ACHIEVEMENTS OF THE EC NETWORK OF EXCELLENCE HYSAFE

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1. Introduction

Still coined by the national schemes of old European policies also the European research suffered in many relevant areas from a high degree of fragmentation. For instance research activities in the field of hydrogen safety in Europe mainly originated from three areas: there were safety investigations for natural gas applications and studies of the automotive industries planning to introduce hydrogen driven fuel cells into the market. On the other hand, in the field of nuclear technology, hydrogen is a safety issue in severe accident and operational research since more than 20 years. Of course the related research topics had different weights on national agendas and associated knowledge was dispersed, not compiled and partially even confidential.

To overcome this fragmentation, to support the needed integration and to focus related efforts the European Commission created a new instrument, the so-called Networks of Excellence (NoE).

To facilitate the safe introduction of hydrogen as an energy carrier and to remove any safety related obstacle on this way the NoE HySafe – Safety of Hydrogen as an Energy Carrier - was initiated and supported by the European Commission (EC).

There was a need to identify the partners' best expertise, potentially overlapping activities but also possible gaps. Furthermore, in order to achieve a high standard in the quality of available relevant data, the know-how transfer between the partners needed to be enforced. The exchange of expertise and know-how between the partners is one of the keys to provide high quality and highly efficient experimental and theoretical research work.

The objectives of the NoE HySafe were to

1. strengthen, focus and integrate the fragmented research on hydrogen safety,
2. form a self-sustained competitive scientific and industrial community,
3. promote public awareness and trust in hydrogen technologies and
4. develop an excellent safety culture.

The network, coordinated by the Forschungszentrum Karlsruhe, has been constituted with 24 partners from 12 European countries including Russia and one partner from Canada. There are 12 partners from public research institutions, 7 industry partners, 5 universities and one governmental authority. Details are given

More than 120 scientists from these institutions have been nominated to contribute to the network. This number was the basis for the determination of the maximum EC grant, which is 7 Mio Euro for 5 years. The total budget is approximately 13 Mio Euro for the same period.

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[2] Approximately 120 researchers from the 25 institutions in Table 1 and the HySafe Advisory Council

The network activities formally started on March 1st, 2004. The NoE follow-up, the International Association for Hydrogen Safety HySafe (IA), has been founded by a huge majority of the NoE consortium February 26th, 2009, in Brussels, Belgium. This non-profit association will continue the integration work and will maintain the network's successful activities like the conference, the website and databases, the handbooks etc.

Figure 1. The NoE HySafe logo

All network activities - 15 work packages and 3 internal projects - were arranged in four activity clusters. In line with the main objectives these clusters were the following: "Basic Research", "Risk Management", "Dissemination" and "Management". The allocation of the activities in the clusters is depicted in the figure 1 below.

Name of Institution	*Abbrev.*	*Country*
Forschungszentrum Karlsruhe GmbH	**FZK**	**DE**
L'Air Liquide	**AL**	**FR**
Federal Institute for Materials Research and Testing	**BAM**	**DE**
BMW Forschung und Technik GmbH	BMW	DE
Building Research Establishment Ltd	BRE	UK
Commissariat à l'Energie Atomique	**CEA**	**FR**
Det Norske Veritas AS	**DNV**	**NO**
Fraunhofer-Gesellschaft ICT	**Fh-ICT**	**DE**
Forschungszentrum Jülich GmbH	**FZJ**	**DE**
GexCon AS	**GexCon**	**NO**
The United Kingdom's Health and Safety Laboratory	**HSE/HSL**	**UK**
Foundation INASMET	**INASMET**	**ES**
Inst. Nat. de l'Environnement industriel et des RISques	**INERIS**	**FR**
European Commission - JRC - Institute for Energy	JRC	NL
National Center for Scientific Research Demokritos	**NCSRD**	**EL**
Norsk Hydro ASA	**SH**	**NO**
DTU/Risø National Laboratory	**DTU/Risø**	**DK**
TNO	TNO	NL
University of Calgary	**UC**	**CA**
University of Pisa	**UNIPI**	**IT**
Universidad Politécnica de Madrid	**UPM**	**ES**
University of Ulster	**UU**	**UK**
VOLVO Technology Corporation	**Volvo**	**SE**
Warsaw University of Technology	**WUT**	**PL**
Russian Research Centre Kurchatov Institute	**KI**	**RUS**

Table 1. NoE HySafe members (bold= IA founding member, status 02/2009)

