Development of H_2 Safety Expert Groups and due diligence tools for public awareness and trust in hydrogen technologies and applications

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List of Abbreviations

ATEX	EXplosive ATmosphere
APU	Auxiliary Power Units
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
cH_2	Compressed (gaseous) Hydrogen
CHP	Combined Heating and Power
CO_2	Carbon Dioxide
DOW	Description Of Work
EC	European Commission
EC DG	European Commission Directorate General
EC-JRC	European Commission – Joint Research Centre
EFTA	European Free Trade Association
EREP	European Resource Efficiency Platform
EU	European Union
FCH	Fuel Cell and Hydrogen
FCH-JU (or JTI)	Fuel Cell & Hydrogen Joint Undertaking (or Joint Technological Initiative)
FCEV	Fuel Cell Electric Vehicle
H_2	Hydrogen
HE	Hydrogen Embrittlement
HIAD	Hydrogen Incident and Accident Database
HyCO	Hydrogen plant where carbon monoxide is captured
HRS	Hydrogen Refueling Station
ILO	International Labour Organization
ISO	International Organization for Standardization

LH_2	Liquid Hydrogen
LPG	Liquefied Petroleum Gas (or Liquid Petroleum Gas)
P2G	power-to-gas
N_2	Nitrogen
NEW-IG	Industrial Group in FCH-JU
NFPA	(US) National Fire Protection Association
NG	Natural Gas
NSB	National Standards Bodies
O_2	Oxygen
RCS	Regulations, Codes and Standards
R&D	Research and Development
R&I	Research and Innovation
SAE	Society of Automotive Engineers
SBS	Small Business Standards
SME	Small and Medium size Enterprise
UNECE	The United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
USA	United States of America
US DOE	United States Department of Energy
US NASA	United States National Aeronautics and Space Administration
WHO - IPCS	World Health Organization - International Programme on Chemical Safety
WP	Work Package
˚C	Degree Celsius

Executive Summary

In this Report the main results of the following Tasks of H2TRUST are presented:

- Task 4.1 Mapping safety issues,
- Task 4.2 Identify best practices
- Task 4.5 Recommendations

The 1st Chapter of the Report focuses on the main safety issues in the FCH industry and where they lie. An overview of the FCH industry, processes, infrastructure and applications is given, mapped to a set of safety hazard and risk factors and documented in a comprehensive map (Annex I), allowing quick and complete understanding of the potential safety issues and where they lie. The analysis and the mapping follow the categorization used throughout H_2TRUST and presented in D 2.1.

In the 2nd Chapter the report include also the description and comparison of the safety records and practices of similar risks of similar industries (with a focus on LPG and NG) with both negative and positive experiences, described and compared so to be relevant and useful for the FCH industry.

Finally, in the 3rd Chapter, the WP4 leader CTECH, with the collaboration of all other H_2TRUST partners has wrapped up the main results and findings of the work done throughout the project and developed recommendations for (immediate) FCH deployment and further safety efforts by FCH community.

Extensive review and analysis of all the Deliverables produced so far by the H2TRUST Consortium have been ensured by CTECH, as well as additional research from various sources of information, and relevant information extracted to inform the recommendations.

In line with the approach at European level and the work already done, the H_2TRUST consortium organized the recommendations following the following categories:

- Research, Technology and Infrastructures
- Regulations, Codes and Standards (RCS)
- Training, Education and Public Communication

The document starts with describing an overview of the state-of-the-art in each of the three categories. This provides insight into the measures that are currently in place, but even more importantly, also provides insights into which types of measures are not used in each of the categories (Gaps analysis). This insight provides important input for developing the recommendations in this Task, which are presented at the end of each category. Finally, an overview of the main recommendations with regard to the Roadmap and Action Plan is presented in Annex II to the document. Main recommendations include the following:

Research, Technology and Infrastructures

- Creation of a statistical mass of projects/data and structured information at European level. H_2TRUST strongly supports the consolidation/revamping of existing and/or new databases on accidents/incidents (e.g. HIAD), crucial to establish a statistical source of information for monitoring safety aspects in all FCH applications at European level. Moreover, we propose the creation of a structured organization (or the strengthening of existing ones, such as HySafe and EC-JRC) acting as constant observatory on FCH safety and risk assessment, to become a EU think-tank on safety of hydrogen, etc.., able to monitor the situation of safety, produce updated reports with a statistical basis (e.g. at least annually), guide the debate on safety and risk associated to such an emerging and crucial energy technology for Europe.
- Increase the funding of large demo projects (in scale and numbers), also using different sources of financing (R&I funds, structural funds, private investments, loans, etc..). Moreover, more efforts in ensuring continuation of a project after ending its demonstration phase can also be seen as fruitful.
- Wherever possible, foster H_2 use to implement and enlarge industrial symbiosis could help to structure small grids at local level and prepare for further deployment of a future H_2 grid. To this end, a mix of public funds/incentives, coupled with the decreasing cost of FCH technologies, could turn the Business model appealing. On the other hand, fostering industrial proactivity and concerted action in this sector could lead to a successful deployment of this model, at the same time guaranteeing that safety elements are fully taken into account as intrinsic development and planning of industrial projects (i.e. risk assessment and risk management practices at district level, etc.)
- Enforce crisis management activities specifically dedicated to address safety aspects and with the aim of increasing the level of acceptance of FCH technologies and hydrogen at large in the public community. This could include, for example, working with the local communities to explain safety aspects linked to hydrogen.
- Improving the refuelling infrastructure to the several hundred numbers of points around Europe; to this end, the recent Directive on the use of alternative fuels should help implementing a more structured refueling infrastructure, also through the definition at Member State level of an appropriate number of points for refueling by 2025;

Regulations Codes and Standards (RCS)

- Improve harmonization. Foster single and simple (clear) legislation at EU level and among Member States. H_2TRUST partners registered in some cases an excess of safety measures, which often resulted in “over-engineering” of FCH facilities (production, distribution, etc..), thus resulting in an increase of costs associated to the technology and unjustified alarm in public perception. Also in stationary non-industrial and non-vehicles applications there’s a lack of safety information on hydrogen components and systems used in a hydrogen fuel infrastructure, and a limited availability of appropriate RCS to ensure uniformity and facilitate deployment. To this end, it could be also useful to compare the different normative of European countries (or other world regions) concerning different issues regarding hydrogen, and take the most effective ones as an example;
- Foster industry collaboration and leadership in safety RCS, in order to build up on the extensive body of codes and standards already developed at industrial level since several decades. It is needed that the legislation is generated by experts. To this end, H_2TRUST strongly supports the implementation of a system to collect data and information for the entities appointed to the standardization and regulation, as already established by the new FCH JU2, in order to be facilitated in the pre-normative phase.
- Revise and simplify safety standards, especially safety distances. For example, prescribed safety zones for ATEX areas.
- Strengthen RCS also for the production, transportation and storage and use of hydrogen for non-industrial applications in the public domain, in order to ensure safety and minimize the risk of accidents and hazards for the general public. In particular, there’s a need for development and consolidation of RCS that are infrastructure-specific.

Training, Education and Public Communication

Professionals

- Up-to-date knowledge on what is required (regulations, certification and standards) when implementing hydrogen technology (now and in the future) and personnel should receive specific training in dealing with emergencies involving hydrogen. In particular they should know how hydrogen explosions and fires differ from those involving the more conventional gaseous fuels such as natural gas and LPG. One example of a difference, which is of particular relevance to hydrogen fires, is that hydrogen flames are often invisible, especially in bright sunlight, increasing the likelihood of people fleeing an incident or emergency workers inadvertently straying into a flame.

- In order to support creating sufficient knowledge-base for first responders, it is recommendable to develop an additional set of prevention rules and trainings. Research in Task 3.1. – 4.3. suggest no complete set of new regulations in this regard are necessary
- Need to have access to state-of-the-art tools and resources to train professionals within their own field of expertise. Especially web based-resources are considered to play a key role in educating different stakeholders at their own level.
- Stakeholders need access to trainers (or should have the opportunity to educate in-house employees to become a trainer) which will be able to train professionals on multiple levels and determinations.
- Moreover, considering hydrogen will increasingly be used as an alternative fuel, it is recommendable to create a training system specifically focusing on education young professionals and/or students.
- In order to create sufficient critical mass to help shape a clean and comprehensive education and training strategy, it is recommendable professionals organize an efficient lobby with regulators and public safety officials.

Regulators and Public Safety Officials

- European, National and Regional schemes should be more aligned and translated into a new educational curriculum for professionals. Moreover, an educational curriculum as well as the harmonisation of regulations, legislations, certification, codes and standards can contribute to creating the right boundary conditions for the introduction of hydrogen.
- Policy makers need to be informed on the needs of professionals in order to ensure that they understand the need for an additional hydrogen specific policy support scheme on top of current support schemes.
- Set up and implement education and training programmes on hydrogen and fuel cells to facilitate the potential large employment shifts.
- Limited information was found on specific guidelines for the handling, storage and use of hydrogen in the public domain. More detailed research on the needs for this specific actor group is recommended.
- In addition, dissemination and educational activities - on tools and training material developed by regulatory bodies - are needed to support uptake by the relevant actors. In this context, this will most likely improve societal awareness and acceptance as well.

General Public

- Train and educate the general public more on the properties and benefits of hydrogen in comparison to other gases;
- Outreach activities of demonstration projects have generally only informed the public in the vicinity of demonstration projects, leaving the larger public uninformed. It would be beneficial to demonstrate the safety of hydrogen (e.g. with crash test of vehicles with different fuel systems in place) in a public setting.
- To develop layman level materials (e.g. flyers, folders, publications) which can be disseminated through e.g. conventions, websites on sustainable energy or by energy companies to create more awareness of hydrogen technology applications in society.
- Fostering dissemination of positive results from demo project in FCH and FCH2 related to technology advancements and deployment, would support optimal use of best practices and mainstreaming them into training/education material.
- Hydrogen energy providers (household power generation/storage, vehicles etc) could train and educate the general public on hydrogen technologies outside the industrial world, how the general public could personally benefit from these technologies and how strict safety measures (e.g. provision of hydrogen detectors) would prevent major risks. In addition, during the interviews it was indicated that the general public would most likely quickly adapt to new household gases, as they did with previous household gases.
- The results of the Tasks indicate that it might be beneficial to include the general public in translational activities for transferring hydrogen from industrial level to applications used in household or on societal level (hydrogen fuel stations etc). This would support acceptance and awareness of hydrogen technology as well.

From a methodological point of view, we can state that the H_2TRUST consortium encountered several problems in the collection of data and valuable, updated information for at least the following reasons (inter alia):

- Low level of responses of stakeholders to interviews (as anticipated in D 3.1);
- Lack of a structured body and channel of information on H2 safety and risk assessment at European level (see also chapter on recommendations);
- Lack of structured and updated database on accidents, info, data (e.g. the HIAD database is a good initiative, but need to be strengthen considerably and the database populated at a higher level of granularity)

- Lack of structured references bodies at European level (think tanks and/or observatories) producing studies, reports, etc…on a regular basis at EU level. The only relevant initiatives in this sense are the network structured around HySafe and the EC-JRC Institute for Energy and Transport, but they look more concentrated on Research priorities.
- Complexity of the hydrogen sector, fragmented at stakeholders as well as policy-making level (EC, Member States, regulatoy framework, RCS, etc..)

For these reasons, the recommendations provided in this Report do not have the ambition to cover all the aspects and the complexity of the subject of study.

On the other hand, several studies, recommendations and road-mapping exercises have been carried out in recent years by the EC and relevant stakeholders on the subject, especially at R&D and technological deployment level. Authors took into consideration most of this works and most recent development in the legislative/regulatory framework, such as the last Directive of the European Parliament and of the Council on the deployment of alternative fuels infrastructure (among them hydrogen), approved on 29/09/2014.

The H_2TRUST consortium hopes that the analyses and recommendations provided in this Report could be useful for the EC, the FCH-JU and for all stakeholders involved in the hydrogen industry, thus contributing to form the basis of a zero incident hydrogen economy and to build public confidence based on sound shared evidence on safety, hazard and risk associated to hydrogen.

Finally, all the results gathered in this report will be made available as content for the dissemination phase of H_2TRUST (part of WP5).

Introduction and H_2TRUST Framework

In most cases hydrogen is still not so familiar and fear is due to lack of knowledge and education. However, beyond the subjective perception of risk, a careful analysis reduces the perception of dangerousness of this energy vector.

