A SURVEY AMONG EXPERTS OF SAFETY RELATED TO THE USE OF HYDROGEN AS AN ENERGY CARRIER

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ABSTRACT

Based on the increasing need of energy for the future and the related risks to the environments due to burning of fossils fuels, hydrogen is seen as an efficient and application related clean energy carrier that may be derived from renewable energy sources. A variety of applications connected with production and use of hydrogen and the related risks have been identified, and a survey has been conducted among a number of experts as an internet exercise for unveiling the potential lack of necessary knowledge in order to handle hydrogen in a safe way concerning the various applications.
The main results concern hazardous situations related to release and explosions of hydrogen in confined and semi-confined areas, tunnels and garages, and mitigation of hazardous situations, i.e. preventions of accidents and reduction of consequences from accidents happening anyway.

1.0 INTRODUCTION

Due to the prospect of decreasing energy reserves and growing costs of the present energy resources, the age of increasing use of renewable energies has drastically approached. In this respect the need of storage of energy produced by fluctuating energy resources like the wind, solar energy, wave energy, etc., as well as the need of transport of the energy, has increased the demand of energy carriers, of which hydrogen turns out to be a very promising candidate.

Electricity - being the most established energy carrier mostly related to centralised energy production, and including an extensive distributive network - seems to be an unbeatable energy carrier for highly developed industrial areas concerning stationary installations. For movable or portable applications, however, including combustion engine or electrically equipped vehicles or other battery equipped installations, electricity will fail, and other means must be developed and implemented.

Hydrogen as an energy carrier is still in its infancy phase, and will probably not have a significant market share for 10 to 15 years from now. However, hydrogen production, storage and conversion have reached a technological level - although plenty of improvements and new discoveries are still possible – at which its use as an energy carrier is of high interest. On the other hand, a number of problems have to be solved before hydrogen will be a main competitor on the energy marked.

The storage of hydrogen is often considered a problem causing a bottleneck in the renewable energy economy based on hydrogen as an energy carrier. Since hydrogen is the lightest elements and has very small molecules, it can escape from tanks and pipes more easily than conventional fuels. However, if it is to be used as a fuel for transport or power generation there need to be ways of storing it cost-effectively, and to get it from the place where it is generated to the place where it is used.

Furthermore, hydrogen has to be accepted by the public from a safety point of view due to the fact that refuelling stations for hydrogen fuelled vehicles will be part of the infrastructure like normal gas stations are today. Linked with this, another major negative to widespread usage of hydrogen is economic. There is currently a large, well-established system of delivering hydrocarbon fuels (gasoline, natural gas, propane, etc.) to consumers. To have a hydrogen fuelled fleet of cars would require duplicating much of the infrastructure presently used to deliver gasoline to the local gas stations. This would include the complete line of hydrogen production and transport from the refineries to the gas stations including delivering tanks, storage tanks, pumps, etc. adding up to a huge amount of money. One important issue here to be considered and tested is the possibility of using the existing network of pipelines - e.g. for natural gas - for transport of hydrogen.

Even though hydrogen used for vehicles – either as a direct fuel for combustions engines or as the fuel for fuel cells for electrically driven vehicles - has been dealt with for many years, the field is still in a developing and testing state except for a few commercially implemented applications like buses for person transport. Since 2003, city buses with fuel cell drive have been on the move in regular route service in ten major European cities. Three buses are also in operation in Perth, Australia and another three will operate in Peking, China. These vehicles must prove their ability in the most varied climatic conditions. The city buses alone have already covered more than 300,000 miles (500,000 km) and transported more than two million passengers, who have been convinced by the advantages of this quiet, emission-free technology. Several fuel cell powered 'Sprinter Vans' also are currently being used in day-to-day delivery operations with dispatching companies in the United States and Germany. Iceland, especially, has converted to the use of hydrogen powered city buses, benefiting from the almost unlimited geothermal primary energy sizzling beneath its surface. Iceland has an official goal of making the country oil-free by shifting cars, buses, trucks and ships over to hydrogen by about 2050.