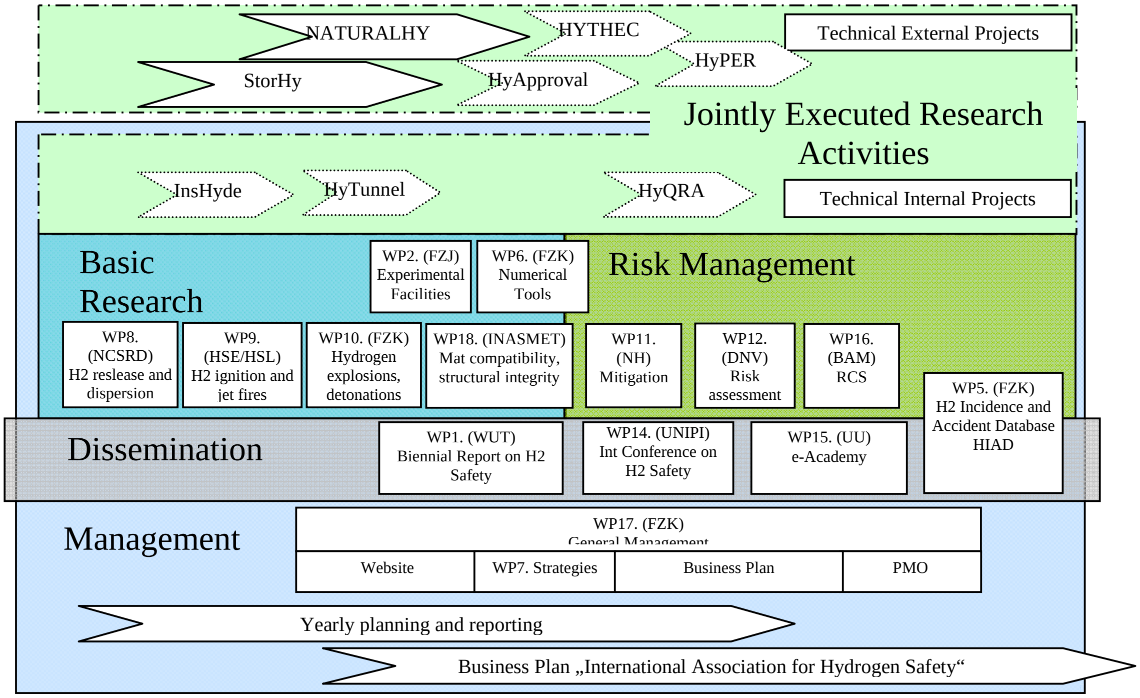

Figure 2: HySafe Activity Clusters

2. Results of Cluster "Basic Research"

The Cluster "Basic Research" consisted of the phenomena orientated work packages for hydrogen distribution, ignition and fires, explosions and material compatibilities. Additionally the two work packages integrating the hardware and software research tools ad the internal projects InsHyde and HyTunnel were accommodated in this cluster.

Integration of the Experimental Facilities

In the first period of the project, a compilation of the experimental facilities [1,2] was provided to serve as a starting point for further activities. The final version of the IEF documentation [7] including the updated IEF documents [2,4,5] contains a total of 109 technical descriptions of HySafe facilities operated by 15 partners. A web presentation [3] of all facilities is available through the HySafe website.

In order to ensure a common quality standard, a series of biannual workshops was initiated related to measurement techniques and experimental work. The general aim of the IEF workshops is to become acquainted with the partners' activities, to share knowledge in the field of experimental work and to support jointly planned and performed experiments. A total of 8 well received workshops have been organised covering topics from measurement technologies to safety issues. Based on the information presented by the partners, a working document on best practice [6] including the joint experimental knowledge of all partners with regard to experiments and instrumentation was created. Preserving the character of a working document, it was implemented in the IEF wiki page, which was set up in order to provide a communication platform. The series of workshops supports the wiki-based working document on best practice intended to be a guide for experimental work in the field of hydrogen safety.

Numerical Tools

A series of single effect tests was identified to allow for model verification and a large collection of Standard Benchmark Exercises Problems (SBEPs) was compiled, where the focus lied on the use of hydrogen in industry relevant scales. In these more than 20 validation tests the physical and numerical adequacy of the models used in CFD simulations was identified. The main phenomena addressed in these exercises were turbulent transport in particular in buoyant flows, hydrogen releases with small to strong inertial effects, effective flame velocities, transitional combustion phenomena etc.
The participation in these SBEPs, quantified by the number of participants and codes was comparatively large, e.g. 12 partners with 10 different 3D CFD codes and one analytical 0D solver in SBEPV3.

The results of the SBEP exercises were compared and published regularly, in particular using the own conference ICHS.

The capabilities of this strong group was offered and in quite a few cases applied in external projects, e.g. HyApproval, HyPer etc.

Phenomena Orientated Work Packages (WP8 Mixing, WP9 Ignition and Fire, WP10 Explosion, WP18 Material Compatibilities)

The actual work of these expert groups was to collect, review and compile existing know-how in the related areas. Thus knowledge gaps were identified as a by-product. This collected know-how was mainly used in the internal projects InsHyde and HyTunnel but also applied in the other activities. A good example is the survey on ignition, deliverable D42 of WP9 which was used in the risk assessment work package as a basis for recommendations regarding selecting ignition models (deliverable D71 provided by WP12 and WP9 commonly). The work package WP18 compiled information regarding high pressure high purity material compatibility in deliverable D108 and regarding test procedures for nano-scaled storage materials in deliverable D112.

