015, London (UK), Oral presentation

[169] Towards Harmonization of Measurement Procedures of Solid State Hydrogen Storage Materials, Ulrich Ulmer, Marek Bieliewski, Pietro Moretto, Andreas Borgschulte, Christoph Frommen, Olivier Gillia, Georgia Charambopoulou, Magnus Sorby, Maximilian Fichtner, **9th Int. Symposium Hydrogen & Energy**, 25 – 30th January 2015, Emmetten, Switzerland, Oral presentation

[170] Neutron Imaging of Water in Fuel Cells: From Differential Cells to Stacks, Johannes Biesdorf (PSI), A. Iranzo, M. Page, P. Stahl, P. Boillat, **9th International Symposium Hydrogen and Energy**, 29.1.2015, Emmeten, Switzerland, Oral Presentation, Presentation of the outcome of transnational access at PSI

[171] International Status of Molten Carbonate Fuel Cell (MCFC) Technology, S.J. McPHAIL(ENEA), L. LETO(ENEA), M. DELLA PIETRA(ENEA), V. CIGOLOTTI(ENEA), A. MORENO (ENEA), **ENEA-International Energy Agency Dossier brochure**, ENEA, 2015, *http://www.enea.it/en/publications/enea-english-edition*

[172] Long-term tests in dual atmosphere of a novel Cr-free interconnect for SOFC applications, D. PUMIGLIA (ENEA), C. BOIGUES-MUÑOZ(ENEA), S.J. MCPHAIL(ENEA), F. POLONARA, M. CARLINI, S. FRANGINI(ENEA), M. FALCONIERI(ENEA), S. GAGLIARDI(ENEA), A. MASCI(ENEA), A. MALAKHOV, S. SOMOV, **6th Int. Conf. On Fundamentals and Developments in Fuel Cells**, Toulouse, France, 03/02/2015, POSTER

[173] In situ diagnostics for PEM fuel cells and electrolysers, Gareth Hinds, Edward Brightman, **FCH2 Conference**, 19th May 2015, Birmingham (UK), Oral presentation

[174] Corrosion of metallic bipolar plates for PEMFCs: towards a more representative test method, Gareth Hinds, Edward Brightman, **International Workshop on Bipolar Plates for PEM Technology**, 20th May 2015, Fronius GmbH, Sattledt (Austria), Oral presentation

[175] Experimental investigation of SO2 poisoning in a Molten Carbonate Fuel Cell operating in CCS configuration, Massimiliano Della Pietra(ENEA), Gabriele Discepoli (UPG), Stephen McPhail(ENEA), Linda Barelli

(UPG), Barbara Bosio, Ribes-Greus Amparo, **10th International and 5th Asian Molten Salts Chemistry and Technology Joint Symposium**, Shenyang, China, 10/06/2015, POSTER, Paper publication pending (International Journal of Hydrogen Energy)

[176] Open access Cyber-Laboratory tools for hydrogen safety engineering, James Keenan, **HyResponse (Grant Agreement No: 325348) steering group meeting no. 4,** 15th – 17th June 2015, HySAFER centre, Ulster University, Newtownabbey, N. Ireland, Oral presentation

[177] Neutron Imaging of water inside Fuel Cells: Outcome of transnational access at PSI, Johannes Biesdorf (PSI), M. Page, P. Shtal, T.J. Schmidt, P. Boillat, **4th H2FC Technical School**, 22-26.6.2015, Heraklion, Greece, Oral Presentation, Access to slides to participants, Presentation of the outcome of transnational access at PSI

[178] Characterization of key components in High-Temperature FC systems, S.J. McPhail (ENEA), A. Lucci(ENEA), M. Pasquali(ENEA), F. Santoni(ENEA), P. Gislon(ENEA), G. Monteleone(ENEA), D. Pumiglia(ENEA), M. Falconieri(ENEA), N. de Arespacochaga, H. Nabielek, T. Pfeifer, **4th European Technical School on Hydrogen and Fuel Cells**, Crete, Greece, 24/06/2015, Oral presentation

[179] From research to regulations: research on hydrogen and fuel cells at JRC, Pietro Moretto, B. Acosta, D. Baraldi, E. Weidner, D. Melideo, N. De Miguel, **4th Technical School on Hydrogen and Fuel Cells 2015**, 22 – 26th June 2015, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[180] R&D of high pressure hydrogen storage system with increased fire resistance rating, Andreas Friedrich, G. Stern, G. Necker, **3rd Technical School on Hydrogen and Fuel Cells 2014**, 22-26 June 2015, Aquis Arina Sand Hotel, Heraklion (Crete, Greece), Oral presentation, Progress in H2FC-Transnational Access-Projects 2038 and 2088