Limited energy reserves and economy, however, are not the only issues calling for support - including storage and transport - of using fluctuating renewable energy sources. The need of drastically reducing of polluting and especially climate affecting emission is at least as important looking into the future. Also in this respect hydrogen turns out as a good candidate, as hydrogen could be used as a pollution free fuel for traffic applications.

2.0 BACKGROUND

In HySafe[1], 'Safety of Hydrogen as an Energy Carrier' [1], a matrix has been defined presenting a thematic structure of activities for using hydrogen in a variety of applications covering more or less the complete spectrum of the hydrogen lifecycle as an energy carrier from production, over transport and distribution to storage and use of hydrogen. Various hazards and risks related to the use of hydrogen in each application are presented in a broad range from release of hydrogen over risks of fire or explosions to mitigation techniques, risk assessment, and needs of standardisation and legal requirements, see Figure 1.

[1] The HySafe Network is partially funded by CEC, CONTRACT No SES6-CT-2004-502630

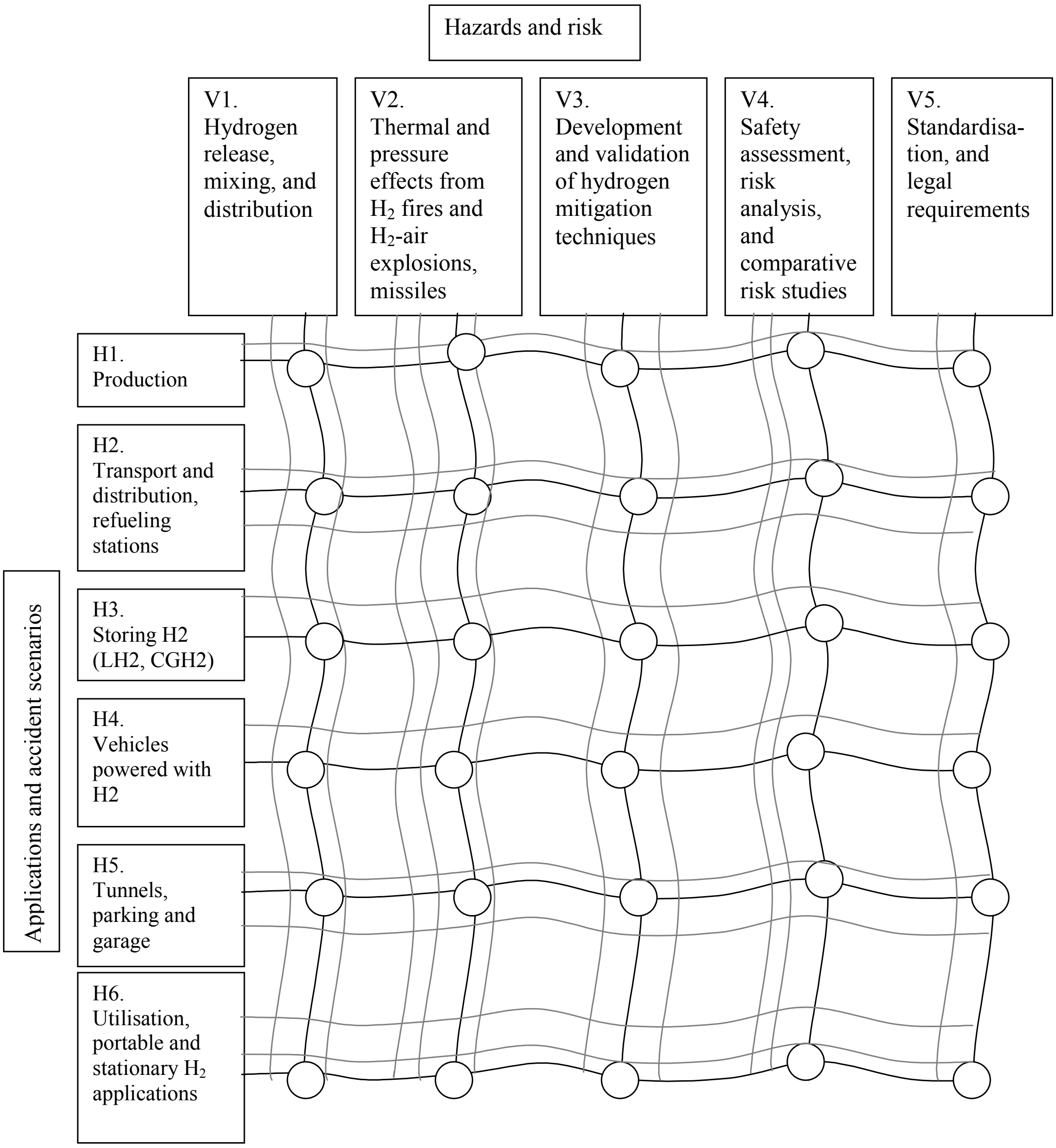

Figure 1, Thematic structure of activities in NoE Safety of Hydrogen as an energy carrier

A progression survey was initiated in order to elicit the needs of knowledge as related to future safe handling and use of hydrogen as an energy carrier. However, in order to illustrate the present potential lack of knowledge, the state of the art was revealed by requesting from members of the HySafe consortium information about previous and present work covering partly or in complete the node structure in Figure 1, and for which nodes efforts are lacking. The latter could be due to low priority for research inside the domain in question, or it could indicate a real lack of knowledge in the area with a real need for dense research.

2.1 Results

A request within the HySafe consortium gave a description of 69 projects, and the content of the project themes were placed on the matrix, see Figure 2. Preliminary results of the analysis are that quite many projects are demo project concerning production and use of vehicles using fuel cells, filling stations and storage of Hydrogen. These projects are mainly located in column V4, safety and risk analysis. These projects do not describe specific tests of hazards. Some projects concern specific tests such as jet releases from Hydrogen tanks, experiments with explosions, detonation and ignition problems. Mitigation issues are also treated such as Hydrogen removal (especially for nuclear projects).