Internal Project “InsHyde”

In the first year of the NoE HySafe the “safety vote” defining the phenomena identification and ranking table (PIRT) and an additional expert survey have pointed out that releases - even slow releases, with “small” release rates - of hydrogen in confined or partially confined geometries represent a serious risk, since combustible mixtures may form, which, if ignited, could lead to explosions and even to detonations. Thus, it revealed necessary to study different configurations of these non-catastrophic releases (position, release rate) and the accompanying sensor equipment and mitigation devices (ventilation or other ways of enhancing mixing, inertisation, active ignition or recombination). The InsHyde program has been initiated during in the 2nd year of the NoE and consisted of a broad experimental and computer simulation program.

Theoretical studies, literature surveys, sensor evaluations, a broad experimental program covering releases, mixing and combustion experiments and associated computer simulations helped to derive recommendations for the indoor usage of hydrogen summarised in the public deliverable D113. This key document gives recommendations deduced from many contributions listed in the literature section [1]-[16].

There is an obvious link between confined environment and settings like residential garages or repair shops, where one has to prove that several kilograms of hydrogen can be stored safely. Here one has to account for imperfections either on the side of the vehicle or on the building itself. Therefore an application of the results of InsHyde to these scenarios was proposed in the HyGarage proposal.

Besides the InsHyde results already proved to be a valuable knowledge basis for other related projects like HyPer, where a handbook for the safe installation of small stationary hydrogen driven devices has been developed.

Internal project "HyTunnel"

The current tunnel regulations and standards identified relevant requirements and current practices in respect to the management of hazards and emergencies in the event of a fire were studied. Of particular relevance in Europe was the recently published EU Directive on minimum safety levels now required in the main road tunnels on the trans-European Road Network (*Directive 2004/54/EC)*.
A review of modelling activity from the published literature related to hazard and risk assessment due to fires in tunnels was undertaken, particularly focusing on

- Hydrogen dispersion modelling studies in tunnel environment,
- Fire and explosion modelling studies, and
- Hydrogen release experiments relevant to tunnels.

This review included recent publications and international conferences including the HySafe conference ICHS organised 2005 in Pisa, Italy, and 2007 in San Sebastian, Spain.

Overall, the interaction of the ventilation system, tunnel geometry and hydrogen release is complicated, and recourse to numerical modelling is required. Some of the positive and negative effects that ventilation inside a tunnel may have in respect to a release of hydrogen gas or on the smoke and heat from a fire (not necessarily a H_2 vehicle) can be summarised as follows:

- ✓ The supply of air may dilute the hydrogen such that it is below the flammability limit.
- ✓ The dispersed hydrogen may be transported safely out of the tunnel through either a portal or via en exhaust ventilation duct or shaft.
- ✓ The ventilation system may break down a stratified layer of flammable hydrogen gas mixture such that the resultant fully mixed gas is below the flammable limit.
- ✗ The released hydrogen may be transported such that the cloud of flammable gas mixture is extended well away from the point of release, either within the traffic space or along ventilation ducts or shafts.
- ✗ Hot smoke gases from a fire may get transported to neighbouring H_2 vehicles, exposing them to thermal hazard.
- ✗ Strong mechanical ventilation may create turbulence within the tunnel sufficient to affect the combustion regime (of hydrogen in particular) if ignition occurs.

The research of this work has led to some interesting findings. For example, some findings of the dispersion study are as follows:

- Horseshoe cross section tunnel indicates lower hazard than equivalent rectangular cross-section tunnel with regards to flammable cloud volume and its longitudinal and lateral spread
- Increasing height of the tunnel indicates safer conditions to tunnel users for buoyant releases of H2
- Compressed gas H2 (CGH2) releases pose greater hazard than natural gas releases, but still not significant
- Increase of ventilation velocity decreases the cloud size and hence results in lower hazard;

However, CFD simulation results are not conclusive on the following aspects: level and extent of hazard with no ventilation versus ventilation and hazard posed by liquid hydrogen (LH2) versus CGH2 releases.

Further details, for instance also on the explosion research done in the frame of this activity, are included in the final report of the HyTunnel project, public deliverable D111.

3. Results of Cluster "Risk Management"

This cluster consisted of the work package for mitigation measures including sensors, the risk assessment work package, the regulation and standards work package and finally the work package dealing with the databases. The internal project for quantitative risk assessment HyQRA was successfully launched and provided a comparison of different approaches applied to the basic benchmark case, a prototypical refuelling station.

Hydrogen Incidents and Accidents Database (HIAD)

Before 2004 there was no database dedicated to hydrogen incidents or accidents. Therefore in the original plan for HySafe the development of such a database was included. Furthermore with an early information exchange with the US DOE it was tried to make the parallel efforts compatible for future data merging.

