Final Report

Please note that the contents of the Final Report can be found in the attachment.

4.1 Final publishable summary report

Executive Summary

Many predictions for the hydrogen economy in the last decade have proven optimistic, the maturity of it is now increasingly evident by the substantial investments in R&D, demonstration and industrialisation made by public and private institutions in Europe. However, the USA and Japan are leading the hydrogen based energy infrastructure, becoming a mainstream solution for society's need to transition to clean, renewable and widely available energy sources.
The H2TRUST project has been developed by a team of highly experienced and qualified industry and academic experts to ensure that non-technical barriers to the deployment of Fuel Cell and Hydrogen (FCH) technologies are properly addressed, as well as to promote the knowledge and the acceptance of these technologies by the society,
H2TRUST is a response to the FCH JU call for proposals in their Annual Implementation Plan of 2012, page 101 (Topic SP1-JTI-FCH.2012.5.5: Assessment of safety issues related to fuel cells and hydrogen applications).
The present report provides the background and introduction of the FCH safety hazards, the objectives of the H2TRUST as well as the main outcomes and the potential impact of this project, making emphasis on the recommendations. The contact details, the dissemination foreground as well as the societal implications are included at the end of the report.

Summary description of project context and objectives

H2TRUST is a safety project designed by a team of European Fuel cells and Hydrogen (FCH) industry leaders to foster a smooth and well managed transition to full scale commercialization of FCH applications in Europe and, from a safety perspective, to aid the process by which all industry stakeholders are informed, prepared and confident. H2TRUST help assure mechanisms are in place to inform all stakeholders, including the general public, adequately about H2 related safety issues.
The H2TRUST consortium is formed by 9 European partners (see Figure 1): MATGAS 2000 AIE (MATGAS) Air Products PLC (AIRP), European Hydrogen Association - Federazione delle Associazioni Scientifiche e Tecniche (FAST/EHA), Solvay Specialty Polymers Italy S.P.A. (SPPI), Politecnico di Milano (POLIMI), McPhy Energy S.A. (McPhy), SOL S.p.A., Ciaotech S.r.l. (CTECH), and Technische Universiteit Eindhoven (TU/e). Moreover, the company SE de Carburos Metálicos S.A. participated as third party of MATGAS.

State of play of the FCH industry

Hydrogen is already widely produced and used in industry today, for example, for ammonia synthesis and oil refinery; it has been NASA's shuttle fuel since the sixties. However, there is an increasing interest in hydrogen in recent years due to its use as an energy carrier for stationary power and transportation markets, as an alternative to replace fossil fuels. In fact, it is expected that the hydrogen based energy infrastructure will soon become a mainstream solution for society's needs to transition to clean, renewable and widely available energy sources.
Applications such as forklifts, back-up power and portable power are at an advanced stage of industrial test. Markets that may be expected to reach commercial scale by 2020 are residential Combined Heat and Power (CHP) systems, auxiliary power units, fleet vehicles, public buses and private cars. Regarding the deployment of these technologies, one of the barriers is the acceptance of hydrogen technology by the society, mainly because of a lack of educated knowledge. For this reason, before regulations are in place and the market drives hydrogen to the fuel of choice, the safety issues must be systematically addressed for each application in order to assure that related products and systems are safe and perform as designed. The H2TRUST project, aims at providing society the safety measures, considering each step of the hydrogen value chain (production, storage, distribution, mobility applications, and non-mobility and residential power generation), in order to aid the deployment of the hydrogen technologies by improving its public perception.

FCH Safety Hazards and Risk

The most important properties to be taken into account from a safety perspective are:
- Hydrogen is odorless, tasteless, non-toxic, and non-corrosive.
- It is highly diffusive.
- It presents high buoyancy (proportional to the diffusion coefficient and changes with temperature).
- Small size.
- Small molecular weight.
- Low viscosity.

When compared to other gases and liquids, including methane for home heating or petrol for passenger vehicles, hydrogen is not an especially dangerous substance. However, it presents certain characteristics which, due to its rarity in pure form and the need to pressurise it for efficient transport and storage, give rise to the need for unique safety awareness and new precautionary measures.
The most significant safety differences between hydrogen and other fuels such as natural gas (NG) or gasoline are the ease of ignition and the leakiness, both of which will require more stringent safety measures than today's fuels. Hydrogen has lower ignition energy than NG, where any small spark produced by static energy or tool sparks will be sufficient to ignite it. It also exhibits higher permeation rates. Additionally, the higher operating pressures of hydrogen increases the potential hazard of leaking by increasing the permeation or leakage rates. The combination of both factors requires development and reinforcement of the safety standards and regulations for avoidance of accumulation of hydrogen in closed areas. In order to avoid accumulation of hydrogen, standards and regulations must define stringent ventilation requirements, i.e. forced ventilation (compared to the natural ventilation of existing fuels), detection and positioning of ventilation outlets to avoid high points where hydrogen can accumulate. Another point to reinforce is the manufacturing and maintenance standards and regulations, defining requirements for gas tightness like leak test, welding procedures, frequency of checking and maximum time life of different elements. It is accepted that areas requiring attention are:

1. Harmonization of safety distances for H2 storage systems,
2. H2 refuelling in non-vehicle context,
3. Installation and use of H2 and Fuel Cells (FC) systems for stationary power generation in buildings, installation and use of alternative storage systems
4. Handling/storage/use of liquid hydrogen.