One of the preliminary results is that problems concerning safety in tunnels are just mentioned in very few projects. One project concerns equipment for tunnels and traffic control, another experiments with H2 detonation.

	V1 Hydrogen release, Mixing and distribution	V2 Thermal and pressure effects from H2 fires and H2-air explosions, missiles	V3 development and validation of hydrogen mitigation techniques	V4 Safety assessment, Risk analysis and comparative risk	V5 Standardisation and legal requirements	Total
H1 Production	6	6	2	13	4	31
H2 Transport and distribution, refuelling stations	9	12	5	20	9	55
H3 Storing H2 (LH2, CGH2)	4	6	2	16	7	35
H4 Vehicles powered with H2	4	6	0	16	10	36
H5 Tunnels, parking garage	1	4	2	3	5	15
H6 Utilisation, portable and stationary H2 applications	4	3	2	13	3	25
H7 Nuclear applications	6	5	9	9		29
Total	34	42	22	90	38	226

Figure 2, The thematic structure with a rough indication of past or present activities. The dark colours indicate that several project about the specific topic is either finished, going on or are planned, the more dark the more projects. The light colours indicate that very few projects treat the specific topic

This analysis covers 69 European projects and cannot claim to cover all projects going on. Each project may point to more application/risk relations, and in total 226 relations have been pointed out.

3.0 THE PROGRESSION SURVEY

The progression survey has been based on the opinion of a batch of experts selected inside the HySafe consortium and by a number of ‘hydrogen experts’ outside the consortium, but proposed by members of the consortium (for more details concerning process and results, see [2]).

The prospective analysis has been performed as a Future Goals survey. The Future Goals survey is meant to unveil ideas for compiling a list of new, surprising and plausible problem fields as well as options for safe transition to a more sustainable development in Europe, and to stimulate a future oriented decision-making among HySafe partners.

So, the objective of the survey was to indicate the needs and wishes for future research and applications in relation to safety aspects in using hydrogen as an energy carrier. The survey includes the implications of various hazards and risk situations this may introduce for various applications as related to the (V1 – V5) / (H1- H6) matrix indicated in the thematic structure, see Figure 1. For each node the questionnaire asked for the opinion of the experts concerning the importance of further research for this area, and the time schedule for which this research is needed.