[181] Deflagration-to-Detonation Transition Modelling, Mohamed Sakr, Vladimir Molkov, Dmitriy Makarov, **4nd Technical School on Hydrogen and Fuel Cells 2015**, 22-26 June 2015, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[182] Overview of Cyber-Laboratory: Engineering tools and modelling, James Keenan, **4nd Technical School on Hydrogen and Fuel Cells 2015**, 22-26 June 2015, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[183] Interactive Demonstration: Cyber-Laboratory in action (Safety session), James Keenan, **4nd Technical School on Hydrogen and Fuel Cells 2015,** 22-26 June 2015, Arina Sands Hotel, Heraklion, Crete (Greece), Oral presentation

[184] R&D of high pressure hydrogen storage system with increased fire resistance rating, Andreas Friedrich, G. Stern, G. Necker, **3rd Technical School on Hydrogen and Fuel Cells 2014**, Aquis Arina Sand Hotel, Heraklion (Crete, Greece), 22-26 June 2015, Oral presentation, Progress in H2FC-Transnational Access-Projects 2038 and 2088

[185] Practical Problems of Hydrogen Release Simulations, S.G. Giannissi, **4th H2FC Technical School**, Heraklion, Crete – Greece, 22-26 June 2015, Oral presentation / Abstract

[186] Thermal Coupling of Fuel Cell – Hydrogen Storage Systems, A. Yiotis, **4th H2FC Technical School**, Heraklion, Crete – Greece, 22-26 June 2015, Oral presentation / Abstract

[187] Simulations for Sorbent – Based Hydrogen Storage, A. Gotzias, **4th H2FC Technical School**, Heraklion, Crete – Greece, 22-26 June 2015, Oral presentation / Abstract

[188] Clathrate Hydrates for Gas Storage and Transport Applications, I. Tsimpanogiannis, **4th H2FC Technical School,** Heraklion, Crete – Greece, 22-26 June 2015, Oral presentation / Abstract

[189] Neutron scattering investigations of novel hydrogen storage materials, Jiri Müller, Magnus H. Sørby, **4rd Technical School on Hydrogen and Fuel Cells 2015**, 22-26 June 2015, Heraklion, Crete (Greece), Oral presentation

[190] Fuel Cell Diagnostics through Neutron Imaging, Pierre Boillat (PSI), P. Oberholzer, J. Biesdorf, T.J. Schmidt, **ECS Conference on Electrochemical Energy Conversion and Storage**, 30.7.2015, Glasgow, Scottland, Oral Presentation, Presentation of neutron imaging of fuel cells inclunding some H2FC foreground

[191] Development of nanocomposite polymer electrolyte membranes for fuel cell applications using novel nanofillers, L. Boutsika, A. Enotiadis, I. Nicotera, C. Simari, G. Charalambopoulou, Th. A. Steriotis, **E-MRS Fall Meeting 2015**, Warsaw, Poland, 15-18 September 2015, Poster / Abstract

[192] An unprecedented heterobimetallic In(III)-Pd(II) porous metal-organic framework with soc topology for hydrogen storage, Ch. Tampaxis, I. Bratsos, I. Spanopoulos, N. Demitri, D. Vourloumis, G. Charalambopoulou, P. Trikalitis, Th. Steriotis, **E-MRS Fall Meeting 2015**, Warsaw, Poland, 15-18 September 2015, Poster / Abstract

[193] Facile synthesis of Mesocellular Carbon Foams for Li-Sulfur battery applications, L. Boutsika, A. Enotiadis, G. Charalambopoulou, Th. Steriotis, R. Sahore, E. Giannelis, **E-MRS Fall Meeting 2015**, Warsaw, Poland, 15-18 September 2015, Poster / Abstract

[194] Mg as energy storage material in H storage and electrochemical applications, Maximilian Fichtner, Zhirong Zhao-Karger, **Ê-MRS Fall Meeting Warsaw**, University of Warsaw, (Poland), 17th September 2015, Oral presentation

[195] Corrosion resistance of metallic PEMFC bipolar plates: towards a more representative test method, Gareth Hinds, Edward Brightman, **3rd International Workshop on Degradation Issues of Fuel Cells and Electrolysers,** 29th September – 1st October 2015, Santorini (Greece), Oral presentation

[196] Catalyst degradation in PEM fuel cells and electrolysers, Gareth Hinds, Edward Brightman, **3rd International Workshop on Degradation Issues of Fuel Cells and Electrolysers**, 29th September – 1st October 2015, Santorini (Greece), Oral presentation