First of all this gas is less flammable than gasoline, its auto-ignition temperature is about 550°C, compared to 230-500°C (depending on the type) of gasoline. Hydrogen is the lightest element (fifteen times less than air), and therefore dilutes very quickly in open spaces. It is almost impossible to make it explode, if not in confined spaces.

To identify potentially dangerous concentrations (> 4% in air) sensors are used which can easily control adequate security systems. There are for example prototype vehicles with windows that in case of presence of the gas are automatically opened.

The hydrogen burns very quickly, always with direct flames upwards and characterized by a thermal radiation at wavelength very low, then easily absorbed from the atmosphere. Materials such as gasoline, diesel, LPG or natural gas are heavier than air and do not disperse, they remain a source of danger for much longer.

It has been calculated, using experimental data, that the fire of a petrol vehicle lasts for 20-30 minutes, while a hydrogen vehicle does not last more than 1-2 minutes (M. Swain, 2003).. The low thermal radiation, its flames from hydrogen, means that there is little possibility (beyond direct exposure to the flame) that neighboring materials can in turn be burned, thus reducing the duration of the fire and the danger of emissions toxic. The hydrogen, in contrast to fossil fuels, is not toxic nor corrosive and potential losses from the tanks do not cause problems of pollution of soil or groundwater aquifers.

In particular, in this deliverable we are going to map safety issues in four areas:

- H2 Production;
- Storage and Distribution;
- Mobility and vehicles;
- Non-vehicles and residential power generation.

In attachment it's available a map where the potential safety issues are presented in a format allowing quick and complete understanding.

According with the H_2TRUST DOW, Figure 1 shows the general framework of the project, where the WP leaders are included.

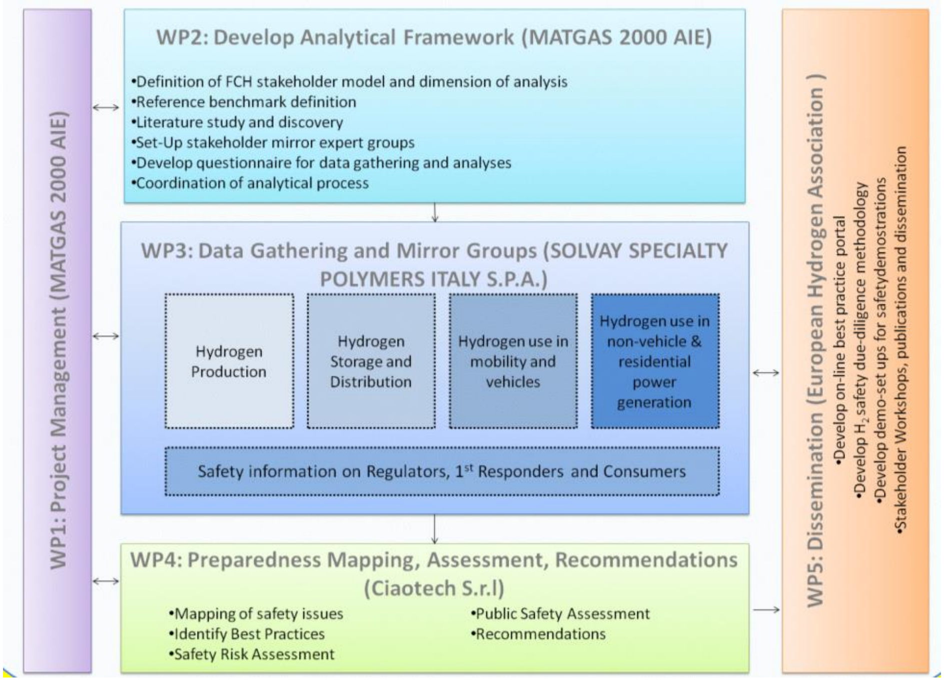

Figure 1: H_2TRUST WPs.

More specifically the framework of WP4 is summarized in Figure 2. In the corresponding schemes, the different development areas of each team, making emphasis at the points specified on it, are indicated.

This deliverable “FCH Safety Issues, Industry Best Practices and Recommendations” will follow the structure in Fig. 2 and include outcomes derived from WP2 - WP3 .

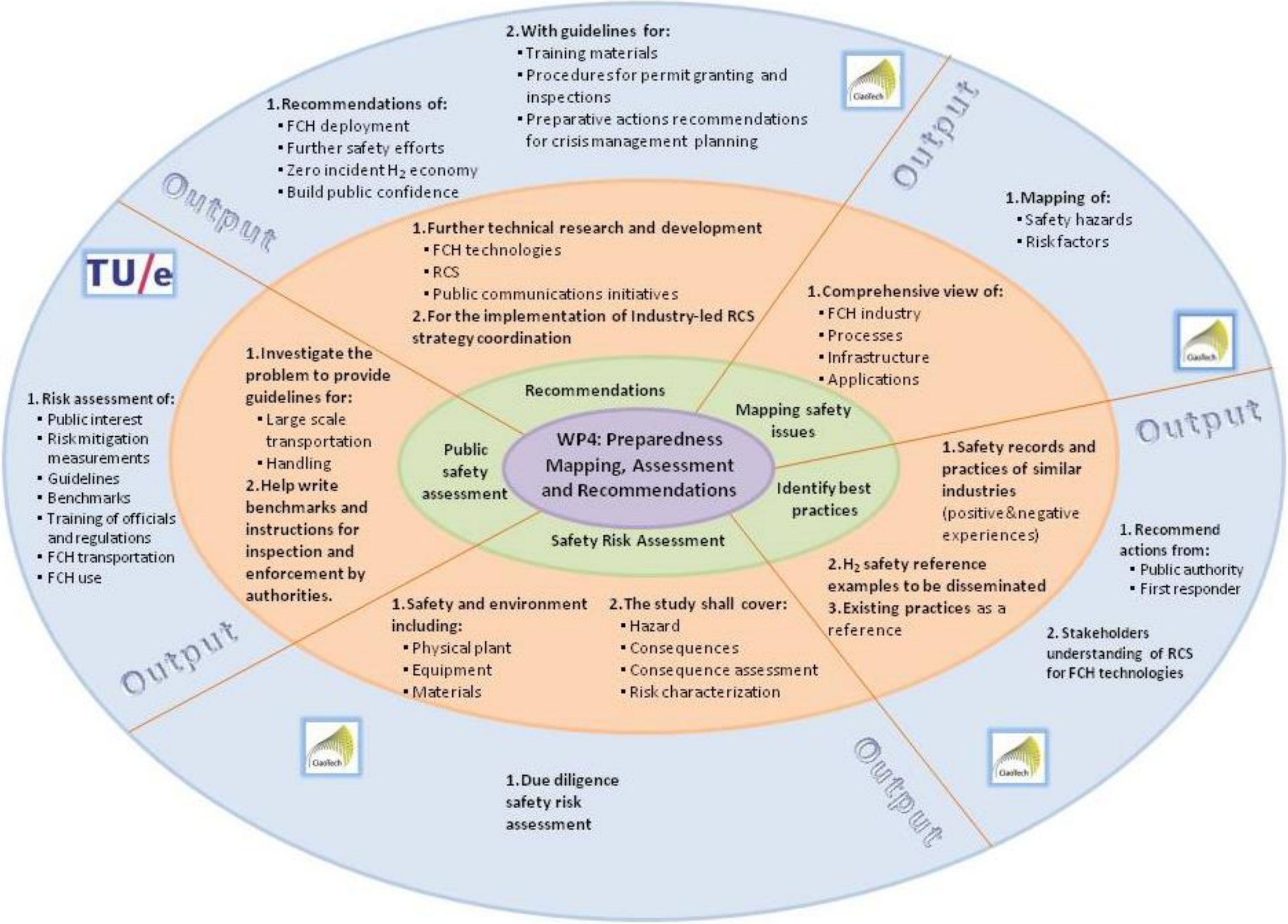

Figure 2: WP4's framework

Chapter 1 - FCH industry, processes and safety issues

As shown in the deliverable 2.1, the industrial hydrogen-related processes start from production of hydrogen (whether from steam reforming of natural gas such as alkaline electrolysis of water) to the phases of storage, distribution, refueling and consumption in fuel cells.

This paragraph aims to highlight the inherent technology hazards among a number of components, technologies, processes and to identify relative safety issues.

The tools used to collect data belong to:

- Data gathered from WP2 and WP3 (with focus on benchmark for H2 industry, and interviews);
- Data from stakeholders, from online database (as HIAD, h2bestpractice, etc…) and from internal research;
- Literature.

First of all the production phase has been analyzed. In general, safety issues linked with hydrogen industry are the same causes of major industrial accidents. Summarizing, works management should control major hazard installations by correct engineering and management practices, for example by:

- good plant design, fabrication and installation, including the use of high-standard components;
- regular plant maintenance;
- good plant operation;
- good management of safety on site;
- regular inspection of the installation, with repair and replacement of components where necessary.

Works management should consider the possible causes of major accidents, including:

- component failure;
- deviations from normal operation;
- human and organizational errors;
- accidents from neighboring plant or activities;
- natural occurrences and catastrophes, and acts of mischief.

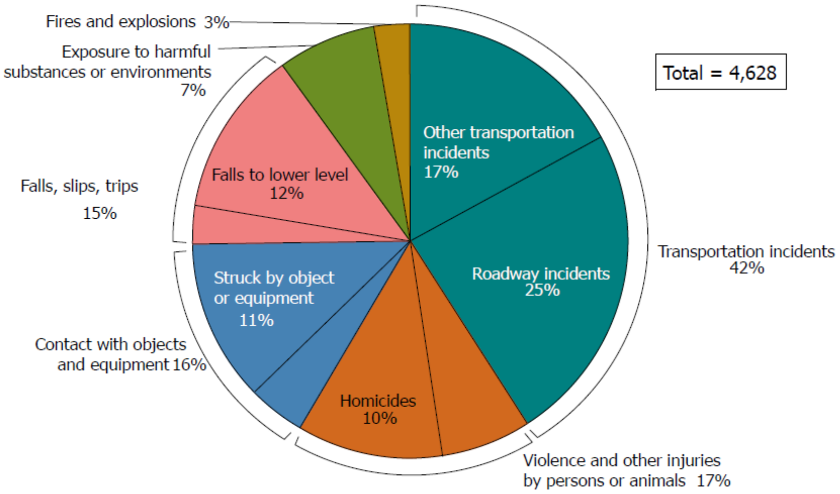

Figure 3: Fatal occupational injuries, by major event, 2012 (U.S. Bureau of Labor Statistics)

Works management should regularly evaluate these causes taking into account any changes in plant design and operation. In addition, further available information arising from accidents world-wide and technological developments should be included in this evaluation.According to “Census of Fatal Occupational Injuries, 2012” (U.S. Bureau of Labor Statistics), more fatal work injuries resulted from transportation incidents than from any other event in 2012. In U.S. roadway incidents alone accounted for one out of every four fatal work injuries (Census of Fatal Occupational Injuries Summary, 2013)while fire and explosion accidents include only 3% (Figure 3).

Low degree of danger is also shown in the diagram about safety performance by Industry Sector in Figure 4 where chemical sector is safer than many other (such as metal industries, transportation, public utilities, etc.).

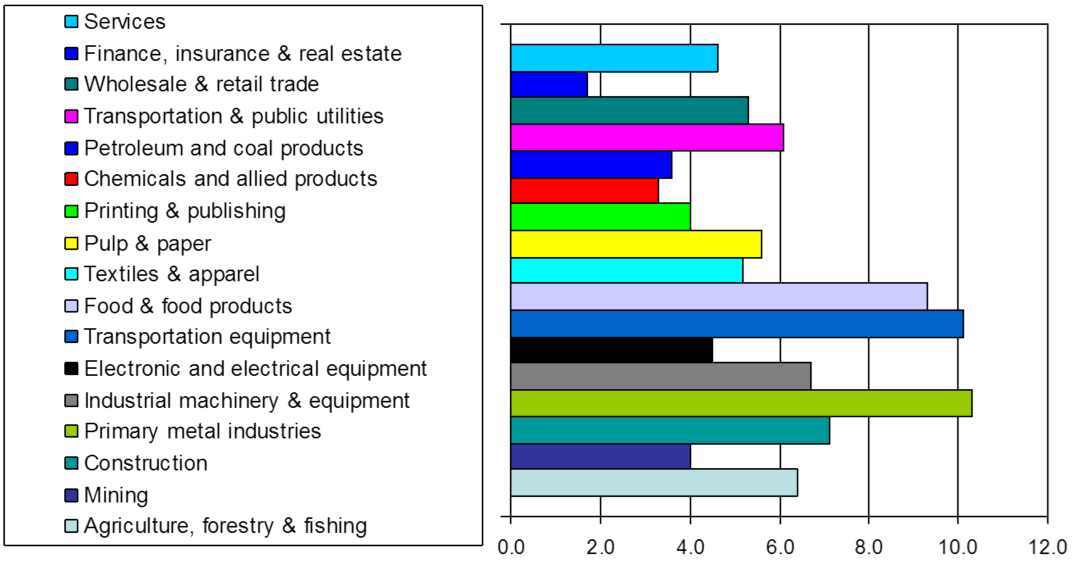

Figure 4: Safety Performance by Industry Sector (http://www.bls.gov/iif/)

One of the main objectives of this chapter is to provide a rapid view of the FCH industry, processes, infrastructure and applications mapped to a set of safety hazard and risk factors and documented in a format allowing quick and complete understanding of the potential safety issues.