In order to increase the selectivity in the survey some of the nodes were split into sub-groups. H2, the transport, distribution, and refuelling stations, e.g. was split into each of these groups in the questionnaire.

The state of the art survey indicates, however, that the thematic matrix (V1-V3)/(H1-H6) describes experiments useful for identifying safety assessment and risk analysis methods, and specifying in the end standards and legal requirements. So, the questions in the questionnaire for surveying the future needs were restricted to the nodes (V1-V3)/(H1-H6).

Examples of questions related to the H2-V1 node could be:

- Do you agree that the existing knowledge related to transport of hydrogen in tanks on trucks is sufficient concerning hydrogen release and mixing?
- Do you agree that the existing knowledge related to transport of hydrogen in tanks on trains is sufficient concerning hydrogen release and mixing?
- Do you agree that the existing knowledge related to distribution in a network of tubes is sufficient concerning hydrogen release and mixing?
- Do you agree that the existing knowledge related to refuelling stations is sufficient concerning hydrogen release and mixing?
- ….

The aim of the questionnaire was to prioritise the nodes in the thematic matrix in order to point out the most important issues to deal with for the next period of HySafe, and the possible response was ‘Totally agree’, ‘Partially agree’, ‘Neither agree nor disagree’, ‘Partially disagree’, or ‘Totally disagree’. Furthermore, the questionnaire should – in free text - point out new aspects of interest to avoid that issues not included in the first phase of HySafe should automatically be neglected also for the next period of time.

The responses have been analysed

- Partly from a frequency distribution point of view indicating how often and how strongly the participants of the survey have agreed or disagreed to the statement of need of more research within each node of the thematic matrix, i.e. each area of use of hydrogen as an energy carrier, and
- Partly based on comments provided by the participants for the individual topics, and concerning wishes for the future.

106 experts were invited to respond to the questionnaire. 27 of these were members of the HySafe consortium, and the remaining 79 were external experts. The overall number of respondents is 38 giving a responding percentage of 35,8. The number of respondents from inside the consortium is 15 corresponding to a percentage of 55,6. The number from outside the consortium is 23, corresponding to a percentage of 29,1.

At the end of the questionnaire the respondent were asked about their personal expertise as related to the types: 'R&D and consultancy', 'public authority/agency', 'industry', and 'other'. The distribution of respondents turned out to be 22, 5, 6, and 3, respectively, plus 2 of no reply to this question.

The result of the overall statements concerning priority of the topics is presented in Figure 3. For each topic (node in the matrix) the result of the query is stated based on the point of view of need of more experiments, need of improved modelling, and need of standards.