[197] Recent development on hydrogen purity analysis, Thomas Bacquart, Arul Murugan, **Hydrogen Fuel Quality Assurance for PEM Fuel Cells - OEM Workshop**, 9th October, Brussels (Belgium), Oral presentation

[198] Non-monotonic overpressure vs. h2 concentration behavoiur during vented deflagration. experimental results, Martino Schiavetti, Marco Carcassi, **6th International Conference on Hydrogen Safety (6th ICHS)**, 19-21th October 2015, Yokohama (Japan), Oral presentation, Www.ichs2015.com

[199] Risk analysis of complex hydrogen infrastructures, F. Markert, A. Marangon,M . Carcassi, N.J. Duijm, **6th International Conference on Hydrogen Safety (6th ICHS)**, 19- 21th October 2015, Yokohama (Japan), Oral presentation, Www.ichs2015.com

[200] Removing the disrupting wind effect in single-vented enclosure exposed to external wind, S.G. Giannissi, I.C. Tolias, A.G. Venetsanos, **6th International Conference on Hydrogen Safety**, Yokohama, Japan, 19-21 October 2015, Oral presentation / Abstract

[201] Scientific and Organizing Committees, Iñaki Azkarate, **6th International Conference on Hydrogen Safety (6ICHS)**, 19-21th October 2015, ICHS, Yokohama (Japan)

[202] Detonation wave propagation in semi-confined layers of hydrogen-air and hydrogen-oxygen mixtures, Joachim Grune, K. Sempert, A. Friedrich, M. Kuznetsov, T. Jordan, **6th International Conference on Hydrogen Safety (ICHS 2015)**, 19-21 October 2015, Yokohama (Japan), Oral presentation

[203] Modelling and simulation of high-pressure hydrogen jets using H2FC European Cyber-Laboratory, James Keenan, Dmitriy Makarov, Vladimir Molkov, **ICHS 2015**, 19th – 21st October 2015, Yokohama, Japan, Oral presentation, Paper to be expanded to include deflagration model and submitted to IJHE

[204] The pressure peaking phenomenon: validation for unignited releases in laboratory-scale enclosure, Volodymyr Shentsov, Mike Kuznetsov, Vladimir Molkov, **ICHS 2015**, 19th – 21st October 2015, Yokohama, Japan, Oral presentation, Paper to be expanded and submitted to IJHE

[205] Venting deflagrations of local hydrogen-air mixture, Dmitriy Makarov, Philip Hooker, Michael Kuznetsov, et.al., **ICHS 2015**, 19th – 21st October 2015, Yokohama, Japan, Oral presentation

4.4 List of Scientific Publications (International Journals)

[206] Surface and bulk reactions in borohydrides and amides, A. Borgschulte, M. O. Jones, E. Callini, B. Probst, S. Kato, A. Züttel, W. David and S. Orimo, **Energy & Environmental Science,** Paper, **2012, 5,** RSC, http://dx.doi.org/10.1039/C2EE02975H, 23/03/2012, 6823-6832.

[207] Zr doped anatase supported reticulated ceramic foams for photocatalytic water purification, G. Plesch, M. Vargova, U.F. Vogt, M. Gorbar, K. Jesenak, **Materials Research Bulletin,** Paper, **47 ,** Elsevier, http://dx.doi.org/10.1016/j.materresbull.2012.03.057, 29/03/2012, **1680–1686**

[208] Electrochemical Characterization of Porous Diaphragms in Development for Gas Separation, J. Stojadinovic, D.Wiedenmann, M. Gorbar, F. La Mantia, L. Suarez, V. Zakaznova-Herzog, U. F. Vogt, B. Grobety, and A. Züttel, **ECS Electrochemistry Letters,** Paper, **1 (4) ,** ESC, http://dx.doi.org/10.1039/C2EE02975H , 23/03/2012, **F25-F28**

[209] Simultaneous neutron imaging of six operating PEFCs: Experimental set-up and study of the MPL effect, Pierre Oberholzer, PSI, Et al., **Electrochemistry Communications**, Paper, Vol.20, Elsevier, 01.07.2012, 67-70, Work done at the installation open to acces, but not with H2FC budget (neither within an access project nor within a JRA)

[210] Experimental study of hydrogen releases in the passenger compartment of a Piaggio Porter, Martino Schiavetti, Marco Carcassi, **International Journal of Hydrogen Energy,** Paper, Vol.37 Issue 22, Elsevier, 01.11.2012, 17470-17477, Publication is related but not referred to H2FC project