Figure 5: Approach map safety issue

A comprehensive map (in Annex I) was built to have a clear understanding of the safety issues.

Following the categorization developed in H_2TRUST, the same approach (visualized in Figure 5) was used for each area of application to describe:

1. **Incidents** which are more common;
2. **Lesson learned** from the incidents;
3. **Protection system** that is recommended.

As described in the WP2, we started from the cycle of hydrogen production to the phases of storage and distribution, refueling and consumption (vehicles and non –vehicles use) (Figure 6). For each stage we mapped a set of safety hazard and risk factors. During the generation (water electrolysis or steam reforming) combustion, fire and explosion are considered. After that, during the phases of distribution for liquid state risks of the low temperature effects are analysed and in the last part of the processes such as storage, distribution, refueling and consumption phases pressure releases are studied. Obviously, the analysis takes into account of human health effect of hydrogen during the entire cycle.

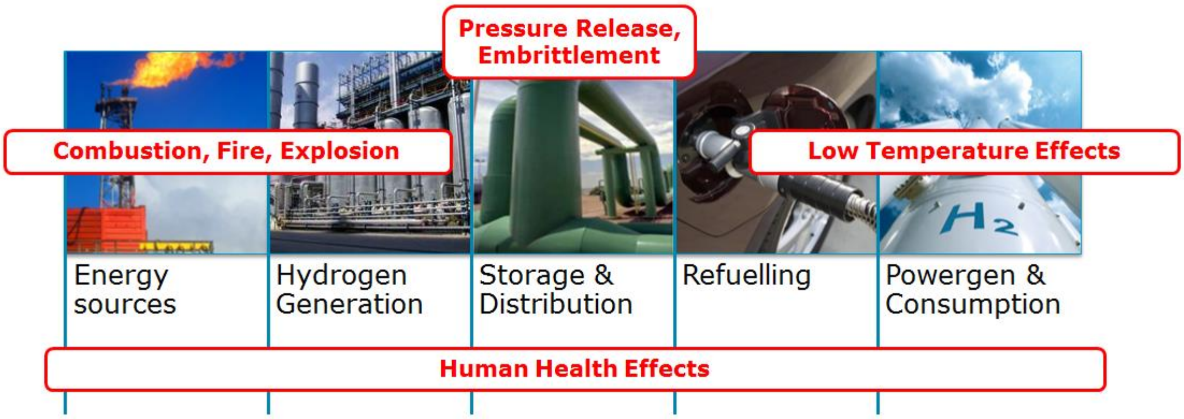

Figure 6: Mapping safety issues

1.1 H_2 production

Safety map (in Annex I) separates two main hydrogen production processes:

- Steam reforming of Natural Gas
- Alkaline electrolysis System

For each case Incident, Lesson Learned and Protection System are described. From literature and available data it was possible to identify the main risks. Particular attention has been paid to explosions, embrittlement and cracking as risks associated to the production phase. Actually, these kinds of incidents happened in very few cases, as it is possible to see on HIAD portal. In this paragraph some more details are provided. It’s important to notice that in “Steam reforming of natural gas” process the hazardous materials were mapped in Figure 7 in each production phase because not only Hydrogen can release or create emergency, but also a quite long list of other chemicals (listed in deliverable 3.1, section 1.3.2). The figure 7 gives an example of configuration related to alarge scale hydrogen production through steam reforming from natural gas, and it pointing out the materials in the elements.

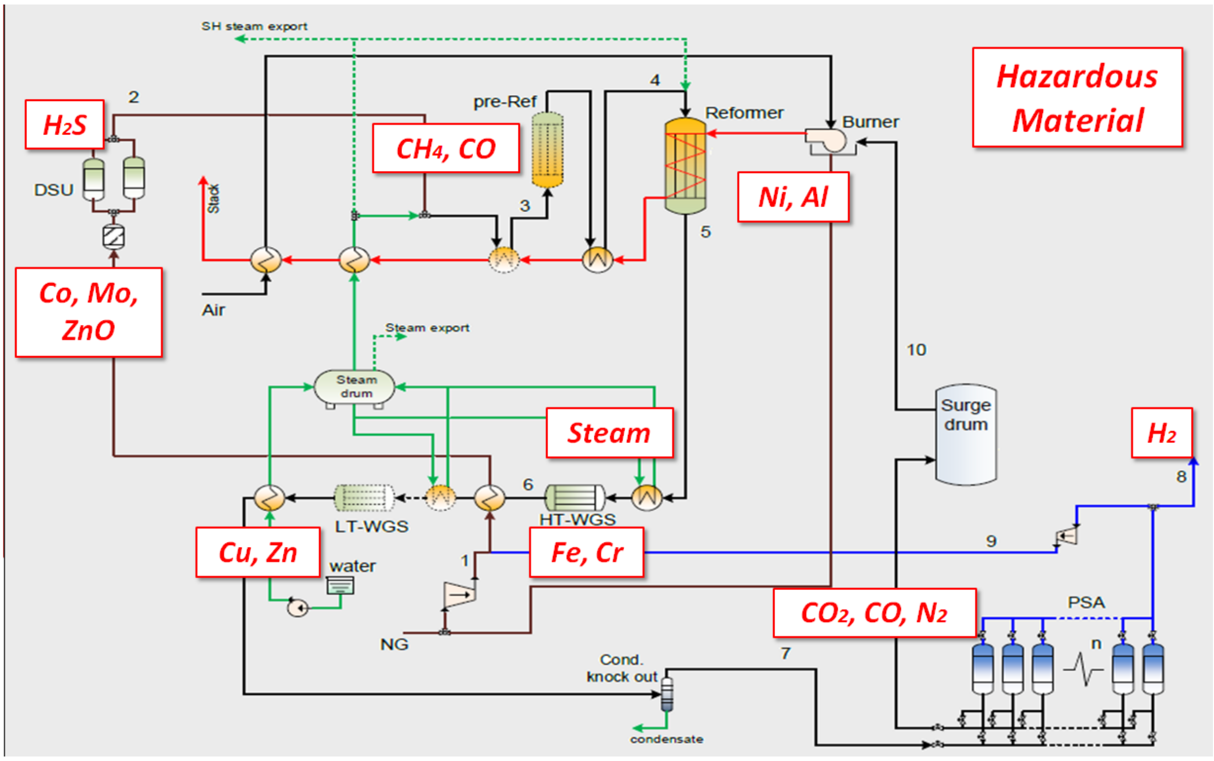

Figure 7: Hazardous Materials in Hydrogen production (steam reforming from NG).

Other chemicals involved in this process not shown in the picture and susceptible of creating an emergency event are: ammonia (NH_3), amines (NH_2), argon (Ar), caustics, chlorine, diesel fuel, monoethanolamine (MEA) and monodiethanolamine (MDEA), sodium hydroxide (NaOH) and Bromine (Br).Regarding the H_2 production by "Alkaline electrolysis System", the main cause of accident is due by insufficient maintenance of individual cell (mapped in Figure 8). Checking on a routine basis the individual cell behaviour and health (typically by electrical and impedance measurements) allows to monitor the deterioration of the performance and supply supervision alarming. Other possible sources of accident come from lack of cooling and electrolyte circulation faults. It is important to take into consideration the inverse relationship between hydrogen accidents and regular maintenance.

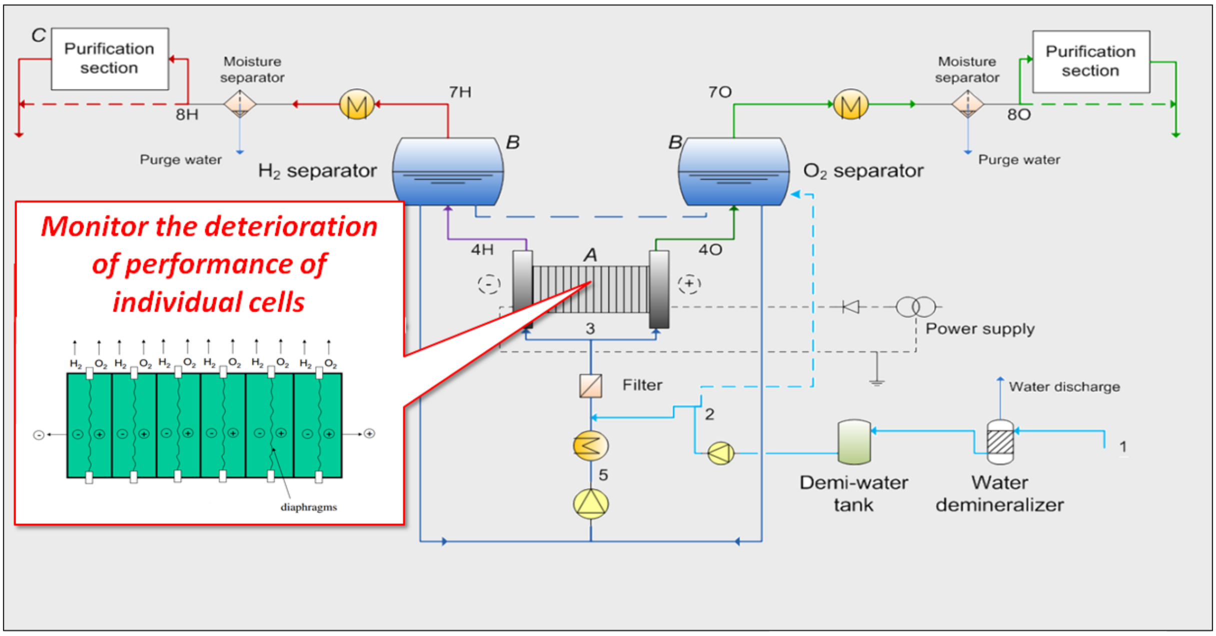

Figure 8: Maintenance of cells in an *Electrolysis system configuration*

1.2 Storage and distribution

Avalaible data from literature allow recognizing low temperature effects, pressure release such as cracking, penetration and embrittlement as main risks in storage and distribution phases. All the information have been summarized and mapped on the Annex I. The largest hydrogen storages are based on liquid hydrogen (LH_2), but it is also possible storing H_2 as compressed gas (cH_2) or solid as gas adsorbed.

In particular there are three options for H_2 transportation:

- Pipelines and tube trailers;
- Trucks, rails, barges and ships with cryogenic tanks;
- High energy-density carriers such as ethanol, methanol, and other liquids

The hazards related to storage are listed below:

- Penetration;
- Explosion;
- Weakening of Service Materials;
- Potential leaking points (seals, valves, etc.)

Potential risks are:

- Hydrogen Embrittlement (HE);
- Diffusion;
- Deflagration;
- Detonation.

Pipeline damage tolerance depends on mechanical loading, material and H_2 pressure. In the future, it expected that other innovative materials and methods will be available to store hydrogen due to::

- The development appropriate barriers (coating or surface treatment) to minimize H_2 penetration into metal materials.
- The development of new material such as:
    - New ceramic materials (compound made from mixture of calcium hexaboride, strontium and barium hexaboride);
    - Metal hybrids;
    - Glass microsphere.

Mobility and vehicles

Hydrogen on-board a vehicle may pose a safety hazard. The hazards should be considered in situations when vehicle is inoperable. When vehicle is in normal operation and in collisions potential hazards are due to *fire, explosion* or *toxicity*.

The largest amount of hydrogen at any given time is present in the tank. Several **tank failure** modes may be considered in both normal operation and collision, such as: catastrophic rupture, massive leak or slow leak.

In general terms, hydrogen appears to poses risks of the same order of magnitude as other fuels. In spite of public perception, in many aspects hydrogen is actually a safer fuel than gasoline and natural gas (see properties in Table 1). As a matter of fact, hydrogen has a very good safety record, as a constituent of the “town gas” widely used in Europe and USA in the 19th and early 20th century, as a commercially used industrial gas, and as a fuel in space programs. There have been accidents, but nothing that would characterize hydrogen as more dangerous than other fuels.