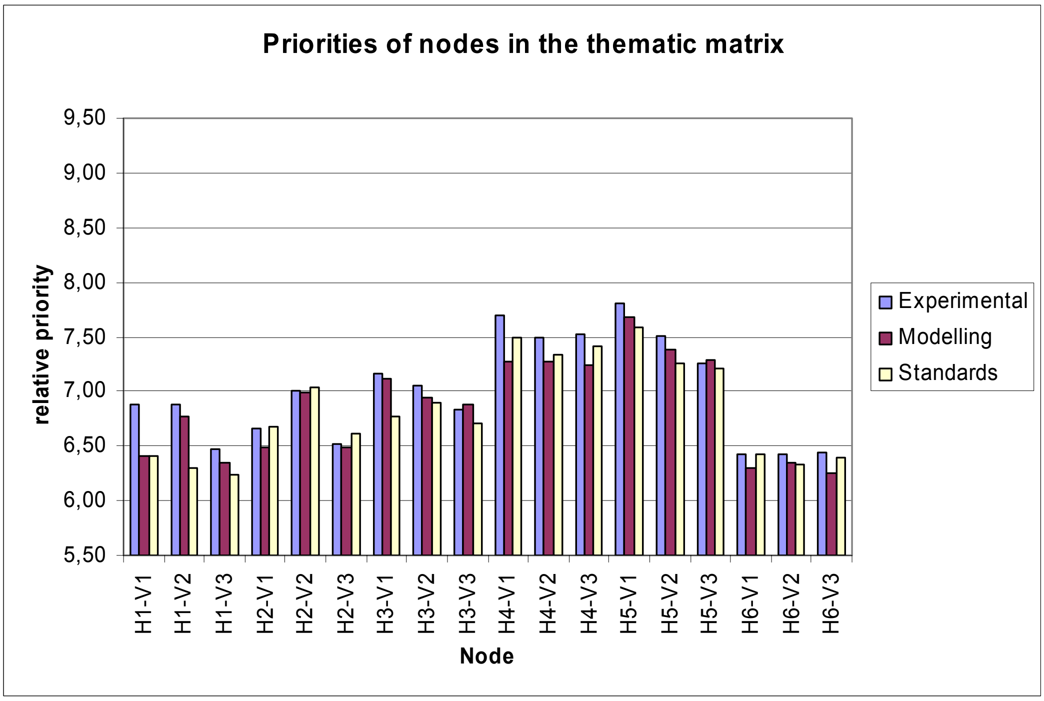

Figure 3, Priorities of topics in the thematic matrix

Even though – and not surprising – all aspects were seen as important, and therefore the response is varying in the order of 'partially agree' and 'totally agree', the result indicates that some aspects are seen as more important than others. Especially, parts of the applications 'Vehicles powered with H_2' (H4 in the matrix) and 'Tunnels, parking and garage' (H5 in the matrix) are indicated as very important applications.

For a few of the applications we have been more detailed than specified in the thematic matrix. This goes for 'Transport and distribution, refuelling stations' and for 'Tunnels, parking and garage'. For the first, we have split up in various types of transport of hydrogen: transport in tanks on trucks, in tanks on trains, or by a pipeline system, and separately we have included risks related to refuelling stations. For the second, we have split into 'tunnels' and 'parking and garage'.
Figure 4 presents the relative priority concerning transport of hydrogen by various means: by trucks, trains, or pipeline systems; and problems related to refuelling stations. Even though respondents related to 'Production of hydrogen powered vehicles' are very scarcely represented, it is quite obvious that problems related to refuelling stations on all levels: experiments, modelling, and standards, are highly prioritised as compared with transport and distribution. For the latter it seems that problems related to hydrogen fires and explosions (V2) are prioritised higher than problems related to hydrogen release and mixing (V1) and mitigation techniques (V3).