[211] Evaluation of notional nozzle approaches for CFD simulations of free-shear under-expanded hydrogen jets, Daniele Baraldi, (JRC, Petten), Et al., **International Journal of Hydrogen Energy,** Paper, Vol.37, Elsevier, 01.12.2012, 17240-17245, Publication is related but not referred to H2FC project

[212] Flammability limits and laminar flame speed of hydrogen–air mixtures at sub-atmospheric pressures, Mike Kuznetsov, (KIT), Et al., **International Journal of Hydrogen Energy,** Paper, Vol.37, Elsevier, 30.06.2012, 17580-17588, Publication is related but not referred to H2FC project

[213] Reversible hydrogen absorption in sodium intercalated fullerenes, Ph. Mauron, A. Remhof, A. Bliersbach, A. Borgschulte, A. Züttel, D. Shwptyakov, M. Gaboardi, M. Choucair, D. Pontiroli, M. Aramini, A. Gorreri, M. Riccò, **International Journal of Hydrogen Energy,** Paper, **37, 14307 (2012),** Elsevier, http://dx.doi.org/10.1016/j.ihydene.2012.07.045, 28/07/2012

[214] Impact of Water on PEFC Performance Evaluated by Neutron Imaging Combined with Pulsed Helox Operation, Pierre Boillat, PSI, Et al., **Journal of the Electrochemical Society**, Paper, Vol.159, Electrochemical Society, 01.01.2012, F210-218, Work done at the installation open to access, but not with H2FC budget (neither within an access project nor within a JRA)

[215] Safety assessment of unignited hydrogen discharge from onboard storage in garages with low levels of natural ventilation, Sile Brennan UU, Et al., I**nternational Journal of Hydrogen Energy,** Paper, Elsevier Limited, 01.06.2012, 8159-8166, Publication is related but not referred to H2FC project, (FCH JU/Private)

[216] Diborane release and structure distortion in borohydrides, Elsa Callini, A. Borgschulte, A. J. Ramirez-Cuesta and A. Züttel, **Dalton Transaction,** Paper, **2013, 42, 719,** RSC, http://dx.doi.org/10.1039/C2DT31608K, 29/09/2012

[217] High resolution neutron imaging for pulsed and constant load operation of passive self-breathing polymer electrolyte fuel cells, Matthias Weiland, TU Berlin, Et al., Electrochimica Acta, Paper, Vol.87, Elsevier, 01.10.2012, 567-574, Work done at the installation open to acces, but not with H2FC budget (neither within an access project nor within a JRA)

[218] Influence of gas compression on flame acceleration in the early stage of burning in tubes, Mike Kuznetsov, (KIT), Combustion and Flame, Paper, Vol.160, Elsevier, 01.10.2012, 97-111, Publication is related but not referred to H2FC project

[219] Parameterization of Laminar Burning Velocity Dependence on Pressure and Temperature Inhydrogen-Air-Steam Mixtures, Tobias Szabó, (KIT), **Combustion Science and Technology**, Paper, Vol.184, Taylor & Francis, 01.10.2012, 1427-1444, Publication is related but not referred to H2FC project

[220] Preparation, scale-up and testing of nanoscale, doped amide systems for hydrogen storage, U. Ulmer, J.J. Hu, M. Franzreb and M. Fichtner, **Int. J. Hydrogen Energy**, Paper, **38 (2013),** Elsevier, doi:10.1016/j.ijhydene.2012.10.115, 01/12/2012, **1439–1449**

[221] Critical conditions of hydrogen–air detonation in partially confined geometry, Mike Kuznetsov, (KIT), Et al., Proceedings of the Combustion Institute, Paper, Vol.34, Elsevier, 01.01.2013, 1965-1972, Publication is related but not referred to H2FC project

[222] Towards hydrogen safety engineering for reacting and non-reacting hydrogen releases, Jean-Bernard Saffers UU, Et al., Journal of Loss Prevention in the Process Industries, Paper, Elsevier Limited, 01.03.2013, 344-350

[223] Investigation of hydride powder bed swelling and shrinking during hydrogen absorption/desorption cycles under different compressive stresses, Benoit Charlas, Albin Chaise, Olivier Gillia, Pierre Doremus, Didier Imabaut, **Journal of Alloys and Compounds**, Paper, Elsevier, http://dx.doi.org/10.1016/j.jallcom.2013.01.192, 15/02/2013,in press