Importantly, pure hydrogen is not poisonous or toxic to plants, animals or humans; it disperses quickly into the atmosphere and does not leave harmful residues. H2TRUST has examined not just the H2 compound, but also the ancillary materials, technologies and processes required as enablers for FCH applications such as the platinum alloys employed as catalysts, the new materials required for cryogenic containment, or the impact of high volume transport and storage

H2TRUST objective

The H2TRUST general objective was targeted at increasing and securing trust within European society that all the necessary work is done to guarantee the maximum level of safety for an accelerated deployment of the hydrogen economy in Europe. To achieve this objective, the project involved all relevant stakeholders within the European H2 production, distribution and consumption value chain, to carry out the required data-collection, analysis and safety measure evaluations.
According with the FCH JU, the specific project objectives were:
- Assess industry efforts to assure that FCH technology is safe and that there is preparedness for incidents, adequate standards/regulations, hazard awareness and ability to respond to public concerns.
- Systematically map safety issues and explain/assess how they are addressed.
- Compile information demonstrating safety due diligence and best practices.
- Seek input from previous, on-going and upcoming FCH JU demonstrations and pre-normative and training projects and from similar international activities.
- Monitor FCH stakeholder risk management.
- Make recommendations for further safety efforts by FCH community which will form the basis of a zero incident hydrogen economy.
- Build public confidence based on sound shared evidence.

- Develop communications network to manage public reaction to incidents and give documented responses.
- Disseminate the results in such as way as to create a long lasting culture of safety practices.
- Include highly experienced and qualified industry and public safety experts speaking for the public interest.

In order to achieve these objectives, the H2TRUST project was structured in 5 Work Packages (WPs), according to the chart in Figure 2.

Description of main S & T results/foregrounds

The most remarkable results obtained along the project are explained in detail for each WP.

WP1: Project Management (led by MATGAS)

In this WP, MATGAS as coordinator, assured the project met its objectives by a combination of administration tasks relating to finance, logistics, reporting and projects tools, and also by providing leadership in terms of articulating and communicating the project mission, promoting H2TRUST among involved stakeholders and monitoring progress and results.
The defined tasks for WP1 were:
Task 1.1 Set-up and kick-off teams, tasks, communication (MATGAS) .
Task 1.2 Coordination, planning, communication & management meetings (MATGAS) .
Task 1.3 Project administration tools, task tracking, deliverables validation (MATGAS).
Task 1.4 Financial planning system & Distribution of funds (MATGAS).
Task 1.5 Reporting to FCH JU/ EC (MATGAS).
Main results/Foreground
With the support of all partners, MATGAS carried out all coordination activities including the distribution of funds, agreements preparation, meetings organization including the writing of the minutes of the meetings, the validation of deliverables, being the contact point with the FCH JU, as well as coordinating the final report among others, assuring the correct development of the project. Moreover, on October 2014, an amendment was sent in order to ask for a 3 months extension and, in agreement with the Project Officer (PO), to withdraw Air Products Gmb (third party of AIRP). The work initially assigned to Air Products Gmb was transferred to SE de Carburos Metálicos S.A (CM, already a third party of MATGAS).

Summarizing the main outcomes of this WP:
- Preparation of amendment and contact with the Project Officer.
- Quarterly meetings were carried out. Three of these meetings were face to face on:
o Kick off meeting: 18th-19th June 2013 in MATGAS and Tarragona, Spain (including a visit to the hydrogen production plant of Carburos Metálicos (Air Products Group).
o Mid-term meeting: 19th March 2014 in MATGAS.
o Final meeting: 25th -26th February 2015 in Barcelona (at Carburos Metálicos facilities). Dr. Pietro Moretto, from the JRC, participated as an external invited expert.

- All deliverables were uploaded in the participant portal (including the minutes of the meetings), and the Forms C from each partners have been sent through FORCE.
- A joint workshop on hydrogen and safety was held on 25th February 2015 in Barcelona with a total of 4 project partners (HYPER, FC Powered RBS, SUAV and H2TRUST), and 3 experts (Prof. Wolfgang Winkler from the University of Hamburg -recently retired-; Luis Muñoz Sebastián from Iberdrola; Pietro Moretto from JRC). Also networking dinner was prepared together with the H2TRUST consortium
- MATGAS, as coordinator of the H2TRUST, has been the contact point with Pacific Northwest National Laboratory (PNNL), from U.S.A. to exchange information as well as to look for possibilities for future collaborations.