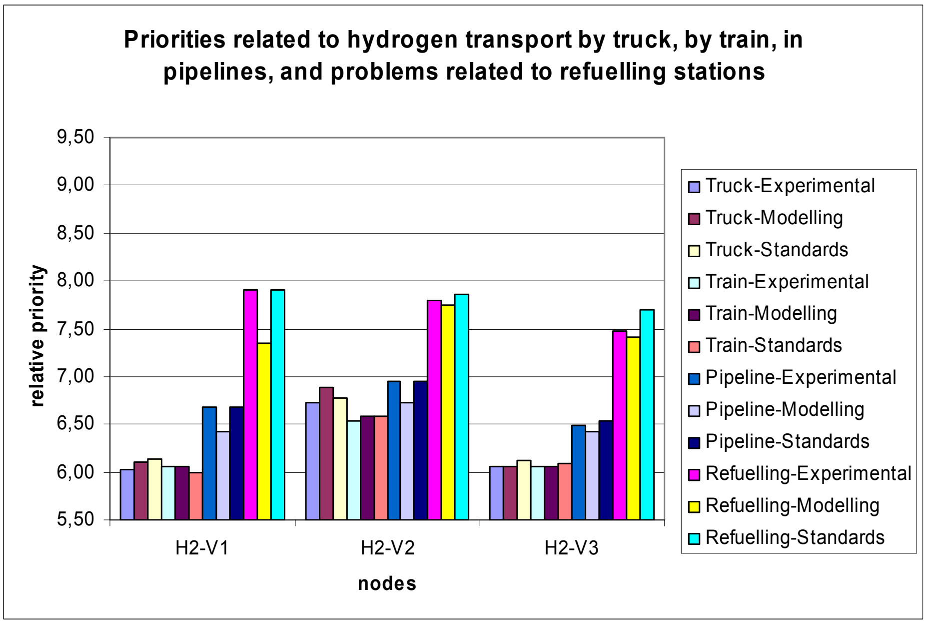

Figure 4, Priorities related to transport means and refuelling stations

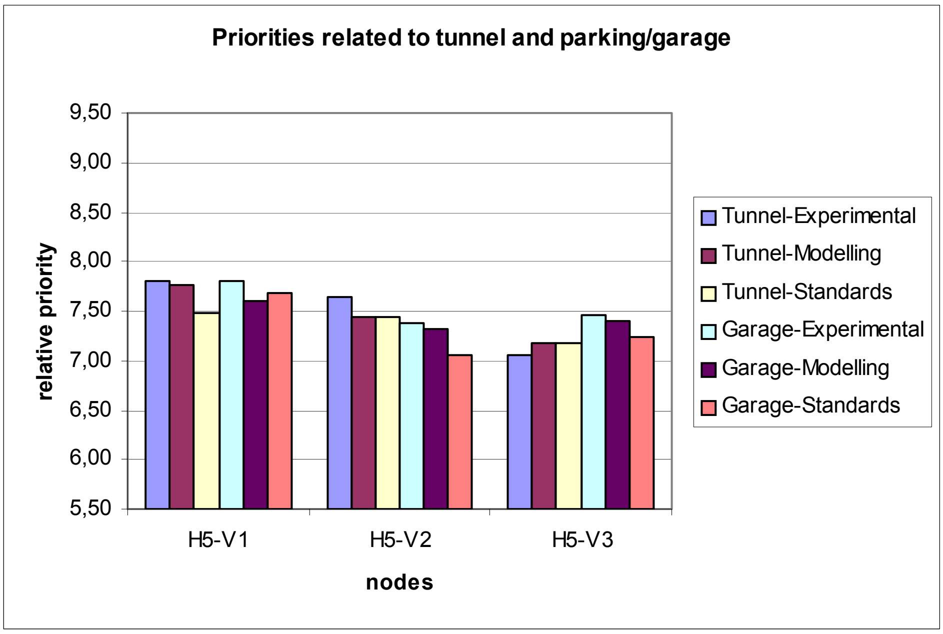

Figure 5, Priorities related to tunnel and parking/garage

In Figure 5 the difference of importance concerning problems related to tunnels and in parking and garage have been presented. A vague indication of more importance for tunnels as related to parking and garage is seen for fire and explosion (V2), whereas the opposite seems to be valid for mitigation techniques (V3). However, the outcome is - as mentioned – only indicative and in no way statistical significant.

4 CONCLUSION

A broad interest is seen in all domains presented in the thematic matrix. However, preliminary results of the state of the art analysis indicate that quite many projects are demo projects concerning production and use of vehicles using fuel cells, of filling stations, and of storage of hydrogen. On the other hand problems related to safety in tunnels are just mentioned in very few projects.

The interest in vehicles fuelled by hydrogen and the lack in standards and legislations concerning tunnel safety is in harmony with the results of the progression survey, which point to needs of experiments, improved modelling, and standards related to applications dealing with safety of vehicles powered with hydrogen (H4), with transport and re-fuelling problems with the main emphasise on refuelling (H2), and related to tunnels and parking areas (H5).

The free comments given for the different topics additionally point to topics that go beyond simple experimental and modelling activities to understand the basic phenomena. They also deal with issues on accident prevention and methods to mitigate eventual consequences. These topics may be headed under keywords as reliability, maintenance, human factors and land use planning aspects, which are also important to development of the legislation in the area of hydrogen applications.

Finally, important issues for the next phase of HySafe are related to education and training of 'operators' dealing with handling of hydrogen. In relation to that, the education and training of rescuing personal dealing with accident and emergency situations is necessary.

REFERENCES

1 HySafe, Safety of Hydrogen as an Energy Carrier, 'http://www.hysafe.net/'

2 HySafe, D28. Report on priorities and further steps in JPA (Joint Programme of Activities), Risoe National Laboratory, Version 1.3, 12. January 2005, 'http://www.hysafe.net/index.php?ID=40', (D28_final_010305.zip)