[224] Etude du comportement mécanique d'un hydrure intermétallique utilisé pour le stockage d'hydrogène, Benoit CHARLAS, **PhD dissertation**, Paper/ Dissertation, Université de Grenoble, 14.03. 2013, pp. 85-87, at disposal at university library

[225] Diagnosis methodology and technique for Solid Oxide Fuel Cells: a review, Linda Barelli, E. Barluzzi, G. Bidini, **International Journal of Hydrogen Energy**, Paper, 38/12 (2013), Elsevier, http://dx.doi.org/10.1016/j.ijhydene.2013.02.024, 12/04/2013, 5060-5074

[226] Innovative sorbents for SE-SR: Test bench and Procedure, L. Barelli, G. Bidini, A. Di Michele, F. Gallorini, C. Petrillo, F. Sacchetti, Poster, **European Fuel Cell Technology & Applications Conference** - Piero Lunghi, December 2013, Rome, Italy, ISBN 978-88-8286-297-8

[227] Thermal transients modeling of a reformer unit for diagnostic analysis of SOFC-based systems, L. Barelli, G. Cinti, U. Desideri, A. Ottaviano, European Fuel Cell Technology & Applications Conference - Piero Lunghi, December 2013, Rome, Italy, Oral, ISBN 978-88-8286-297-8

[228] Hydrogen jet flames, Vladimir Molkov UU, Et al., **International Journal of Hydrogen Energy**, Paper, Elsevier Limited, 01.06.2013, 8141-8158, Publication is related but not referred to H2FC project, (FCH JU/Private)

[229] Characterizing Local O-2 Diffusive Losses in GDLs of PEFCs Using Simplified Flow Field Patterns ("2D","1D","0D"), Pierre Oberholzer, PSI, Et al., **Journal of the Electrochemical Society**, Paper, Vol.160, Electrochemical Society, 01.01.2013, F659-669, Work done at the installation open to access, but not with H2FC budget (neither within an access project nor within a JRA)

[230] Pressure limit of hydrogen spontaneous ignition in a T-shaped channel, Maxim Bragin UU, Et al., **International Journal of Hydrogen Energy**, Paper, Elsevier Limited, 01.06.2013, 8039-8052

[231] Plane hydrogen jets, Dmitriy Makarov UU, Et al., **International Journal of Hydrogen Energy**, Paper, Elsevier Limited, 01.06.2013, 8068-8083

[232] The acoustic–parametric instability for hydrogen–air mixtures, Jorge Yáñez, (KIT), Et al., **Combustion and Flame,** Paper, Vol.160, Elsevier, 31.05.2013, 2009-2016, Publication is related but not referred to H2FC project

[233] In Situ Diffusimetry of Porous Media in Polymer Electrolyte Fuel Cells Using Transient H-2 Labeling and Neutron Imaging, Pierre Oberholzer, PSI, Et al., Journal of Physical Chemistry C, Paper, Vol.117, ACS Publications, 03.10.2013, 19945-19954, Work done at the installation open to acces, but not with H2FC budget (neither within an access project nor within a JRA)

[234] Origin of the large anharmonicity in the phonon modes of LiBH4, R. Gremaud (ref. EMPA), Et al., **Chemical Physics**, Paper, CP427, Elsevier, Available online 22 October 2013, 01.12.2013, 22-29

[235] Distinction of Liquid Water and Ice Based on Dual Spectrum Neutron Imaging, Johannes Biesdorf, PSI, Et al., **ECS Transactions**, Paper, Vol. 58, Electrochemical Society, 31.08. 2013, 309-314, Work done at the installation open to access, but not with H2FC budget (neither within an access project nor within a JRA)

[236] Experimental investigation of fast flame propagation in stratified hydrogen–air mixtures in semi-confined flat layers, Joachim Grune, (ProScience), Et al., Journal of Loss Prevention in the Process Industries, Paper, Vol.26, Elsevier, 01.10.2013, 1442-1451, Publication is related but not referred to H2FC project

[237] Fuel-cell (hydrogen) electric hybrid vehicles, Bruno G. Pollet, Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance, **Book (chapter 22)**, Chapter 22, Woodhead Publishing Limited, ISBN: 978-0-85709-522-0, March 2013, 685-735, Publication is related but not referred to H2FC project

[238] Local Characterization of PEFCs by Differential Cells: Systematic Variations of Current and Asymmetric Relative Humidity, Pierre Oberholzer, Et al., **Journal of the Electrochemical Society**, Paper, Vol.161, Electrochemical Society, 04.12.2013, Vol. 161, Pages F139-152, Work done at the installation open to access, but not with H2FC budget (neither within an access project nor within a JRA)