Table 1: Comparison between Explosivity Limits for different gases

	Hydrogen	**Methane/Natural gas**	**Gasoline**
Lower Flammability Limit (% in air)	*4*	*5,3/3,8*	*1*
Upper Flammability Limit (% in air)	*75*	*15*	*7,8*
Min. Ignition Energy (mJ)	*0,02*	*0,29*	*0,30*

1.3 Non-vehicles and residential power generation

Hydrogen supplied to buildings (e.g. residential) can be used to provide energy in the form of heat and electricity by using fuel cells (FC) as combined heat and power (CHP) generators. There are two CHP options, i.e. *CHP-based natural gas* and *CHP-based pure hydrogen*. The advantages of CHP Fuel cell systems for households include low noise level, potential for low maintenance, excellent part load management, low emissions, and a potential to achieve an overall efficiency of 85-90% even with small units.

There are a wide range of applications but it still missing a normative framework and the research highlight a lack of documentation.

As stated in Deliverable 3.1, a set of safety hazard and risk factors were analyzed in the map in attachment in:

- Small or Medium application with FCH (from hundreds of Wh to few kWh)
- Big Plant for energy production (from hundreds of kWh to MWh)

In both cases from a safety, codes and standards perspective, the fundamental challenges to the commercialization of hydrogen technologies are the lack of safety information on hydrogen components and systems used in a hydrogen fuel infrastructure, as well as the limited availability of appropriate codes and standards to ensure uniformity and facilitate deployment.

For these reasons industry has developed new safety designs and equipment because hydrogen’s properties and behavior are different than the fuels commonly used (see D3.1 for practical examples and case studies). Hydrogen will make us re-think operating practices already in place for gaseous and liquid fuels. Education of those differences is the key enabler to making hydrogen a consumer-handled fuel in order to be used safely and responsibly.

Chapter 2: Best Practices

Safe practices in the production, storage, distribution, and use of hydrogen are essential for the widespread acceptance of hydrogen and fuel cell technologies. In this chapter best practices of similar industries have been considered and, where possible, taken as a guiding reference to be translated into hydrogen.

In general, potential hazards in any work, process or system should always be identified, analyzed and eliminated or mitigated as part of sound safety planning. Other safety aspects that may be adversely affected by a failure should be considered. These aspects include threats or impacts to:

- **Personnel.** Any hazards that pose a risk of injury or loss of life to personnel and the public at-large must be identified and eliminated or mitigated. A complete safety assessment considers not only those personnel who are directly involved in the work, but also others who are at risk due to these hazards.
- **Equipment.** Damage to or loss of equipment or facilities must be prevented or minimized. Damage to equipment can be both the cause of incidents and the result of incidents. An equipment failure can result in collateral damage to nearby equipment and property, which can trigger additional equipment failures or even present additional risks. Effective safety planning considers and minimizes serious risk of equipment and property damage.
- **Business Interruption.** The prevention of business interruption is important for commercial entities. Hazardous events may lead to interruption in providing service or product. A complete safety plan in these instances would also include a contingency plan for providing needed services or manufacturing.
- **Environment.** Damage to the environment must be prevented. Any aspect of a natural or built environment that can be harmed due to a failure should be identified and analyzed. A qualification of the failure modes resulting in environmental damage must be considered.

Fortunately, the gas hydrogen industry doesn’t need to start from scratch with respect to safety and risk. Even the industry’s most vocal critics in the environmental community acknowledge that many of the concerns they raise could be addressed if the best practices of some producers were followed more widely and consistently at all new gas production. That gives the industry a unique opportunity to use its own expertise to solve these challenges, before regulators decide how they should be solved. Moreover, there is already a good foundation of best practices to build upon. Here we summarize two of the main reference industry that could be looked at to find best practices in the way safety aspects, hazard and risk assessment have been addressed appropriately.

LPG Industry

The term LPG is an abbreviation for Liquefied Petroleum Gas and refers to hydrocarbon products, sometimes also described as light fractions. Butane and Propane are the predominant constituents of LPG.

In common with other forms of energy, LPG can be hazardous unless it is properly handled in a controlled manner. It is potentially hazardous from the time of production until it has been used and the products of combustion have been disposed of safely.

The principal potential hazard with LPG is fire and explosion. This derives from its inherent quality of high flammability and in extreme cases may combine with another condition, i.e. high pressure, and lead to the BLEVE (Boiling Liquid Expanding Vapour Explosion) phenomenon. This is a type of explosion that can occur when a vessel containing a pressurized liquid is ruptured due to high temperature and pressure. Such explosions can be extremely hazardous. There are also hazards incidental to the various modes of transport for distribution and use.

Basic safety principles of the LPG industry that can be replied in hydrogen industry are:

- In planning or evaluating proposals for the location of LPG facilities due account should be taken of the hazards created and of the risks associated with those hazards within and beyond the facility, with a special attention to population;
- Participants in the LPG industry should actively promote a safety culture within their own businesses and at industry level;
- Personnel engaged in LPG operations should receive formal training by competent trainers for their normal activities and for emergencies. LPG facilities should have emergency planning and response programmes appropriate to the hazards and risks which they represent. These include correct handling procedures to avoid injury;
- Above a certain quantity LPG should be clearly identified during transportation, using classification numbers and appropriate warning signs. Appliances and equipment for the handling, transportation and use of LPG should be fit-for-purpose, correctly installed and well-maintained. Sub-standard appliances, equipment and installations should be excluded if necessary by regulation.

Natural Gas Industry

Natural Gas (NG) is a hydrocarbon gas mixture consisting primarily of methane, but commonly includes varying amounts of other higher alkanes and even a lesser percentage of carbon dioxide, nitrogen, and hydrogen sulfide. NG is an energy source often used for heating, cooking, and electricity generation. It is also used as fuel for vehicles and as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals.

In NG industry the primary aims of gas control systems is to prevent explosions and asphyxiation risks (especially in underground coal mines). Protection measures are available to reduce the propagation of an explosion after it has occurred and are important second lines of defence.

The fundamental principles of reducing explosion risk, suitable also for hydrogen industry, are as follows:

- Wherever possible, prevent occurrence of explosive gas mixtures (e.g., use of high-efficiency methane drainage methods, prevention and dispersal of methane layers by ventilation velocity);
- If explosive gas mixtures are unavoidable, minimise the volumes of explosive mixtures (e.g., rapid dilution in ventilation air to permissible methane concentrations);
- Separate unavoidable gas mixture occurrences from potential ignition sources (e.g., by using especially designed face-end ventilation systems to prevent gas accumulations near electric motors or avoiding use of electricity in longwall district return airways);
- Avoid ignition sources as much as possible (e.g., unsafe electric devices, naked flames, smoking);
- Control gas emissions from worked-out, sealed areas of the mine by using gas drainage methods regulated to maintain gas purity and by draining gas to accommodate fluctuations in barometric pressure.

On top of the above-mentioned technical best practices, consumer safety awareness campaigns are an essential part of gas safety principles which could be translated to the hydrogen case, and which should emphasize:

- The quality/safety linkage for gas, appliances and equipment including safe practices;
- The risks associated with inferior installation standards and/or practices;
- The need for care and in particular for adequate ventilation;
- How to recognise the risks and the action to take when gas is used and an incident occurs.

Chapter 3 – Recommendations

This chapter describes the recommendations corresponding to the results presented in Deliverables 3.1, 4.2, and 4.3 and takes the results of the other studies already performed under the H_2TRUST project into account as well.

As stated in the FCH-JU2 Multiannual Work Programme, "*Fuel Cell and Hydrogen (FCH) technologies hold great promise for energy and transport applications from the perspective of meeting Europe's energy, environmental and economic challenges. The European Union is committed to transforming its transport and energy systems as part of a future low carbon economy. It is recognised that FCH technologies have an important role in this transformation and are part of the Strategic Energy Technologies Plan (SET-Plan).*"

In the last years Europe has deployed several efforts at different levels to increase the level of deployment of FCH from a technological, as well as policy and public awareness point of view.

As most recent development, The EU Directive on the deployment of alternative fuels infrastructure (among them hydrogen), approved on 29/09/2014, aims at addressing the missing links of the single transport market, namely by:

- The build-up of an EU-wide network of recharging and refuelling points
- The development of harmonized EU-wide standards and common technical specifications
- The provision of relevant, consistent and clear consumer information

On the other hand, Research & Innovation at European level led to the creation of the Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) public-private initiative in 2008, with the aim of close coordination between public and private stakeholders, in order to maximise cost efficiency and accelerate the technological shift. The FCH-JU was founded in 2008 to develop and implement a targeted R&D programme with an initial total budget of €940 million up to 2013, of which 50% was contributed by the EC and 50% by the participating members.

The success of the first round of Calls brought the EC and involved stakeholders to lunch the 2nd round of FCH-JU for the period 2014-2024, with an increased overall budget up to 1,3Bln€, with the same share between EC and participating members.

Methodology

The recommendations presented in this chapter have been created by constructing specific typologies of the results presented in deliverables 4.1. – 4.3. Moreover, a Roadmap and an Action Plan[1,2] on hydrogen technology in Europe were taken as a starting point, to be able to reflect in this Task what is already initiated in Europe and what future initiatives are being / should be deliberated. In line with the above-mentioned overall approach at European level and the work already done, the H_2TRUST consortium organized the recommendations following the following categories:

CATEGORY 1: TECHNOLOGY AND INFRASTRUCTURES

- Overview of state-of-the-art technologies and infrastructures;
- Recommendations for further technical R&D in FCH technologies, including infrastructure deployment;
- Recommendations on how to improve current knowledge and infrastructures;

CATEGORY 2: REGULATIONS, CODES AND STANDARDS (RCS)

- Overview of state-of-the-art regulations, standards and codes;
- Recommendations on how to implement an industry-led RCS strategy coordination function to ensure that the needs of European stakeholders are well addressed, industry collaboration is supported and to establishment of an efficient regulatory EU framework which provides a greater alignment between EU and national RCSs;
- Recommendations on how regulations standards and codes could minimize the risk of accidents and hazards for the general public, but also for the production, transportation and storage and use of hydrogen for non-industrial applications in the public domain.

CATEGORY 3: TRAINING, EDUCATION AND PUBLIC COMMUNICATION

- State-of-the-art on Training, Education and Public Communication initiatives;

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[1] http://www.ecn.nl/docs/library/report/2008/b08008.pdf

[2] ROADMAP 2050, a practical guide to prosperous low carbon Europe - European Climate Foundation (ECF).

- Recommendations on how to train and educate the main actors in the field of Hydrogen technology: Professionals, regulators and Public Safety Officials and the General Public.
- Recommendations on inspections and preparative action recommendations for crisis management planning;
- Recommendation on Public Communication, Outreach and dissemination activities for an effective support in mass-spread deployment of FCH technologies in the public domain.

This document starts with describing an overview of the state-of-the-art in each of the three categories selected for this Task in H_2TRUST. This provides insight into the measures that are currently in place, but even more importantly, also provides insights into which types of measures are not used in each of the categories (gap analysis). These insights will provide important input for developing the recommendations in this Task, which are presented at the end of each category. Finally, an overview of the main recommendations with regard to the Roadmap and Action Plan is presented in Annex to this document, including recommendations for (immediate) FCH deployment, in short-term, mid-term and long-term timeframes.

3.1 Research, Technology and Infrastructures

FCH Technologies are indeed at a mature stage from several points of view, and it reached already commercial deployment in several application areas.

The status of the technological development and the gaps that need further effort are extensively analysed and addressed in several EC strategic Documents, such as (non-exhaustive list):

- the recent "FCH-JU Multiannual Work Programme 2014-2020" (2014),
- the NEW-IG FCH-JU, "Fuel Cell and Hydrogen technologies in Europe, Financial and technology outlook on the European sector ambition 2014- 2020" (2011);
- the EC-JRC's publications "Prioritisation of Research and Development for modelling the safe production, storage, delivery and use of hydrogen" (2011), and "State of the art and research priorities in hydrogen safety" (2014)

From an in-depth analysis of these documents, the main points relevant for H_2TRUST could be summarized as follows:

- ➢ In the transportation sector, FCH technologies are most advanced in propulsion applications for fuel cell electric vehicles (FCEVs), i.e. passenger vehicles and buses. For instance, some car manufacturers have already announced the market introduction of FCEVs in 2015 and the following years (e.g. Toyota[3] and Hyundai[4]);
- ➢ A European wide network of hydrogen refuelling stations (HRS) has yet to be established, although numbers are now approaching 100;
- ➢ Non-road applications of FCH are primarily in the form of Auxiliary Power Units (APU) for aviation, maritime, rail and the off-road sectors. The levels of maturity are generally lower than for road propulsion, with further developments necessary;
- ➢ In the energy sector, FCH technologies are used in a wide range of applications and have great promise in the integration of intermittent renewable energy sources into the overall energy system. However, the key technologies of electrolysis, large scale storage and injection of hydrogen into the grid require development.