WP2: Develop Analytical Framework (led by MATGAS)
The objective of WP2 was to create a framework, methodology and detailed plan for the data gathering and analysis stages in WP3 and WP4 in order to provide procedures, tools and plans for the gathering of information in a controlled and normalized manner. Moreover, in this WP a set of

internal stakeholder mirror groups was created, defining the mandate and role of these groups in order to assure that the project has researched and absorbed the relevant information relating to: (i) FCH industry development, (ii) FCH hazards and risks, (iii) the safety and regulatory context and (iv) to the state of the art of related or similar programmes whether under the European Commission or under other national, regional or private bodies. Moreover, MATGAS as leader of WP2 has been responsible for fine tuning the H2TRUST processes over the life of the project and assuring that the method was effective, workable and that it generated the information needed for the dissemination phase.

The defined WP2 tasks were:

Task 2.1 Define FCH stakeholder model and dimensions of analysis (MATGAS).

Task 2.2 Definition of a reference benchmark (POLIMI).

Task 2.3 Literature study and discovery (MATGAS).

Task 2.4 Set-Up stakeholder mirror expert groups (CTECH).

Task 2.5 Develop info gathering process and questionnaires (CTECH).

Task 2.6 Coordinate the analytical process (MATGAS).

Main results/Foreground

Task 2.1 "Define FCH stakeholder model and dimensions of analysis" was carried out by MATGAS in collaboration with CTECH, who defined the dimension of analysis. As a result, the deliverable 2.1 included a guide for the execution of WP3 and 4, explaining the different methods for the data gathering (see Figure 4), the best practices for collecting and writing data as well as the dimension of analysis. For this dimension of analysis, the FCH value chains and components (see Figure 5), the FCH safety matters (see Table 1), vehicles and instruments for progress in safety and the FCH market introduction timing were introduced.

The task 2.2 was carried out by POLIMI, resulting in a deliverable entitled "Reference Benchmark for H2 production, storage and distribution technologies". In deliverable 2.2, an explicit benchmark for the operating conditions of selected production-storage-distribution technologies, defining reference component operating conditions (e.g. pressure, temperature, stream chemical features) and basic component risk relevance were described. The benchmark has been later used as reference for subsequent safety analysis and project discussion.

Resulting from task 2.3, an online library is available at the project website (h2trust.eu), with more than 145 references classified in 5 categories: (i) hydrogen production, (ii) storage & distribution, (iii) mobility and vehicles, (iv) non-vehicles and residential power, and (v) regulators, 1st responders, consumers. It is important to note that this library is dynamic, so additional references can be added, if required.

The deliverable 2.4. "Mirror groups organisation chart and Data gathering procedures" comes from tasks 2.4 and 2.5. This document includes the explanation of the different data gathering tools, including the Key Performance Indicators (KPIs) for each one, the relevant stakeholders to be contacted and the questionnaires to be sent for the selected stakeholders. Moreover, in this task a mirror group was created according to the chosen main application areas. Each mirror group was led by a H2TRUST partner, focused on the specific main application area where they have relevant expertise:

- H2 production led by CM (third party of MATGAS), supported by AIRP and TU/e.
- Storage and distribution led by McPHY, with the support of POLIMI.
- Mobility and vehicles led by SPPI, with the support of POLIMI.
- Non-vehicles and residential power generation led by SOL, with the support of POLIMI.
- Regulators, 1st responders, consumers led by FAST/EHA.

Conclusion

In conclusion, WP2 gave the required indications to carry out the WP3 and WP4, as agreed in the Document of Work (DoW) of the Grant Agreement (GA).

WP3: Data Gathering and Mirror Groups (led by SPPI)

The WP3, as indicated its name, has the WP dedicated to collecting information and data for each step of the hydrogen value chain, sub-dividing these areas into multiple sub-areas and process steps. This WP was the core of the H2TRUST project, collecting and packaging the required information

(the regulatory and safety stakeholders, consumers and incident response bodies) in structured and accessible format for the risk analysis and recommendations phase in WP4.
The approach and the methodology applied in WP3 for collecting data was based on indications that came out from the activities of WP2 above mentioned.
The defined WP3 tasks were:
Task 3.1 Collect H2 Production Safety Data (MATGAS).
Task 3.2 Collect Safety Data on Storage and Distribution (MCPHY).
Task 3.3 Collect Safety Data relating to Mobility and Vehicles (SPPI).
Task 3.4 Collect Safety Data relating to non-vehicles and residential power generation (SOL).
Task 3.5 Collect Safety Information on Regulators, 1st Responders, Consumers (FAST/EHA).