[239] Water management in proton exchange membrane fuel cell at sub-zero temperatures: an in operando SANS-EIS study, Arnaud Morin (CEA), Et al., **Solid State Ionics**, Paper, Vol.252, Elsevier, 01.12.2013, F139-152, The project has been acknowledged for partial support

[240] Advancing the analysis of impurities in hydrogen by use of a novel tracer enrichment method, Arul Murugan, Andrew S. Brown, **Analytical Methods**, Journal paper,Vol. 6, RSC, **06/03/2014**, 5472-5482

[241] Hydrogen safety engineering framework and elementary design safety tools, Jean-Bernard Saffers UU, **International Journal of Hydrogen Energy**, Paper, Elsevier Limited, 01.04.2014, 6268-6285, Publication is related but not referred to H2FC project

[242] Effect of fuel utilization on the carbon monoxide poisoning dynamics of Polymer Electrolyte Membrane Fuel Cells, Luis Pérez, **Journal of Power Sources**, Paper, Vol.258, Elsevier Limited, 01.07.2014, 122–128, Publication is related but not referred to H2FC project

[243] Experimental study of ignited unsteady hydrogen releases from a high pressure reservoir, Joachim Grune, (ProScience), **International Journal of Hydrogen Energy**, Paper, Vol.39, Elsevier, 01.04.2014, 6176-6183, Publication is related but not referred to H2FC project

[244] Concentration measurements in a round hydrogen jet using Background Oriented Schlieren (BOS) technique, Mike Kuznetsov, (KIT), **International Journal of Hydrogen Energy**, Paper, Vol.39, Elsevier, 01.04.2014, 6201-6209, Publication is related but not referred to H2FC project

[245] Rayleigh–Taylor instability: Modelling and effect on coherent deflagrations, James.J. Keenan, **International Journal of Hydrogen Energy**, Paper, Vol.39/issue 35, Elsevier Limited, 25.04.2014, 20467-20473, Publication is related but not referred to H2FC project

[246] SOFC thermal transients: modelling by application of experimental system identification techniques, Linda Barelli, G. Cinti, U. Desideri, A. Ottaviano, **Fuel Cells**, Paper, 2014, 14 (1), Wiley-Blackwell, http://dx.doi.org/10.1002/fuce.201300164, 01.02.2014, 107-122

[247] Advancing the analysis of impurities in hydrogen by use of a novel tracer enrichment method, Arul Murugan, Andrew Brown, **Analytical Methods**, Journal paper, Vol. 6, Royal Society of Chemistry, 01/01/2014, 5472-5482, Selected as a 'Hot Article' by RSC

[248] Probing hydrogen spillover in Pd@MIL-101(Cr) with a focus on hydrogen chemisorption†, , P. A´. Szilagyi (ref. EMPA), Et al., **Physical Chemistry Chemical Physics (PCCP)**, Paper, Vol.16 (12), Royal Society of Chemistry, DOI: 10.1039/c3cp54898h, 01.01.2014, 5803-5809

[249] Passive ventilation of a sustained gaseous release in an enclosure with one vent, Vladimir Molkov, et al., **International Journal of Hydrogen Energy,** Paper, Vol.39 Issue 15, Elsevier Limited, 01.05.2014, 8158-8168, Publication is related but not referred to H2FC project (FCH JU/Private)

[250] In situ mapping of potential transients during start-up and shut-down of a polymer electrolyte membrane fuel cell, Edward Brightman, Gareth Hinds, **Journal of Power Sources**, Journal paper, Vol. 267, Elsevier, 01/12/2014, 160-170

[251] Gas−Solid Reaction of Carbon Dioxide with Alanates, Cedric L. Hugelshofer, et al., **Journal of Physical Chemistry**, Paper, Vol. 118 (29), ASC, 29.06.2014, 15940-15945, **DOI:** 10.1021/jp505323j, Budget H2FC/ Private

[252] Hydrogen non-premixed combustion in enclosure with one vent and sustained release: Numerical experiments, Vladimir Molkov UU, **International Journal of Hydrogen Energy**, Paper, Elsevier Limited, 01.07.2014, 10788-10801, Publication is related but not referred to H2FC project

[253] Numerical and physical requirements to simulation of gas release and dispersion in an enclosure with one vent, Vladimir Molkov UU, **International Journal of Hydrogen Energy**, Paper, Elsevier Limited, 01.08.2014, 13328-13345, Publication is related but not referred to H2FC project