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[3] http://www.toyota.com/fuelcell/

[4] http://worldwide.hyundai.com/WW/Showroom/Eco/ix35-Fuel-Cell/PIP/index.html

Europe is a technology leader in many of the above-mentioned FCH technologies and very competitive in others. Lots of effort has been put by the EU to support R&D and technology development of FCH in the last decades. Since 1986 the EU has funded **some 200 projects** on hydrogen and fuel cell energy technologies with a total contribution of over EUR 550 Mio[5]. Main topics of these projects could be grouped in the following categories:

- Hydrogen production, including from renewable sources;
- Hydrogen distribution;
- Hydrogen storage;
- More durable and cost-effective fuel cells;
- Integration of fuel cell technology in stationary power applications;
- Hydrogen-fuelled vehicles;
- Best policies to promote a transition to a cleaner energy system benefiting from hydrogen technologies.

Fuel Cell and Hydrogen technologies are currently supported through the Fuel Cells and Hydrogen Joint Technology Initiative (FCH-JTI), aiming at improving research, technological development and demonstration to accelerate the commercialization of FCH technologies in a number of application areas.

Under the FCH 1 JU (2008-2013), FCH technologies have made significant progress, especially in terms of reducing life-cycle cost and increasing their overall performance. This has enabled the commercialization process to begin within some specific market segments, e.g. passenger cars, buses, materials handling vehicles, back-up and portable power. However, the levels of cost competitiveness and performance required for large-scale deployment have not yet been achieved. Furthermore, important framework conditions required to foster widespread commercialization of these technologies, such as the infrastructure to sustainably produce, distribute and store hydrogen, end-user confidence and the availability of appropriate regulations, codes and standards have not yet been fully met. The new FCH-JU2 Program was launched in July 2014 under the new Horizon 2020 prerogatives, with the following specific objectives:

- reduce the production costs of fuel cells used in transport applications whilst increasing their lifetime to levels competitive with conventional technologies;

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[5] http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=research-fch-support

- increase electrical efficiency and durability of the different fuel cells used for power production, whilst reducing costs for power and CHP applications to levels competitive with conventional technologies;
- increase energy efficiency of the production of hydrogen from water electrolysis and renewable sources whilst reducing operational and capital costs so that the combination of the hydrogen and the fuel cell system is competitive with the alternatives available in the marketplace;
- demonstrate on a large scale the feasibility of using hydrogen to support the integration of renewable energy sources into energy systems including through its use as a competitive energy storage medium for electricity produced from renewable energy sources; and
- reduce the use of EU defined ‘critical raw materials’.

The FCH-JU2 Programme is structured around two research and innovation Pillars dedicated to Transportation and Energy Systems and complemented by a number of Overarching projects (integrating both transport and energy technologies) and a cluster of Cross-cutting research activities.

There’s a clear input on dealing with more demonstration projects (“Innovation Projects” type have approximately 66% of budget reserved). In the view of the FCH-JU members and the EC, these key technical developments, such as prototyping, piloting, testing and demonstrations, should accelerate the achievement of large scale production volumes, taking into account issues around simplifying and harmonizing regulation (for example in authorization processes for refuelling stations), standardization, consumer awareness and public procurement.

For what it concerns **safety and risk assessment**, as stated in the above-mentioned 2011 JRC study “*Hydrogen safety issues must be addressed in order to ensure that the wide spread deployment and use of hydrogen and fuel cell technologies can occur with the same or lower level of hazards and associated risk compared to the conventional fossil fuel technologies”.*

In FCH-JU2, special attention will be paid to the technology transfer from the professional community to the general public. Emphasis will be on technical safety, including, but not limited, to pre-normative research. Actions may include technology projects on safety, development of best practice guidelines, development of data bases of incidents/accidents for use in education and training, and development of intervention techniques for first responders at an incident/accident scene. Moreover, FCH-JU2 will look at **innovative safety strategies and safety solutions** that: support both Pillars and protect lives and property at levels not below that for fossil fuel technologies, and allow commercial deployment of the FCH technologies (e.g. separation distances where appropriate, mitigation measures etc); Best practices and guidelines for various emerging FCH applications; Intervention techniques and procedures for first responders for different situations (outdoor, indoor, etc.) and different technologies; New safety culture at the customer level.

Gap analysis

A relevant and detailed gap analysis for research priorities in hydrogen safety has been recently performed by JRC and HySafe network in the above-mentioned 2014 Report. On the other hand, is not the aim of H_2TRUST to perform a complementary analysis under this point of view. At the same time, looking on the considerable efforts that the EC and relevant stakeholders are putting in this field, the H_2TRUST partners, using H_2TRUST documents (mostly Deliverables 3.1, 4.2 and 4.3) and desk research from different sources, came up with the following statements related both to safety and general public awareness:

- Technological safety has been proved at small-to-medium level for production (see for example projects under FCH 1), but probably more efforts are needed at larger scale and on a large number of applications and case studies;
- There is extensive production of technical guidelines, specifications, standards, etc. already developed at industrial level in the past years. However more efforts are needed in translating the technology safety to a more public domain (i.e. vehicles, stationary production and refueling stations in public areas, households). Here technology (as well as standards) developed by industry could be taken as a first reference point, but for sure adaptation and harmonization will be needed, also including safety aspects;
- There's a considerable lack of data and information available at European level on safety-related aspects, including accidents/incidents databases, updated monitoring reports, etc. The HIAD database is a good initiative, but need to be strengthen considerably and the database populated at a higher level of granularity. The comparison with the situation in other world Regions (i.e. USA) is compelling, calling for an immediate action to fill this gap. Information is lacking and dispersed in Europe at the moment;
- Moreover there's a lack structured organizations/bodies in charge of monitoring and promoting safety aspects at European level. The only relevant initiatives in this sense

are the network structured around HySafe and the EC-JRC Institute for Energy and Transport, but they look more concentrated on Research priorities;

- There is a need of more demo projects, including actions devoted to safety aspects (technological and non-technological). For example, up to now level of demo projects in FCH-JU for stationary applications of H2 production trough electrolysis is in the range of 1-100kW at stack level, or 500kW-1MW for stationary production plant (i.e. recent PowerUP project). Upscaling to 2-5 MW power installations, as well large deployment as parallel or series of smaller modules is needed, working on connections, interactions, synergies, etc. This includes elements of safety to be taken into account in the upscaling of the plants/applications. For Transport: there is still a need for larger fleet deployment (cars, buses), as well as larger refuelling infrastructure projects, both in the number of several hundreds. What is missing is also a large number of projects and especially at large scale to collect also a critical mass of data to create statistical evidence on accidents/incidents-related issues and/or best practices on how to address safety aspects in large scale projects;
- Lack of infrastructure – Hydrogen Refuelling Stations (HRS). As anticipated, a full deployment of a European hydrogen infrastructure is probably at its infancy and need concerted support by EC and Member States. A relevant barrier to infrastructure deployment is the high investment required to put hydrogen in the HRS. Another point related to this, is that people is reticent to change to the hydrogen technology in vehicles because there are not enough HRS with hydrogen to drive without restrictions, thus alimenting a vicious circle. To this end, even the most recent Directive on deployment of alternative fuels infrastructure issued on 29/09/2014 has not been designed to ensure infrastructure coverage for H_2 in all the EC countries, but at least it creates a platform for the approval of a set of harmonized standards related to HRS.
- Lack of infrastructure - hydrogen distribution grid: thinking of a wide-spread hydrogen grid, such as the one for NG, is still considered a futuristic vision for dreamers. However, if we compare the development and deployment of NG with the one of H2, and the higher environmental benefit that the latter brings, it becomes reasonable to think that in the mid-term, hydrogen will become a mass-spread gas and energy carrier used at all levels, from industry to households, from vehicles to planes. To this end, the formation of a future hydrogen grids could start from already existing and emerging initiatives at industrial district level in Europe, where the hydrogen waste streams from several industries (i.e. chemical companies) are starting to be used by other industries in the vicinities (or the same industry) for the production of electricity. Up to now this model

proved still not economically viable, due mainly to the high costs associated to FCH technologies, but this is rapidly changing. Two examples are the new AIRPRODUCTS HyCO unit in the port of Rotterdam, which capture already and save a high quantity of CO_2 due to its integration with the Exxon refinery[6], and the recently FCH-JU funded PowerUp project[7]. Moreover, this is in line with the rapidly emerging "industrial symbiosis" paradigm and with the objectives of the Manifesto of the European Resource Efficiency Platform (EREP, 2012). A possible role of 'bridging technology' could be played by the power-to-gas (P2G) projects aiming at partial hydrogen injection in the NG pipelines, developed for the purpose of electric grid balancing of non-dispatchable renewables like large wind power plants[8].

- Crisis management planning (especially in public domain areas): up to date the crisis planning of FCH plants is mainly left to industrial partners, and it follows consolidated industrial rules and procedures. These are surely sound from an industrial point of view, but probably lack to take into consideration elements to improve the acceptance and the perception on hydrogen currently present in the public domain.

Analyzing the above-mentioned gaps and issues, the following **recommendations** could be inferred by the H_2TRUST tasks and deliverables, as well as additional sources searched for the purpose of this study:

➢ Creation of a statistical mass of projects/data and structured information at European level. H_2TRUST strongly supports the consolidation/revamping of existing and/or new databases on accidents/incidents (e.g. HIAD), crucial to establish a statistical source of information for monitoring safety aspects in all FCH applications at European level. Moreover, we propose the creation of a structured organization (or the strengthening of existing ones, such as HySafe and EC-JRC) acting as constant observatory on FCH safety and risk assessment, to become a EU think-tank on safety of hydrogen, etc.., able to monitor the situation of safety, produce updated reports with a statistical basis (e.g. at least annually),

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[6] http://www.portofrotterdam.com/en/News/pressreleases-news/Pages/air-products-factory-fits-perfectly-long-term-development-industry.aspx

[7] http://project-power-up.eu/2014/project-description/

[8] See for instance : http://www.northseapowertogas.com , and http://www.dena.de/en/projects/renewables/power-to-gas-strategy-platform.html

guide the debate on safety and risk associated to such an emerging and crucial energy technology for Europe.

- Increase the funding of large demo projects (in scale and numbers), also using different sources of financing (R&I funds, structural funds, private investments, loans, etc..). Moreover, more efforts in ensuring continuation of a project after ending its demonstration phase can also be seen as fruitful.
- Wherever possible, foster H_2 use to implement and enlarge industrial symbiosis could help to structure small grids at local level and prepare for further deployment of a future H_2 grid. To this end, a mix of public funds/incentives, coupled with the decreasing cost of FCH technologies, could turn the Business model appealing. On the other hand, fostering industrial proactivity and concerted action in this sector could lead to a successful deployment of this model, at the same time guaranteeing that safety elements are fully taken into account as intrinsic development and planning of industrial projects (i.e. risk assessment and risk management practices at district level, etc.)
- Enforce crisis management activities specifically dedicated to address safety aspects and with the aim of increasing the level of acceptance of FCH technologies and hydrogen at large in the public community. This could include, for example, working with the local communities to explain safety aspects linked to hydrogen.
- Improving the refuelling infrastructure to the several hundred numbers of points around Europe; to this end, the recent Directive on the use of alternative fuels should help implementing a more structured refueling infrastructure, also through the definition at Member State level of an appropriate number of points for refueling by 2025;

3.2 Regulations, Codes and Standards

Regulations, Codes and Standards (RCS) are critical to establishing a market-receptive environment for commercializing hydrogen-based products and systems.

A good level of information on the state of the art of RCS was already provided in H_2TRUST Deliverables D3.1 (chapter 5) and D.4.3, highlighting main gaps and future deployments.

We can add here that, in general terms, Standards development is getting at an advanced with ISO and SAE standards providing globally harmonized requirements with regards to key items such as:

- hydrogen refueling interface,
- hydrogen fuel quality,

- hydrogen refueling station safety and lay out requirements.

These standards are foreseen to be validated and ready by 2016.