In HIAD only events involving hydrogen are included. Due to the reluctant attitude of industry to share their data the database had to be designed from the beginning to be based on public information mainly. The structure of the database was carefully designed and is documented in the deliverable D22.

Agreements with other organisations providing databases (Mars, ARIA, VARO, Fireworld,…) with at least some relevant entries have helped to fill HIAD and to make it with currently more than 310 events the largest database for hydrogen incidents and accidents currently.

The data entry module was continuously improved and manuals for users were developed and updated. A first Data Analysis Module has been developed and a HIAD Quality Assurance Expert Group (QAEG) was formed. In the remaining time of the EC supported phase the QAEG approved the quality of 60 events.

The public database HIAD is maintained by the JRC, which as the EC body runs also other EC levelled databases on their ODIN server (see https://odin.jrc.ec.europa.eu/engineering-databases.html).

Mitigation (WP11)

Similar as in the phenomenological work packages the main result of WP11 was to compile a survey of experimental facilities and numerical capabilities with regard to effect of mitigation measures. The results of this work has been reported in the deliverable D43/61. Also this activity mainly supported the internal projects with regard to sensor evaluation and consulting the participants in HyTunnel with regard to suitable mitigation technologies in tunnels. In close collaboration with WP12 and HyQRA WP11 delivered contributions to the InsHyde final report regarding risk reducing measures in garages, tunnels, refuelling stations etc.

Risk Assessment Methodology (WP12)

This activity prepared the basis for comparison of risk information and communication. The achievements are collected in the reports D26 and D44. Moreover, the issue of risk tolerance has got more attention both within HySafe and beyond. An important conclusion from our work is that risk criteria are never absolute, even where specific criteria are part of the legislation. Establishment of "basic" criteria thus is thus not seen as a purposeful objective.

Further, the basis for communication of risk has been established with the D44, which is also an important step as most partners have been using different terminology and/or the terminology was not in accordance with European and ISO standards.

The work on explosive atmosphere hazardous zones has been based on the ATEX directive and underlying standards, in particular on the interpretation of the ATEX directive in Italian legislation, as this interpretation encompasses the use of risk assessment based evaluations for establishing the hazardous zones as an alternative to the standard templates. The work has resulted in a paper presented at the 2nd ICHS conference giving guidelines for ATEX hazardous zoning for a hydrogen applications as well as calculation examples for a hydrogen station. This paper is a part of the HySafe deliverable D64 on Hazardous zones.

The work on safety distances has resulted in a report (D84) and the establishment of a benchmark base case (HySafe BBC) for testing of the methodology for safety distances and for quantitative risk assessment. The quantitative risk assessment has been carried out in HyQRA, while safety distance calculations have been carried out by several partners in WP12. An abstract was submitted to the 3rd ICHS conference and when the paper is published, the D84 will be updated accordingly.

Regulation Codes and Standard (WP16)

This activity had the main function to serve as an information exchange platform for scientific groups and standards developing organisations, i.e. industry.

The experts of WP 16 held a number of meeting during which they discussed matters of current interest in the international committees, mainly the ISO TC 197 and IEC TC 105. To be noted is also the participation in the development of an European regulation for the type approval of hydrogen road vehicles. The European Commission had invited experts to comment a draft, and HySafe, represented by WP16, submitted such a comment which was approved by the group after intensive discussions.

As far as the effect on the international standard committees is concerned the general impression is that the weight of the European P members has increased. This is necessary because with India and China ISO TC 197 has now two new Asian members which will add considerable weight to the committee.

A long discussion about ways to improve the communication of involved parties is summarised in a milestone report. An internet forum was installed which makes it possible to exchange the relevant papers among the interested parties and to collect opinions on them. This is to prevent that a paper which poses problems for one partner is more or less automatically approved by the others simply because they do not know about these problems. This activity is still developing.

Although targeting a concerted, scientifically based concerted voting from all European P members is too ambitious, certain coordination via HySafe became already obvious.

HyQRA

HyQRA is considered as the important bridging element between basic scientific work and industry relevant application. The aim with the activity is to develop a reference Quantitative Risk Assessment (QRA) methodology for hydrogen technologies applying, where necessary, simplified methods for acceptable answer times as required for engineering tools.
After the common definition of the HyQRA Benchmark Base Case (BBC) refuelling station scenario, including detailed geometry, piping and flow diagram, etc, all backed up by the associated HyApproval work, 8 HySafe members participated in the benchmarking exercise.
With the motivation of gradually better validated modelling of physics, in particular with modern CFD tools, numerous assumptions and analytical steps should be improved:

1. Optimal scenario selection
2. Methods/assumptions on leak probabilities
3. Ignition probability models (time dependent, S, I, C)
4. Acceptance criteria, structural response
5. Develop screening models (where appropriate)
6. Include fire modeling

The results are summarised in the final report D106. As quantitative risk assessment was also on the agenda of the IEA HIA Task 19 both groups cooperated closely on this key topic.