[254] Synthesis and test of innovative sorbents based on calcium aluminates for SE-SR, Linda Barelli, Et all., Applied Energy, Paper, Vol.127, Elsevier, doi:10.1016/j.apenergy.2014.04.034, 01.08.2014, 81-92

[255] Dehydrogenation studies of the bimetallic borohydrides, Marina Chong, et all, RSC Advances, Paper, Vol.4, Royal Society of Chemistry, 101.01.2014, 63933-63940, **DOI:** 10.1039/C4RA10352A, Budget H2FC/Private

[256] Towards more representative test methods for corrosion resistance of PEMFC metallic bipolar plates, Gareth Hinds, Edward Brightman, **International Journal of Hydrogen Energy**, Journal paper, Elsevier, **In press**

[257] CFD modelling of hydrogen dispersion under cryogenic release conditions, S.G. Giannissi, A.G. Venetsanos, N. Markatos, J.G Bartzis, **International Journal of Hydrogen Energy**, Paper, Vol.39, Elsevier, 01.09.2014, 15851–15863

[258] Effect of oxygen on the microstructure and hydrogen storage properties of V–Ti–Cr–Fe quaternary solid solutions, U. Ulmer, K. Asano, Th. Bergfeldt, V.S.K. Chakravadhanula, R. Dittmeyer, H. Enoki, Ch. Kübel, Y. Nakamura and M. Fichtner, **Int. J. Hydrogen Energy**, Paper, **39,35 (2014),** Elsevier, doi:10.1016/j.ijhydene.2014.08.152, 22/10/2014, **20000–20008**

[259] Validation of a three dimensional PEM fuel cell CFD model using local liquid water distributions measured with neutron imaging, Alfredo Iranzo (AICIA), Pierre Boillat (PSI), Felipe Rosa (Universidad Sevilla), **International Journal of Hydrogen Energy (IJHE)**, Paper, Vol.39, Elsevier, http://dx.doi.org/10.1016/j.ijhydene.2014.02.115, 01.04.2014, 7089-7099, Results of user project 2008

[260] Experimental investigation of flame and pressure dynamics after spontaneous ignition in tube geometry, Joachim Grune, (ProScience), **International Journal of Hydrogen Energy**, Paper, Vol.39, Elsevier, 01.12.2014, 20396-20403, Publication is related but not referred to H2FC project

[261] CFD benchmark on hydrogen release and dispersion in a ventilated enclosure: passive ventilation and the role of an external wind, S. G. Giannissi, J. Hoyes, B. Chernyavskiy, P. Hooker, J. Hall, A.G. Venetsanos, V. Molkov, **International Journal of Hydrogen Energy**, Paper, Elsevier, **Under review (2014)**

[262] Layer by layer segmentation of water distribution from neutron imaging of large scale cells, Pierre Boillat (PSI), Alfredo Iranzo (AICIA), Johannes Biesdorf (PSI), **Journal of the Electrochemical Society**, Paper, The Electrochemical Society, **Submitted for publication**, Method development applied in the frame of user project no. 2008, Medium-scale experiments on vented hydrogen deflagration, Mike Kuznetsov, (KIT), Journal of Loss Prevention in the Process Industries, Paper, Elsevier, **Submited 2014,** Publication is related but not referred to H2FC project

[263] Hydrogen Storage Properties of Pd-doped Thermally Oxidized Single Wall Carbon Nanohorns, G. Charalambopoulou, D. Giasafaki, Ch. Tampaxis, D. Mirabile Gattia, A. Montone, G. Barucca, Th. Steriotis, **Journal of Alloys and Compounds**, Paper, Elsevier, **In press (2014)**

[264] Degradation behavior of a commercial 13Cr ferritic stainless steel (SS405) exposed to an ambient air atmosphere for IT-SOFC interconnect applications, S. FRANGINI (ENEA), A. MASCI(ENEA), S.J. McPHAIL(ENEA), F. ZAZA(ENEA), **Materials Chemistry and Physics**, paper, Vol. 144 (3), 2014, pp. 491-497

[265] Hydrogen–methane mixtures: Dispersion and stratification studies, A. Marangon, M. carcassi, **International Journal of Hydrogen Energy**, Paper, Vol.39, Elsevier, 01.12.2014, 6160-6168, Publication is related but not referred to H2FC project

[266] Experimental study of vented hydrogen deflagration with ignition inside and outside the vented volume, M. Schiavetti, M. Carcassi, A. Marangon, **International Journal of Hydrogen Energy**, Paper, Vol.39, Elsevier, 01.12.2014, 20455-20461, Publication is related but not referred to H2FC project