In the regulatory area, some important steps have already been made such as the European regulation for EC type approval of hydrogen fuelled vehicles (2009-2010). The next objective for the transport sector is to have an efficient EC framework supporting large scale deployment of hydrogen fuelling stations and the associated hydrogen production and supply systems.

Although standardization of the interface between FCEVs and the HRS as well as filling protocol standards are already being agreed on the basis of applicable standards, such as those developed by SAE and ISO, it is still necessary to complete the standardization work for HRS. Examples of this work include the purity of the hydrogen delivered by the HRS, the accuracy of the measurement of the amount of hydrogen dispensed to the FCEVs and its temperature level.

For what it concerns what Europe is doing or is planning to do in the next years on RCS, As anticipated in the previous paragraph, as part of the FCH-JU, the EC and other members intend to implement a programme of research, technological development and demonstration to enable the bringing to the market of the most promising applications in stationary and portable power generation and transport. This will go hand in hand with the elaboration of new regulations and standards, which are essential for every new technology to assure safety, reliability and interoperability.

Participation in standards development and definitions necessary for market deployment is part of the FCH-JU Multiannual Programme 2014-2020. Moreover, Cross-cutting deliverables supported by the FCH 2 JU, will include an industry-led RCS co-ordination activity.

As stated in the JRC 2014 report, one of the key areas, preferably to be carried out through international cooperation, is pre-normative research for the establishment of fit-for-purpose Regulations, Codes and Standards (RCS) to ensure fuel cells and hydrogen technologies are deployed safely.

To this end, the new FCH JU 2, building upon the work started in the FCH 1, include harmonization of testing procedures and of reporting templates, as well as establishment of commonly agreed representative loading profiles (stressors) for different applications of FCH technologies, such as automotive and stationary fuel cells. Particular emphasis will be placed on aligning with international efforts in this area e.g. USA and Japan.

Gap Analysis

An extensive technological roadmap has been prepared by the NEW-IG FCH-JU in 2011, as appendix to the Document “Fuel Cell and Hydrogen technologies in Europe, Financial and technology outlook on the European sector ambition 2014- 2020” (see Figure 9). As part of this roadmap, a particular focus was dedicated to RCS and Pre-normative research. It was evidenced in the roadmap that further efforts are needed for instance with regards to fire safety of hydrogen storage systems, lifetime assessment of metallic components in hydrogen service, or metering of delivered quantities.

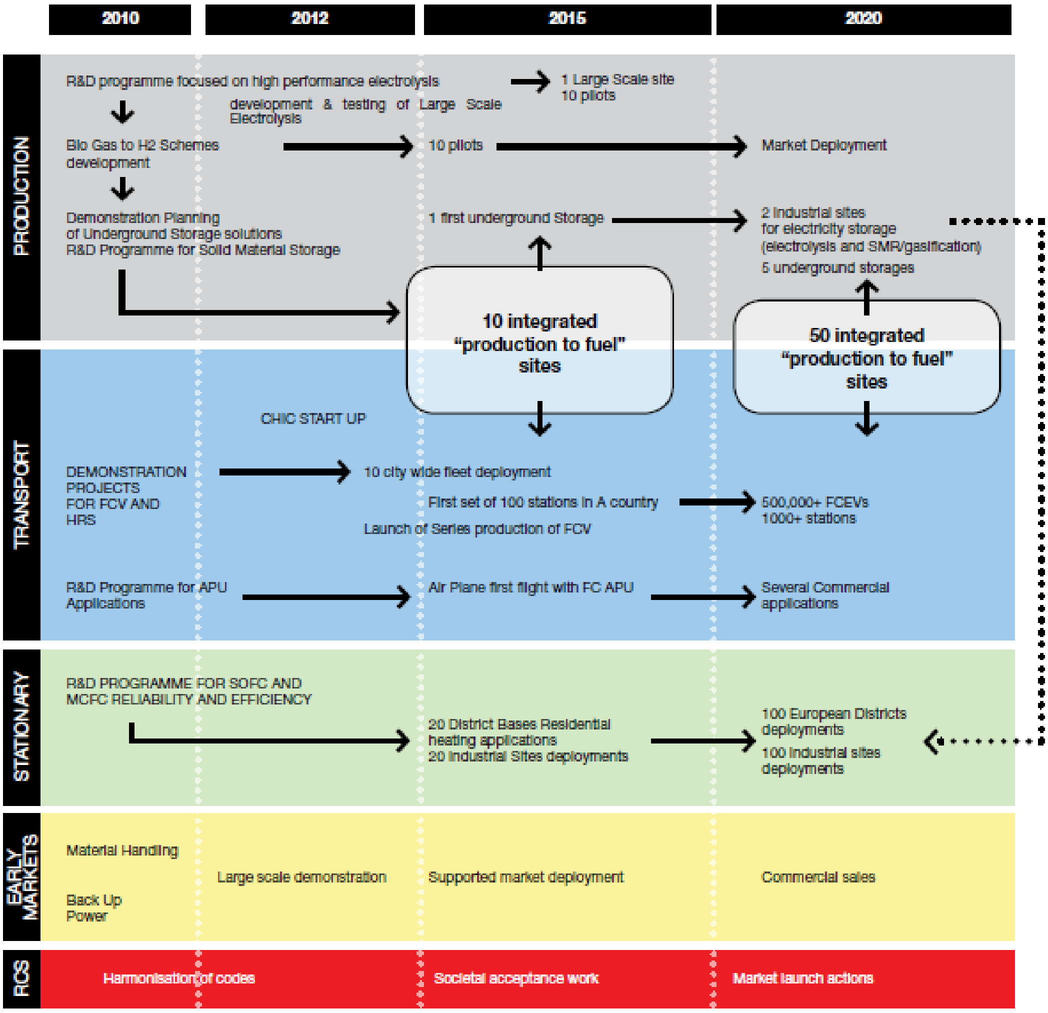

Figure 9: FCH technological roadmap (Source: NEW-IG, 2011)

As a general comment to the 2011 roadmap, it can be said that harmonization of codes and standards is still viewed in 2014 as a main issue and concern by the industrial community. No specific and unique RCS is still present at European level for FCH, while the wide range of technologies, applications sectors and stakeholders involved make it more difficult to come up with a comprehensive framework.

This issue is especially sensed by stakeholders when thinking to the deployment of FCH to public domain applications.

To this end, Europe is currently working on harmonization of regulations and the definition of a single reference legislation. For instance, The Directive of the European Parliament and of the Council on the deployment of alternative fuels infrastructure (among them hydrogen), approved on 29/09/2014, aims to the development of harmonized EU-wide standards and common technical specifications. The above-mentioned main standards related to H_2 should be ready by the end of 2016.

If we look at a more global level, the Proposal for a Council Decision establishing the Specific Programme Implementing Horizon 2020 COM (2011)808, calls for international cooperation with third countries in order to address effectively the societal challenges defined in Horizon 2020. In particular, development of worldwide standards and guidelines is considered as a major enabler to increase the competitiveness of the hydrogen industry.

Analyzing the state of the art and gaps in the H_2 RCS sector, the H_2TRUST partners came up with a series of recommendations for the implementation of an industry-led RCS strategy coordination function to ensure that the needs of European and global stakeholders are well addressed by international standards and to support the establishment of an efficient regulatory framework calling out these standards where appropriate. Main recommendations in this field are as follows:

- **Improve harmonization.** Foster single and simple (clear) legislation at EU level and among Member States. Moreover, H_2TRUST partners registered in some cases an excess of safety measures, which often resulted in “over-engineering” of FCH facilities (production, distribution, etc..), thus resulting in an increase of costs associated to the technology and unjustified alarm in public perception. Also in stationary non-industrial and non-vehicles applications there’s a lack of safety information on hydrogen components and systems used in a hydrogen fuel infrastructure, and a limited availability of appropriate codes and standards to ensure uniformity and facilitate deployment. To this end, it could be also useful to compare the different normative of European countries (or other world regions) concerning different issues regarding hydrogen, and take the most efficient and effective ones as an example;
- **Foster industry collaboration and leadership** in safety regulation, codes and standards, in order to build up on the extensive body of codes and standards already developed at industrial level since several decades. It is needed that the legislation is generated by experts. To this end, H_2TRUST strongly supports the implementation of a system to

collect data and information for the entities appointed to the standardization and regulation, as already established by the new FCH JU2, in order to be facilitated in the pre-normative phase.

- **Revise and simplify safety standards**, especially safety distances. For example, prescribed safety zones for ATEX areas: for a particular system it is needed to have predefined how big the ATEX area is to avoid flammable atmosphere. This is often a point of discussion between customer and supplier, because there aren't specific standards setting it. In the US the NFPA standards define more what it should be done. In Europe each entity has to perform a Risk Assessment of what to do under each circumstance. Besides ATEX areas have no correlation with safety distances. Thus the setting of a specific EU standards for safety distances, as well an overall simplification of procedures will help consistently in solving these issues.
- **Strengthen RCS** also for the production, transportation and storage and use of hydrogen for non-industrial applications in the public domain, in order to ensure safety and minimize the risk of accidents and hazards for the general public. In particular, there's a need for development and consolidation of RCS that are infrastructure-specific.

3.3 Training, Education and Public Communication

Currently, several technical and non-technical resources are already available in multiple EU Member states to support training and educating of stakeholders on different levels (e.g. safety issues, risk assessment, awareness). These resources include for example creation of guidelines on how to handle hydrogen, e-learning resources for professionals, workshops and training sessions for first responders, and several consultancy services. Moreover, it is reflected that the EU is currently funding multiple European projects focusing on training and educating different stakeholders within the hydrogen value chain (e.g. HYPROFESSIONALS[9] HYFACTS[10], HYRESPONSE[11], KNOWHY[12]).

Although several resources and initiatives are currently in place, it is clear that training and education initiatives are still mostly performed on a single-purpose and short-term level, for example training a small group of first responders on how to handle fuel cell vehicles (see H2TRUST Task3.1.). While each intervention contributes to the overall aim of introducing hydrogen as a new sustainable source of energy in Europe, the actual impact for Europe remains relatively limited. Hydrogen education and training initiatives are considered to still be scattered throughout Europe. The reason why these initiatives are scattered is debatable, but the results of H2TRUST indicate that the infrastructure, resources and potential communities are existing and able to create a more coordinated effort of training and education the hydrogen value chain (or at least the early adaptors) in Europe. Hence, in order to really bridge the conceptual gap of introducing and implementing hydrogen as a new generation of sustainable fuel in Europe, there is a clear need for a European-wide strategy and integrated approach with National and Regional actions – building on already available resources and initiatives. Evidently, this includes an education and training curriculum for stakeholders in hydrogen and fuel cell technologies.

The results of H2TRUST show that education and training of the main stakeholders within the hydrogen fuel value chain needs a multi-level approach. For this reason, we carried out a multi-level analysis (Figure 10), which include the gap analysis (requirements) in this field.