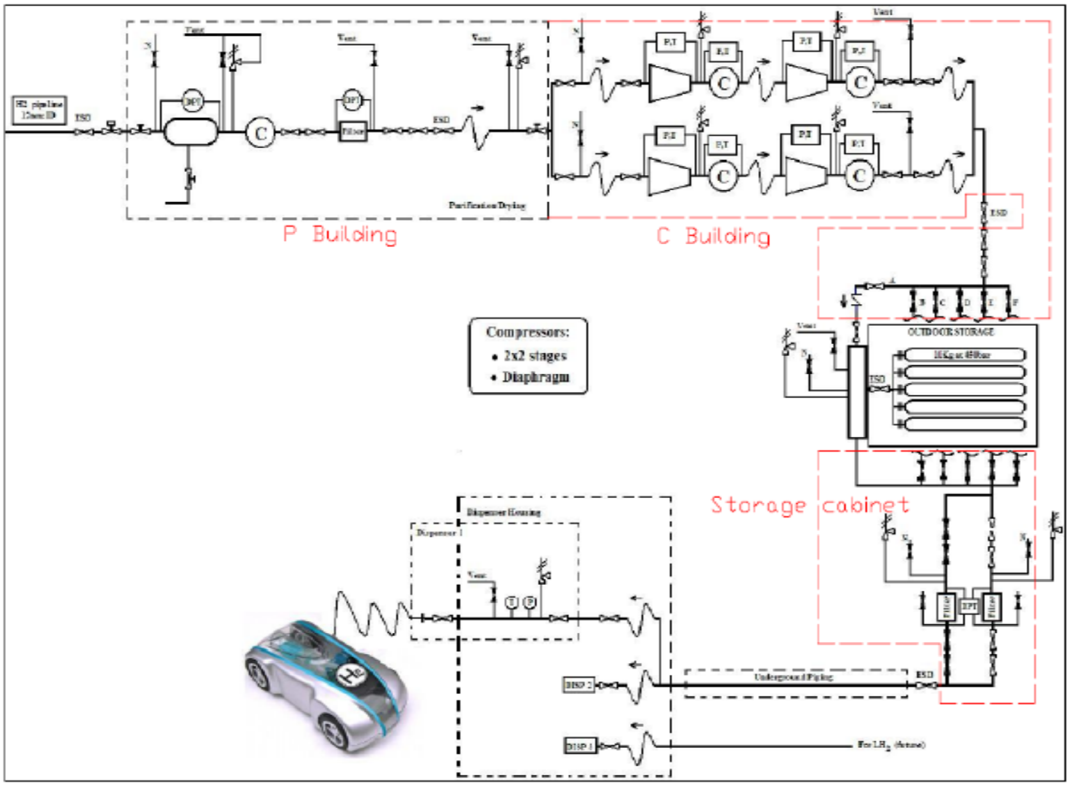

Figure 3. PFD diagram of the BBC hydrogen refuelling station

4. Results of Cluster "Dissemination"

The cluster dissemination consists of the Biennial Report on Hydrogen Safety, the e-Academy and the International Conference on Hydrogen safety.

Biennial Report on Hydrogen Safety (BRHS)

Based on the thematic structure proposed within the first activity period, the BRHS delivers periodically updated information on existing knowledge and progress on hydrogen safety issues. It should pull together existing scientific and technical information shared between members of the consortium and beyond when available. It represents a unique reference to interested parties looking for comprehensive scientific information on different aspects of hydrogen safety, ranging from basic physical and chemical knowledge (dispersion, combustion) up to practical information related for instance to state of the art risk control measures or emergency response plans.

The first issue was developed with standard means like classical word processors and published as printable files on the HySafe website, the second issue was developed with modern Web 2.0 tools, in particular using a Wiki engine for collaborative editing.
The opportunities for paper printed versions are investigated currently.

International Conference on Hydrogen Safety

While safety is one topic among many in most conferences on hydrogen or fuel technology there was no dedicated hydrogen safety conference until the International Conference on Hydrogen Safety (ICHS) was first organised by HySafe September 8 to 10, 2005 in Pisa, Italy. The proceedings (deliverable D31) are available online http://conference.ing.unipi.it/ichs2005/ICHS-Papers/index.htm.

The 2nd ICHS was organised in September 11 to 13, 2007, in San Sebastian, Spain. About 250 international participants from different stakeholder groups, like industry, SDOs, government, authorities and research groups openly communicated results of their research work and participated in intense discussions. Central topics were the applicability of CFD for certification procedures and the status of quantitative risk assessment. The proceedings (deliverable D95) were also published on the conference website http://conference.ing.unipi.it/ichs/index.php?id=122 after a reasonable time span.

A special issue of the "International Journal of Hydrogen Energy" has been published with 16 selected papers of the 1st ICHS (International Journal of Hydrogen Energy, 32, 2007). Also for the 2nd ICHS are similar special issue of the "International Journal of Hydrogen Energy" is going to be published.