[267] Towards more representative test methods for corrosion resistance of PEMFC metallic bipolar plates, Gareth Hinds, Edward Brightman, **International Journal of Hydrogen Energy**, Journal paper, Vol. 40, Elsevier, **12/01/2015,** 2785-2791

[268] Hydrogen–air deflagrations: Vent sizing correlation for low-strength equipment and buildings, Vladimir Molkov, Maxim Bragin, **International Journal of Hydrogen Energy**, Paper, Elsevier, 12 Jan 2015, **1256-1266**

[269] Layer by layer segmentation of water distribution from neutron imaging of large scale cells, Pierre Boillat (PSI), Alfredo Iranzo (AICIA), Johannes Biesdorf (PSI), **Journal of the Electrochemical Society**, Paper, , The Electrochemical Society, 05/03/2015, F531-F536, Method development applied in the frame of user project no. 2008

[270] Review of purity analysis methods for performing quality assurance of fuel cell hydrogen, Arul Murugan, Andrew S. Brown, **International Journal of Hydrogen Energy**, Journal paper, Vol. 40, Elsevier, **22/03/2015**, 4219–4233

[271] Water Distribution Analysis in the Outer Perimeter Region of Technical PEFC based on Neutron Radiography, Peter Stahl (ElringKlinger AG), Johannes Biesdorf (PSI), Pierre Boillat (PSI), Jürgen Kraft (ElringKlinger AG), Andreas Friedrich (DLR), **Journal of the Electrochemical Society**, Paper, The Electrochemical Society, 03/04/2015, F677-F685, Results of user project 2015

[272] Cost reduction possibilities of vanadium-based solid solutions – Microstructural, thermodynamic, cyclic and environmental effects of ferrovanadium substitution, U. Ulmer, K. Asano, A. Patyk, H. Enoki, Y. Nakamura, A. Pohl, R. Dittmeyer, and M. Fichtner, **J. Alloys and Compounds**, Paper, **648 (2015),** Elsevier, doi:10.1016/j.jallcom.2015.07.110, 15/07/2015, **1024-1030**

[273] Electrochemical characterisation of large area anode supported Ni-YSZ/YSZ/YDC/LSCF solid oxide fuel cell, Thomas Malkow, N Kotsionopoulos, G De Marco, V Sdrallis, G Tsotridis, I C Vinke & J Mertens, **12th International Conference on Materials Chemistry (MC12)**, Poster presentation, 20-23 July 2015, York, UK

[274] When Size Matters: Active Area Dependence of PEFC Cold Start Capability, Johannes Biesdorf (PSI), Peter Stahl (ElringKlinger), Muriel Siegwart (PSI(, Thomas J. Schmidt (PSI), Pierre Boillat (PSI), **Journal of the Electrochemical Society**, Paper, The Electrochemical Society, 10/08/2015, F1232-F1235**,** Experimental work done with private funding, data used as high quality validation dataset for WP10

[275] Impact of hydrophobic coating on mass transport losses in PEFCs, Johannes Biesdorf (PSI), Antoni Forner Cuenca (PSI), Thomas J. Schmidt (PSI), Pierre Boillat (PSI), **Journal of the Electrochemical Society**, Paper, The Electrochemical Society, 12/08/2015, F1243-F1252, Experimental work done with private funding, data used as high quality validation dataset for WP10, **New device could aid design and development of next-gen FCVs, says NPL,** Arul Murugan, AW Automotive World, September 30, 2015, http://www.automotiveworld.com/analysis/new-device-aid-design-development-next-gen-fcvs-says-npl/The Hydrogen Impurity Enrichment Device which was developed in the H2FC project into automotive magazines

[276] **NPL development to speed up introduction of hydrogen cars, Improved detection of impurities in fuel,** Arul Murugan, Automotive Engineer, September 16, 2015, http://ae-plus.com/technology/npl-development-to-speed-up-introduction-of-hydrogen-cars, The Hydrogen Impurity Enrichment Device which was developed in the H2FC project into automotive magazines

[277] Hydrogen Storage Properties of Pd-doped Thermally Oxidized Single Wall Carbon Nanohorns, G. Charalambopoulou, D. Giasafaki, Ch. Tampaxis, D. Mirabile Gattia, A. Montone, G. Barucca, Th. Steriotis, **Journal of Alloys and Compounds**, Paper, Elsevier, **5/10/2015**, Volume 645, pages S485-S489

5 Project Website and Relevant Contact Details

5.1 Project Website

Project website: http://www.h2fc.eu/

5.2 Relevant Contact Details

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