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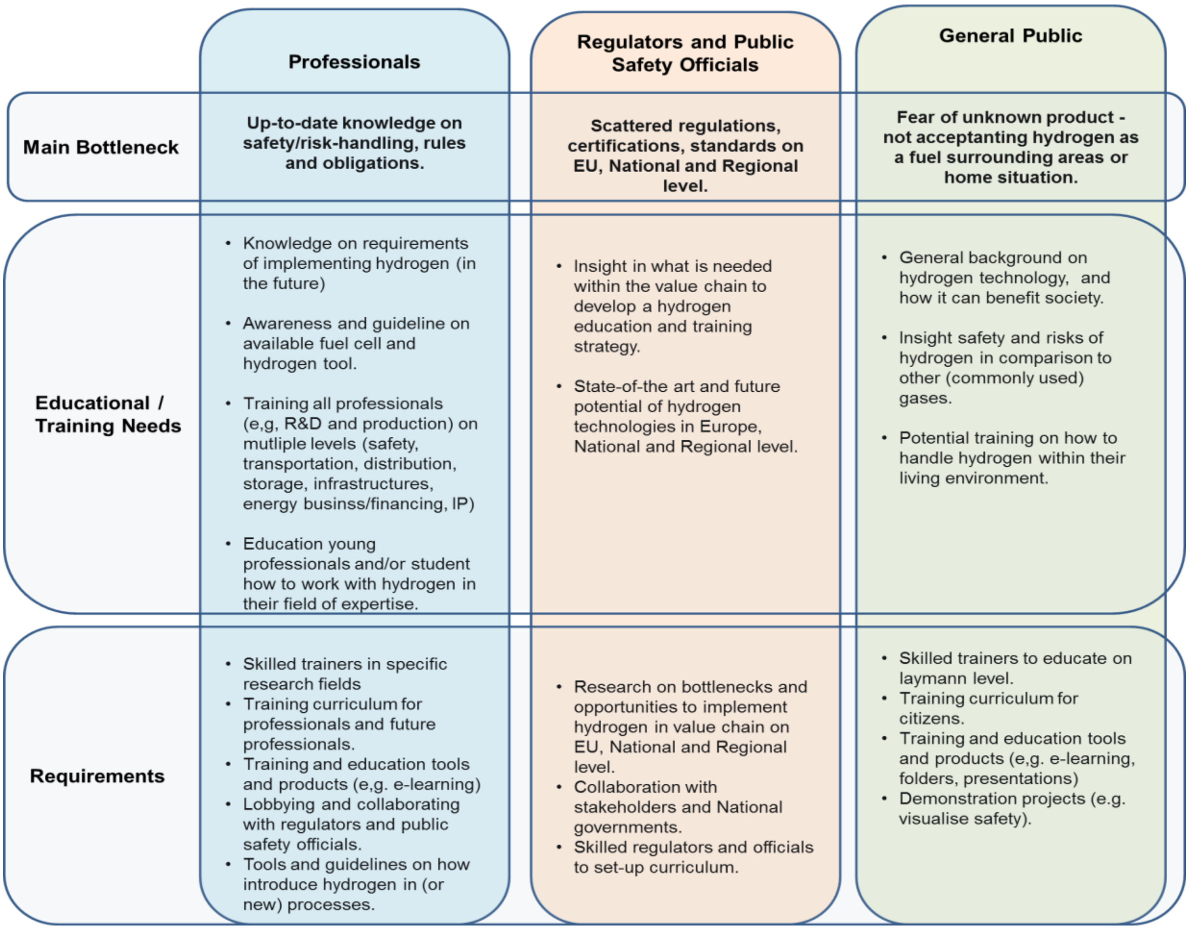
[9] http://hyprofessionals.eu/
[10] http://hyfacts.eu/
[11] http://www.hyresponse.eu/
[12] http://knowhy.eu/



	Professionals	Regulators and Public Safety Officials	General Public
Main Bottleneck	**Up-to-date knowledge on safety/risk-handling, rules and obligations.**	**Scattered regulations, certifications, standards on EU, National and Regional level.**	**Fear of unknown product - not acceptanting hydrogen as a fuel surrounding areas or home situation.**
Educational / Training Needs	• Knowledge on requirements of implementing hydrogen (in the future) • Awareness and guideline on available fuel cell and hydrogen tool. • Training all professionals (e,g, R&D and production) on mutliple levels (safety, transportation, distribution, storage, infrastructures, energy businss/financing, IP) • Education young professionals and/or student how to work with hydrogen in their field of expertise.	• Insight in what is needed within the value chain to develop a hydrogen education and training strategy. • State-of-the art and future potential of hydrogen technologies in Europe, National and Regional level.	• General background on hydrogen technology, and how it can benefit society. • Insight safety and risks of hydrogen in comparison to other (commonly used) gases. • Potential training on how to handle hydrogen within their living environment.
Requirements	• Skilled trainers in specific research fields • Training curriculum for professionals and future professionals. • Training and education tools and products (e,g. e-learning) • Lobbying and collaborating with regulators and public safety officials. • Tools and guidelines on how introduce hydrogen in (or new) processes.	• Research on bottlenecks and opportunities to implement hydrogen in value chain on EU, National and Regional level. • Collaboration with stakeholders and National governments. • Skilled regulators and officials to set-up curriculum.	• Skilled trainers to educate on laymann level. • Training curriculum for citizens. • Training and education tools and products (e,g. e-learning, folders, presentations) • Demonstration projects (e.g. visualise safety).

Figure 10: multilevel analysis of main bottlenecks, needs and requirements (gaps) for FCH traning, education and public communication

On the basis of this multi-level analysis, the H2TRUST partners formulated a more detailed gap analysis, as well as specific recommendations for each of the three categories selected, as follows:

Professionals

This stakeholder group contains all actors involved in the economic value chain of hydrogen technology, including production, handling, processing and transportation of hydrogen. The results of the Tasks reflect that professionals working with hydrogen are considered to be well aware of the regulations, certification procedures, physical properties, safety, risks and measures that need to be taken into account when working with hydrogen. On regularly basis, professionals are trained on the particularities of hydrogen handling, are most of the times familiar with procedures that need to be taken into account when handling flammable gases and follow the governmental recommendations to prevent incidents from occurring.

Training and education is periodically repeated in order, for example, to not becoming confident with repetitive tasks. Besides, mechanisms like Basic Safety Process train individuals and groups to be alerted and to detect situations of risk or risky behaviours, focusing efforts on prevention activities to reduce incidents.

Despite the training and education efforts already in place, the efforts are generally based on procedures for similar gases and do not focus on specific actor groups. For example, a specific training for emergency responders for fuel cell vehicles accidents. However, several initiatives are created on National and Regional level to specify training and education initiatives. A successful and recent example is the training programme created in the 'Introduction to Hydrogen Safety for First Reponders' project organized by the US Department of Energy (D3.1., reference number 50). In this project, the first responders are provided specific information related with the situation in order to limit the damages to property and people or avoid excessive measures. However, these initiatves remain limited and are not organised within an integrated approach. Education programmes have to ensure that new knowledge and the progress in inherently safer use of hydrogen and fuel cells reaches as much actors as possible. New education/training activities should be established in hydrogen safety involving all stakeholders, especially for experts responsible for safety in projects, e.g. funded by European FCH JU[13], to provide means to equip actors and trainers. This will sustenance driving the development of inherently safer hydrogen systems and infrastructure forward as well. Based on the results in the H2TRUST Tasks, it should be considered that this stakeholder group is in need for:

- Up-to-date knowledge on what is required (regulations, certification and standards) when implementing hydrogen technology (now and in the future) and personnel should receive specific training in dealing with emergencies involving hydrogen. In particular they should know how hydrogen explosions and fires differ from those involving the more conventional gaseous fuels such as natural gas and LPG. One example of a difference, which is of particular relevance to hydrogen fires, is that hydrogen flames are often invisible, especially in bright sunlight, increasing the likelihood of people fleeing an incident or emergency workers inadvertently straying into a flame.
- In order to support creating sufficient knowledge-base for first responders, it is recommendable to develop an additional set of prevention rules and trainings. Research in Task 3.1. – 4.3. suggest no complete set of new regulations in this regard are necessary

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[13] http://www.fch-ju.eu/

- Need to have access to state-of-the-art tools and resources to train professionals within their own field of expertise. Especially web based-resources are considered to play a key role in educating different stakeholders at their own level.
- Stakeholders need access to trainers (or should have the opportunity to educate in-house employees to become a trainer) which will be able to train professionals on multiple levels and determinations.
- Moreover, considering hydrogen will increasingly be used as an alternative fuel, it is recommendable to create a training system specifically focusing on education young professionals and/or students.
- In order to create sufficient critical mass to help shape a clean and comprehensive education and training strategy, it is recommendable professionals organize an efficient lobby with regulators and public safety officials.

Regulators and Public Safety Officials

This stakeholder group contains all actors involved in generating, homogenizing and integrating legislations, regulations, certification, codes and standards on hydrogen technology on European, National and Regional level. According to the research performed in H2TRUST, regulations, legislations, certification, codes and standards are currently still scattered throughout Europe. Moreover, it is considered that regulatory bodies and public safety officials do not have up-to-date knowledge on what stakeholders need to be optimally education and trained in this regard. These two aspects need to be taken into account when developing a new training and education strategy. For example, although there are European standards on how hydrogen equipment needs to be installed, and maintained, by a competent person, at present there is no national scheme in place for training and assessing the competency of persons to install hydrogen systems, although some manufacturers do have schemes for training installers and service engineers. Hence, H2TRUST recommends:

- European, National and Regional schemes should be more aligned and translated into a new educational curriculum for professionals. Moreover, an educational curriculum as well as the harmonisation of regulations, legislations, certification, codes and standards can contribute to creating the right boundary conditions for the introduction of hydrogen.
- Policy makers need to be informed on the needs of professionals in order to ensure that they understand the need for an additional hydrogen specific policy support scheme on top of current support schemes.
- Set up and implement education and training programmes on hydrogen and fuel cells to facilitate the potential large employment shifts.

- Limited information was found on specific guidelines for the handling, storage and use of hydrogen in the public domain. More detailed research on the needs for this specific actor group is recommended.
- In addition, dissemination and educational activities - on tools and training material developed by regulatory bodies - are needed to support uptake by the relevant actors. In this context, this will most likely improve societal awareness and acceptance as well.

General Public

This stakeholder group includes people in society who in one way or another encounter activities, developments are services on hydrogen technology. The general public is considered to be an important stakeholder in the uptake of hydrogen as a new alternative energy and are very good ambassadors for the acceptance of hydrogen technology as they often talk to other citizens, communities, tourists and journalists of their experience. Overall, the general public is considered to have relatively limited awareness and knowledge of hydrogen technologies and its implications. Many studies studied in the H2Trust Tasks report a relatively low level of knowledge on hydrogen, implying that the public does not yet have an informed view on hydrogen technologies. Despite this, the public opinion about hydrogen can be considered to be relatively positive. Task 4.3. reflects that, generally, the public is unconcerned and positive about hydrogen fuel technology as a potential alternative for current fossil fuel systems. However, other tasks indicate that the general public can be ‘afraid’ of this new alternative fuel as well. It is deliberated that when the general public indicated to be anxious about hydrogen technologies this is due to the lack of knowledge or wrong information. Moreover, if people are not aware of the fact that hydrogen can be compared to current industrial gases and is extensively used in industry, they are suspicious about its safety and environmental impact. Moreover, research indicated that after being informed, the public understands more about the hydrogen technology processes and implications and feel more confident that sufficient safety measures can be taken and that hydrogen fuels can benefit environmental outcomes in comparison to current fuels. Hence, it is recommendable to focus on raising awareness on the good level of safety already associated to hydrogen technologies and to develop and deploy dedicated training and education on hydrogen handling and safety aspects (especially in non-industrial environments) where risky situations could be created by untrained people. This would imply:

- Train and educate the general public more on the properties and benefits of hydrogen in comparison to other gases;
- Outreach activities of demonstration projects have generally only informed the public in the vicinity of demonstration projects, leaving the larger public uninformed. It would be

beneficial to demonstrate the safety of hydrogen (e.g. with crash test of vehicles with different fuel systems in place) in a public setting.

- To develop layman level materials (e.g. flyers, folders, publications) which can be disseminated through e.g. conventions, websites on sustainable energy or by energy companies to create more awareness of hydrogen technology applications in society.
- Fostering dissemination of positive results from demo project in FCH and FCH2 related to technology advancements and deployment, would support optimal use of best practices and mainstreaming them into training/education material.
- Hydrogen energy providers (household power generation/storage, vehicles etc) could train and educate the general public on hydrogen technologies outside the industrial world, how the general public could personally benefit from these technologies and how strict safety measures (e.g. provision of hydrogen detectors) would prevent major risks. In addition, during the interviews it was indicated that the general public would most likely quickly adapt to new household gases, as they did with previous household gases.
- The results of the Tasks indicate that it might be beneficial to include the general public in translational activities for transferring hydrogen from industrial level to applications used in household or on societal level (hydrogen fuel stations etc). This would support acceptance and awareness of hydrogen technology as well.