The first two events showed a high degree of integration between several international projects, since HyFleet::CUTE (EU), StorHy (EU), NaturalHy (EU), HyPer (EU), Ardenthy (J) and Canadian Hydrogen Safety Program (CDN) were partners in the event organization; also a broad participation of international bodies as ISO, IEA, HELP and H2 Code and Systems for Hydrogen Safety was reached. The first two conferences were held in association with IPHE, as they hosted the IPHE RC&S workshop.

Figure 4. The 3rd International Conference on Hydrogen Safety organised by HySafe

For the 3rd ICHS besides the IPHE recognition also the involvement of and support by the US DOE and the IEA has been successfully negotiated. Meetings of expert groups and educational or training courses like the European Summer School for Hydrogen Safety are arranged in combination with this conference.

The ICHS conference series have been successful both for the public, with more than 700 participants coming from about 25 different countries of the whole world, and for the scientific program with about 220 memories. The 2nd ICHS showed a great number of participants who have already been in the 1st ICHS, thus highlighting the success of the ICHS series in term of continuity and also a great interest in disseminating the hydrogen safety problems/results in the international community.

The again promising number of abstracts arrived for the 3rd ICHS (130 from 18 countries) indicates that with this HySafe activity a demand of the community has been met.

e-Academy- Education and Training

There were no coordinated educational and training activities in Europe in the area of hydrogen safety before March 2004, when the European e-Academy of Hydrogen Safety commenced its activities within the framework of the HySafe consortium. Before the start of the HySafe project, there were no activities to develop dedicated higher educational programmes in the world, including absence of a key element for establishing of any specific educational program - a curriculum. The HySafe e-Academy filled this gap with extraordinary success.

The International Curriculum on Hydrogen Safety Engineering with contribution of more than 60 experts throughout the globe (annual D30, www.hysafe.org/Curriculum) has been developed and implemented by the development of new higher education courses and modules:

- PgCert/PgDip/MSc course in Hydrogen Safety Engineering by UU (www.hysafe.org/MScHSE).
- CPD course *Safe Production, Transportation and Use of Hydrogen as a Fuel* by WUT.
- Module *Hydrogen Safety* in the context of the existing course *Renewable Energy* by UNIPI.
- Module *Safety in Hydrogen Vehicles* by UPM.

The world's first postgraduate course in Hydrogen Safety Engineering (PgCert in HSE commenced in January 2007, full MSc course in HSE commences in January 2009 at the University of Ulster, www.hysafe.org/MScHSE) and the European Summer School on Hydrogen Safety (FP6 Marie Curie Actions HyCourse project, 2006-2010, www.engj.ulst.ac.uk/esshs/hycourse/) have been established. The latter is organised under the auspices of HySafe and in collaboration with US DOE. HySafe partners and international experts delivered contributions to:

- 1st ESSHS (15-24 August 2006, Belfast): 86 participant from 23 countries;
- 2nd ESSHS (30 July – 8 August 2007, Belfast): 79 from 31 countries;
- 3rd ESSHS (21-30 July 2008, Belfast): 87 participants from 30 countries;
- 4th ESSHS (planned for 6-15 September 2009, Ajaccio, Corsica).

The International Short Course Series "Progress in Hydrogen Safety" for joint delivery of educational/training in the state-of-the-art of hydrogen safety (www.engj.ulst.ac.uk/esshs/iscsphs/) have been set up

- Short course No.1: “Hydrogen and fuel cell technologies: Safety Issues”, 29 September - 3 October 2008, Belfast, United Kingdom;
- Short course No.2: “Hydrogen regulations, codes and standards”, 26 - 30 January 2009, Belfast, United Kingdom;
- Short course No.3: “Safety of hydrogen fuelled vehicles” (programme to follow), 27 April - 1 May 2009, Belfast, United Kingdom;
- Short course No.4: “The hydrogen and fuel cell infrastructure” (programme to follow), 15 - 19 June, Ajaccio, Corsica, France.

A pool of specialists from both academic and non-academic institutions able to deliver teaching on hydrogen safety engineering at the highest level by introduction of latest research results into the educational process has been created by the above activities. These experts have been also involved in the joint supervision of research students. In this context a list of consolidated topics for research students at the organisations of the HySafe partnership has been developed (www.hysafe.org/ConsTopics). FP6 Marie Curie Actions have been used to acquire funding for four of these topics. A grant (contract No. MEST-CT-2005-020245, HySAFEST project: *Early Stage Training in Fundamentals of Hydrogen Safety*) has been awarded to complement HySafe activities in this area. Additionally 3 Work-in-Progress workshop/sessions for young researchers in hydrogen safety have been organised (www.hysafe.org/WIPSep2007, http://www.engj.ulst.ac.uk/esshs/2ndesshs/2ndesshsprogramme.php, www.hysafe.org/WIPJuly2008).