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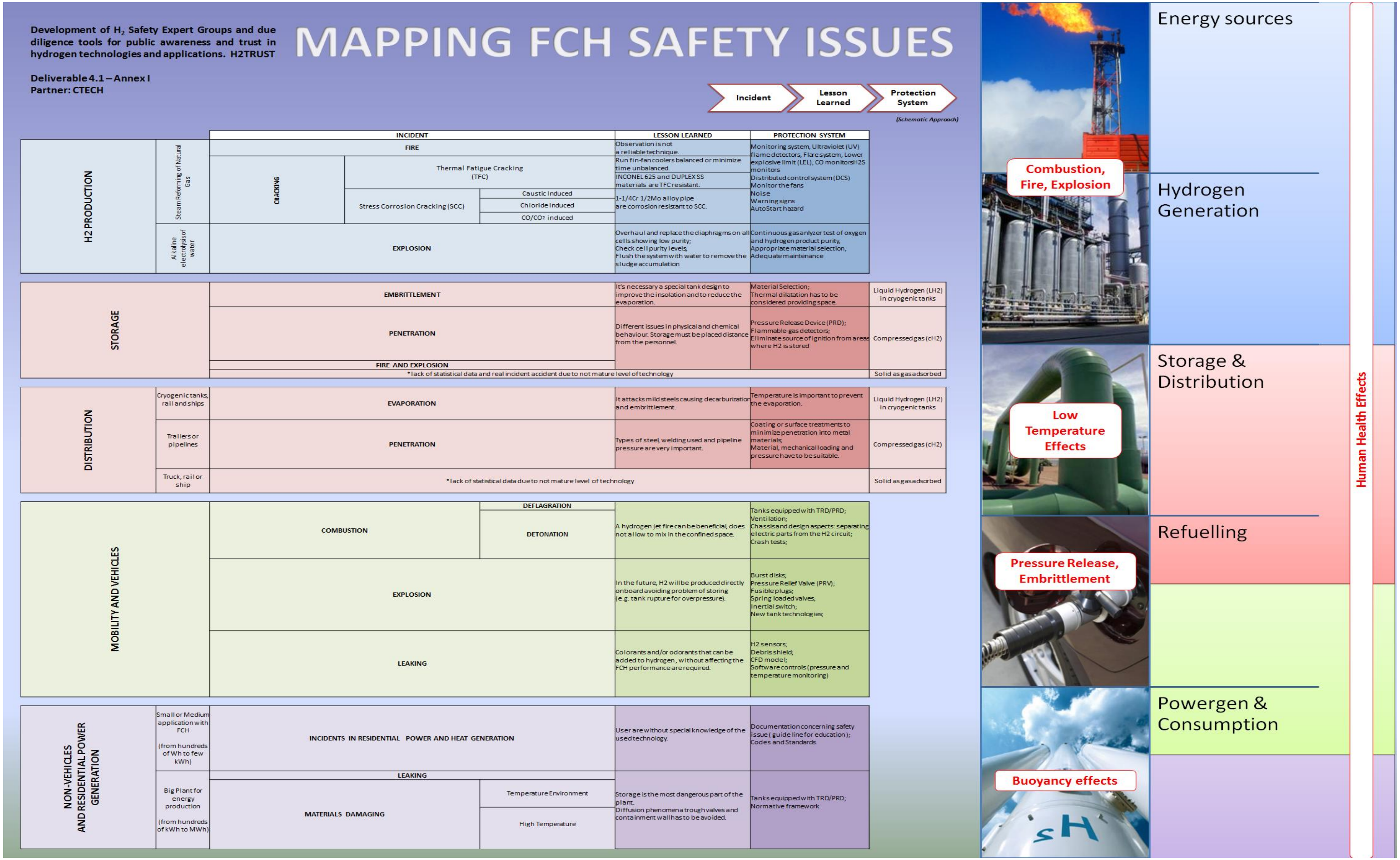
ANNEXES

Annex 1: Map of safety issues

Annex 2: Roadmap and recommendations Action Plan



Development of H_2 Safety Expert Groups and due diligence tools for public awareness and trust in hydrogen technologies and applications. H2TRUST

Deliverable 4.1 – Annex I
Partner: CTECH

MAPPING FCH SAFETY ISSUES

Incident → **Lesson Learned** → **Protection System**

(Schematic Approach)

		INCIDENT			LESSON LEARNED	PROTECTION SYSTEM	
H2 PRODUCTION	Steam Reforming of Natural Gas	FIRE			Observation is not a reliable technique.	Monitoring system, Ultraviolet (UV) flame detectors, Flare system, Lower explosive limit (LEL), CO monitorsH2S monitors Distributed control system (DCS) Monitor the fans Noise Warning signs AutoStart hazard	
		CRACKING	Thermal Fatigue Cracking (TFC)		Run fin-fan coolers balanced or minimize time unbalanced. INCONEL 625 and DUPLEX SS materials are TFC resistant.		
			Stress Corrosion Cracking (SCC)	Caustic Induced	1-1/4Cr 1/2Mo alloy pipe are corrosion resistant to SCC.		
				Chloride induced			
				CO/CO_2 induced			
	Alkaline electrolysis of water	EXPLOSION			Overhaul and replace the diaphragms on all cells showing low purity; Check cell purity levels; Flush the system with water to remove the sludge accumulation	Continuous gas anlyzer test of oxygen and hydrogen product purity, Appropriate material selection, Adequate maintenance	
STORAGE		EMBRITTLEMENT			It's necessary a special tank design to improve the insolation and to reduce the evaporation.	Material Selection; Thermal dilatation has to be considered providing space.	Liquid Hydrogen (LH2) in cryogenic tanks
		PENETRATION			Different issues in physical and chemical behaviour. Storage must be placed distance from the personnel.	Pressure Release Device (PRD); Flammable-gas detectors; Eliminate source of ignition from areas where H2 is stored	Compressed gas (cH2)
		FIRE AND EXPLOSION					
		*lack of statistical data and real incident accident due to not mature level of technology					Solid as gas adsorbed
DISTRIBUTION	Cryogenic tanks, rail and ships	EVAPORATION			It attacks mild steels causing decarburization and embrittlement.	Temperature is important to prevent the evaporation.	Liquid Hydrogen (LH2) in cryogenic tanks
	Trailers or pipelines	PENETRATION			Types of steel, welding used and pipeline pressure are very important.	Coating or surface treatments to minimize penetration into metal materials; Material, mechanical loading and pressure have to be suitable.	Compressed gas (cH2)
	Truck, rail or ship	*lack of statistical data due to not mature level of technology					Solid as gas adsorbed
MOBILITY AND VEHICLES		COMBUSTION	DEFLAGRATION		A hydrogen jet fire can be beneficial, does not allow to mix in the confined space.	Tanks equipped with TRD/PRD; Ventilation; Chassis and design aspects: separating electric parts from the H2 circuit; Crash tests;	
			DETONATION				
		EXPLOSION			In the future, H2 will be produced directly onboard avoiding problem of storing (e.g. tank rupture for overpressure).	Burst disks; Pressure Relief Valve (PRV); Fusible plugs; Spring loaded valves; Inertial switch; New tank technologies;	
		LEAKING			Colorants and/or odorants that can be added to hydrogen, without affecting the FCH performance are required.	H2 sensors; Debris shield; CFD model; Software controls (pressure and temperature monitoring)	
NON-VEHICLES AND RESIDENTIAL POWER GENERATION	Small or Medium application with FCH (from hundreds of Wh to few kWh)	INCIDENTS IN RESIDENTIAL POWER AND HEAT GENERATION			User are without special knowledge of the used technology.	Documentation concerning safety issue (guide line for education); Codes and Standards	
	Big Plant for energy production (from hundreds of kWh to MWh)	LEAKING			Storage is the most dangerous part of the plant. Diffusion phenomena trough valves and containment wall has to be avoided.	Tanks equipped with TRD/PRD; Normative framework	
		MATERIALS DAMAGING	Temperature Environment				
			High Temperature				

Energy sources

Combustion, Fire, Explosion

Hydrogen Generation

Storage & Distribution

Low Temperature Effects

Refuelling

Pressure Release, Embrittlement

Powergen & Consumption

Buoyancy effects

Human Health Effects

	2010-2015	2020	2030	2050
Phases	• **Pre commercial technology refinement & market preparation** • **Technology development with fous on cost reduction** • **Start of commercialisation**	**Materialisation of first impacts:** • New hydrogen supply capacities partially based on low carbon sources • Improvement in local air quality • More than 5% of new car sales Hydrogen and Fuel Cells	**Hydrogen & Fuel Cells are competitive:** • Creation of new 200.000 – 300.000 jobs/safeguarding existing jobs • Shift towards carbon-free hydrogen supply • More than 20% of new car sales on Hydrogen and Fuel Cells	**Hydrogen and Fuels Cells dominant technologies high impact** • 80% of light duty vehicles & city buses fuelled with CO_2 free hydrogen. • Reaching more than 80% CO_2 reduction in passenger car transport. • In stationary end-use applications hydrogen is used in remote locations and island grits
Targets	**LHPs facilitate initial fleet of a few 1,000 vehicles by 2015:** • PPP ‘Lighthouse Projects’ • Financial support for large scale demonstration projects	<u>**Vehicles:**</u> 2.5 million of fleet <u>**Cost:**</u> • Hydrogen: 4€/kg (50€/barrel) • Fuel Cells: 100€/kW • Tank: 10€/kW	<u>**Vehicles:**</u> 2.5 million of fleet <u>**Cost:**</u> • Hydrogen: 3€/kg (50€/barrel) • Fuel Cells: 50€/kW • Tank: 5€/kW	
EU Policy Actions	**Develop Hydrogen specific support framework:** • Create/suport early markets. • Implement performance monitoring framework • Long term security for investing stakeholders • Education and training programmes. • Harmonisation of regilation codes and standards	**Hydrogen specific support framewotk:** • In place before 2015 at MS level. • Deployment supports, e.g. taks incentives of 180M€/year. • Public procurement. • Planning and execution of strategic development of hydrogen infrastructure.	**Gradual switch from hydrogen specific suport to generic support of sustainability**	**Incentives provided through general support schemes for sustainability**

Recommendations (short term < 5 years)	**Recommendations (mid term 5-10 years)**	**Recommendations (long term >10 years)**
Technology & Research • Develop the creation of statistical mass of projects/data also through creation/consolidation of existing databases (e.g. HYAD). • Foster industrial proactiveness (Instrinsic planning and development of industrial projects) • Foster FCH application following industrial symbiosis approach, with immediate resource effiiency results and putting the basis for future H_2 grids. • Design alternative storage technologies available after 2020 may reduce storage pressure, thereby easing certain safety issues and potentially cutting storage system costs.	**Technology & Research** • Support establishment of European obsevatory for FCH safety and risk assessment and monitoring + indipendent think tanks. • Present results from (demo) projects regarding FCH potential and benefits for industry and society. • Enlarge industrial symbiosis model outside indutrial players, involving other local stakeholders (local authorities, logistics, grid entities, etc.) . • Develop and Validate alternative storage technologies.	**Technology & Research** • Translate results into practical solutinos and further uptake of hydrogen in undustry and society. • Create/consolidate a diffused H_2 grid connecting industrial as well as non industrial users • Develop and Validate alternative storage technologies (after 2020)
Regulation, Standards & Codes • Investigate stakeholder's needs regading regulations, certification, codes and standards. • Revise and simplify safety standards, especially safety distances (i.e. ATEX) . • Design easy-adaptable regulations, codes and standards (RCS) at EU level, to be easily translated to National and Regional standards as well. • Strengthen RCS for the production, transportation and storage and use of hydrogen for non-industrial applications in the public domain.	**Regulation, Standards & Codes** • Design easy-adaptable regulations, codes and standards (RCS) on EU level, to be easily translated to National and Regional standards as well. • Develop and consolidation of RCS for infrastructure-specific technologies. • Start promotional activities on the benefits of hydrogen technology for professionals and general public. • Supporting (e.g. funding, collaborating) hydrogen technology initiatives. • Support teh creation of a Lobby for application and development of hydrogen technologies	**Regulation, Standards & Codes** • Investigate 'Lessons Learned' and continuously update RCS according to stakeholder's needs and European strategy. • Adapt EU and National support programmes according to the developments in hydrogen technology domain. • Improve Lobby for application and development of hydrogen technologies.

Training & Education	**Training & Education**	**Training & Education**
• Start lobby for improved training and education programme supported by the EC. • Develop demonstration cases on layman level to create more awareness and knowledge in society. • Design new training/education strategy and curriculum to support all stakeholders on multiple levels (both education level as field of expertise). • Design platform to train professionals to become a trainer for their field of expertise and/or to find external trainers in specific fields of expertise. • Design dessimination plan for all target groups but mainly focusing on educating the general public. • Start lobby for improved training and education programme support by the EC.	• lobby for improved training and education programme supported by the EC. • Implement demonstration cases on European, National and Local leven - to create more awareness and knowledge in society. • Develop and Implement new training/education strategy and curriculum. • Launch platform to train professionals to become a trainer for their field of expertise and/or to find external trainers in specific fields of expertise. • Develop and Implement dessimination plan for all target groups but mainly focusing on educating the general public.	Lobby (and discuss lessons learned) on improved training and education programme supported by the EC. • Implement demonstration cases on European, National and Local leven – and Investigate impact of the programmes in order to determine next steps. • Implement new training/education strategy and curriculum. – and investigate impact to potentially adapt the strategy/curriculum. • Conitue, maintain and potentially increase functionality of the platform. • Continue dessimination plan for all target groups but mainly focusing on educating the general public.