A database of organisations working in the hydrogen industry with currently more than 6000 entries was built up to form a market of potential trainees and to disseminate the results from mutual activities of the network (see annual deliverable D17 www.hysafe.org/OrganisationsDB). Finally two further databases were created: a database with references to peer reviewed journal papers on hydrogen safety, published by HySafe partners (www.hysafe.org/PublHySafe) and a Alumni Database (www.hysafe.org/AlumniDB).

5. Results of Cluster “Management”

This cluster is responsible for the general strategies and the day-to-day management of the network. The coordinator was responsible for the communication internally and externally and provided support for administrative, financial and legal issues.

Management (WP17)

The coordinator supported by the project management office (PMO) and by the coordination committee (CC) set-up and developed further the network’s organisational structure. With the concept of work package clusters a new management layer was introduced to ease the management of the large number of activities. An advisor and supporter group and a diversity committee were established and later a special expert group on the material issues (WP18) was introduced.
The coordinator also arranged the extension of the network by the Russian partner Kurchatov Institute successfully applying to the EC INCO call FP6-2006-TTC-TU.

Communication means, in particular the networks website, a regular newsletter and telephone conferences, were set-up and maintained. Meeting schedules and decision procedures were improved and captured in the management handbook.
For the website www.hysafe.net a special CMS system with a sophisticated access and visibility control has been programmed to provide online staff administration, meeting planning, easy file uploading and other features to support all network activities including the dissemination efforts. For example a Wiki system has been integrated in the website to support the editing of common reports and a newsgroup forum was established to support the discussions on new standards and regulations in particular.

No	Title	WP	Lead
D9	Report on compiled facility descriptions	WP2	FZJ
D22	Specification and definition of HIAD	WP5	DNV
D23	Status report on compilation of results of SBEPs	WP3	UPM
D24	Report on phenomena / scenario ranking	WP4	CEA
D25	CFD models in the simulations of the problems related to H2 safety.	WP6	FZK
D26	Summary on HySafe Risk Assessment methodologies/approaches	WP12	DNV
D27	Sub-task 16.3 List of authorities	WP16	INERIS
D31	Proceedings of the first ICHS	WP14	UNIPI
D33	Website presentation of the facilities	WP2	FZJ
D34	Available information including existing standards for bonfire tests of H2 tank structures	WP9	BAM
D41	Database of Literature on Hydrogen Safety	WP1	INERIS
D44	Established definitions and classifications of incidences and accidents	WP12	DNV
D51	2nd Status report on code validation applicability based on SBEP results	WP3	FZK
D54	Report on sensor evaluation	WP11	INERIS
D64	Report on HZ methodology for H2 including calculation examples	WP12	NH
D66	Report on CFD code validation (SBEP)	WP6	GEXCON
D75	List of Basic Test Problems	WP6	FZK
D80	The 1st "HySafe Hydrogen Accident Statistical Report"	WP5	DNV
D81	Specifications of the set of SBEPs for the 4th period	WP6	FZK
D84	Report on internal safety distances	WP12	DNV
D85	Report on the Updating of the PIRT	WP7	CEA
D87	Report on results of experiments	WP10	FZK
D88	Compilation report on SBEPs results of the 4th period	WP6	FZK
D89	HyTunnel Activity Report	IP.2	BRE
D90	Business Plan EU Institute for Hydrogen Safety 'HySafe'	WP7	FZK
D91	Report on results of FA/DDT experiments	WP10	FZK
D92	Proposal for the Safety Action Plan (identical with D86)	WP7	FZK
D95	Proceedings of the 2nd ICHS	WP14	UNIPI
D96	Updated IEF documents	WP2	FZJ
D97	Updated on existing know-how in the field of Material Compatibility	WP18	INASMET
D99	Database of organisations working in hydrogen industry	WP15	UNIPI
D102	Preparation and performance of the 2nd phase explosion experiments	WP10	FZK
D106	HyQRA-Report on use of simplified methods for QRA	IP.3	GEXCON
D107	Specifications of the set of SBEPs for the 5th period	WP6	FZK
D108	HyFrac-Report	WP18	AL
D109	International Curriculum on Hydrogen Safety	WP15	UU
D110	BRHS (2nd issue)	WP1	WUT
D111	HyTunnel-Final Report	IP.2	BRE
D113	Guidance for using hydrogen in confined spaces - InsHyde final report	IP.1	NCSRD
D115	SBEP data base	WP6	FZK
D116	Report on the results of the experiments	WP10	FZK

Table 2: Public Reference Deliverables of NoE HySafe

The website maintains currently about 2000 documents, including the 120 deliverables, milestone reports, internal and external scientific publications, presentations. Intentionally the majority of the deliverables are public, the most important 42 of them are listed in the Table 2.

With the EC reporting and reviewing activities were coordinated and the due delivery of project results was controlled in meetings and in direct contact with responsible authors. The coordinator and other members of the CC represented and presented the network at more than 60 external events, like conferences workshops etc with oral presentations or posters. Among these the yearly European Technical Review meetings, the Hanover Fair, the IEA HIA Task 19 expert meetings and the yearly US NHA conference have to be highlighted. Additionally, several questionnaires, radio and even TV interviews were provided to inform about the network's activities.

Strategies (WP7)

In an initial effort the network supported by external experts set up a phenomena identification and ranking table (PIRT) for the internal road mapping and definition of research headlines. This work package also organised the yearly activity planning in the joint programs of activities and the revision of the network's orientation.
New dedicated project proposals for EC FP6 and national programs were coordinated or at least supported via WP7. Some examples for this vital activity are the preparations of the HyGuide, IgnHyd, InsHyde, HyTunnel, HyPer, HyQRA, HySchool, HyGlobe, HySafest, HyFrac, HyNano and HyGarage proposals. A few of them succeeded as externally or internally funded projects, others were at least partially treated as internal sub-tasks. The coordinator and 8 further partners represented the HySafe consortium in the important HyFIT project proposal, responding to the EC INFRA call. Although in a first response no support from EC was indicated the partners are still striving to re-submit a revised version to the H2&FC JTI.
Other external projects like HyApproval or HYTHEC for instance were supported by safety peer reviews of their key documents or by safety workshops arranged by HySafe. To provide a unique assessment framework for the safety performance of EC supported projects a "Safety Action Plan" was drafted. It was based on a similar obligatory reporting scheme which is applied in US DOE supported projects.

International Association for Hydrogen Safety (IA) HySafe

A vision and mission statement and a strategy plan for the NoE follow-up were developed by a special task force. The mission statement for the IA is to be the international focus for hydrogen safety related research.

Figure 5. The IA HySafe logo

The statutes for this legal body were developed to comply with the Belgium law concerning the “Association Internationale Sans But Lucratif” AISBL, an international not-for-profit association. The decision to choose this form for the continuation was based on an internal survey and consultations with other NoEs.
The founding membership was restricted to NoE members to resolve issues regarding IP protection in an easier way. On 26 March 2009 the association was founded by 21of the 24 HySafe members (see Table 1).
However, the association is now open for any interested party complying with the requirements laid down in the statutes. A membership fee structure, keeping the association open to as many as possible relevant members, has been set up.

6. Outlook

As the international focus for hydrogen safety related research the IA HySafe will continue even with a broader geographical scope the essential networking activities of the NoE, in particular the conference, the education and training, the research coordination, the benchmarking and the maintenance and further development of related documentation have to be mentioned here.
It is foreseen that one of IA HySafe’s most important operational vehicles is its website, the hydrogen safety information system HySafe-IS. As a consequence, it is of vital importance that the Association develop plans for maintenance, i.e. how to keep the contents of HySafe-IS up-to-date at all times and assess whether it holds all relevant information related to hydrogen safety. This involves both operational field data (non-accident) and the further development of HIAD.
Although already in the NoE phase some critical safety issues could be resolved as described above, from a scientific or technical perspective still many issued have to be addressed. Only to mention a few here:

- Properties and behaviour of cold hydrogen from liquid releases
- Release strategies in accidental scenarios, i.e. scientifically grounded requirements to location and parameters of pressure relief devices
- Impinging jet fires and conjugate heat transfer in conditions of blowdown
- Safety sensor development
- Transitional combustion phenomena in realistic conditions (even low temperatures, congestion, non-uniform mixtures...) and the impact on mitigation measures, like flame acceleration and deflagration-detonation-transition in the presence of water sprays
- Formulate the requirements for permitting the use of hydrogen vehicles (cars and commercial vehicles) in confined spaces
- Increase our understanding on hydrogen behaviour in confined spaces, in looking at vehicle applications but also indoor use of portable hydrogen technologies
- Develop hydrogen safety engineering methodology like reference quantitative risk assessment methodology and apply it to garage, tunnel scenarios etc
- Development of a reliable reference simulation tool for combustion open to the research community
- Composite storage and vehicle safety testing strategies

- Hydrogen pipeline field tests and safety analysis

On a European scale a strong link to the JTI demonstration projects is possibly manageable via a close cooperation with the EC Joint Research Centre Petten, whereas a real international dimension will be achieved by the existent close contacts to the US DOE, Canadian research network, our current Japanese consultants, and the relevant groups at IEA HIA and the IPHE and by hopefully many international members.

7. Literature for InsHyde

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8. Acknowledgement

The author thanks the EC for supporting this NoE HySafe work within the 6th Framework Programme (2002-2006) Contract n°: SES6-CT-2004-502630. The network is contributing to the implementation of the Key Action "Integrating and strengthening the ERA" within the Energy, Environment and Sustainable Development.

In particular the author thanks all HySafe participants for their contributions to this report and the overall integration success.