Main results/Foreground
As a result of WP3, coordinated by SPPI, the deliverable 3.1 “State of play H2 issues” including the following 5 chapters was prepared, according with the different tasks:
- Chapter 1: H2 production (CM).
- Chapter 2: Storage and distribution (MCPHY).
- Chapter 3: Mobility and vehicles (SPPI).
- Chapter 4: Non-vehicles and residential power generation (SOL).
- Chapter 5: Regulators, 1st responders, consumers (FAST/EHA).

Each of the WP leaders, with the support of the whole consortium, were responsible to carry out the data gathering with the different tools (questionnaires, surveys, checklists, interviews, document review, observation, focus groups and case studies), setting the basis for mapping, assessment and recommendations for WP4. Moreover, they organized the gathered information during WP3 in a single document forming each chapter. SPPI, as leader of WP3, make the unification of the 5 chapters in order to generate the deliverable 3.1.
Although different data gathering procedures were defined, the questionnaires were considered the main tool to collect data and information. The questionnaires (prepared in deliverable 2.4) were distributed by using a web-tool created by SOL partner to facilitate the data collection.
All questionnaires included:
- Main questions for all stakeholders, to gather as much information as possible about the market, barriers, safety perception and solutions related to the hydrogen industry.
- Specific questions on safety and hydrogen technologies, according to the stakeholders’ groups and subgroups.
- Supplementary questions beyond the scope of the safety assessment, in particular regarding: suggested actors and stakeholders for the data collection campaign, lack of funding, communication and knowledge issues, transfer of scientific results.

The questionnaires were sent to the relevant stakeholders included in deliverable 2.4 and enlarged in WP3, which included more than 300 contacts. However, the activity did not proceed as planned since the answers received were less than expected and with incomplete data, making difficult their exhaustive analysis.
Several stakeholders were contacted by telephone in order to find out the reasons behind the lack of participation and to encourage the response. The main problem seemed related to the quality or type of questions: the questionnaire was too general and open, and answering all the questions required an extra effort and timing considering no worthwhile by most stakeholders.
LESSONS LEARNT: the suggestion for future development of this kind of activity of data collection is to prepare a multiple-choice questionnaire and to minimize as much as possible the use of the open questions, so that the relevant stakeholders can find it friendly to answer also requiring less time for them.
Taking into account the results, we promoted the participation by telephone and further email contacts, and some of them finally completed the questionnaire. Some others preferred to limit their contribution to informal comments during the phone conversation or personal interviews. In fact, the interviews gave a more positive response from the people contacted in comparison with the written survey, due to it is easier to discuss face to face or by telephone on the topics selected for the survey, not only because the questions can be better explained but also because the discussion can also adjusted on topics that result more interesting for the interviewed person. The outcomes of interviews are reported either specifically or as collective comment in several chapters of Deliverable 3.1,

depending on the possibility to appear explicitly of different stakeholders and/or companies involved. It is important to remark that some stakeholders consider their answer as sensitive data, for this reason, some of them did not answer or did not give permission to publish their names in the report.
An important part of data collection was represented by the document reviews. Given the difficulties already mentioned for data gathering, the literature and document review was an important alternative for this purpose. Papers, project reports, websites and other sources were studied to find the required information, such as hydrogen properties, hazards associated to hydrogen, possible accidents for several areas of applications, risk analysis, countermeasures for risk reduction, etc. Moreover, the literature search was also a good instrument to find and select some case studies that have been more carefully analyzed.
A case study represents a practical experience of hydrogen production, storage, transportation or final use, where specific safety-related issues were faced and discussed. For each main application area, about 4-5 case studies were presented and analyzed. The scope of this data gathering tool was to show examples of best/worst practices in the framework of FCH technologies. On the one hand, best practices were mainly example of installations and/or operations where hydrogen is safely handled without serious incidents. As an example data of operation of a fleet of hydrogen buses were reported, showing hours or driven kilometres without accidents. On the other hand, worst practices, were cases where an accident occurred and the main cause was analyzed in order to avoid similar mishaps in the future. It is important to note that not all the case studies came from literature, since some of them derived from a direct analysis of real cases, for example, by contacting the involved institution. The case studies were reported either anonymously or explicitly according to the source and to the frequent limitation for disclosing proprietary or private information.
Conclusions
Summarizing the main outcomes of WP3, in general the safety issues related to hydrogen utilization are considered important, or even fundamental, but they are not seen as the limiting factors for the widespread dissemination of the technology. Taking into account our analysis, we have noticed that it is not easy to find cases where a serious accident occurred due to the use of hydrogen in a process or application. In fact, similar accidents to what described could happen if methane or another compressed gas are used. For this reason, the level of risk associated to hydrogen is considered similar to that of other fuels like gasoline or natural gas. However, it is important to remark that the analyzed cases were applications in well controlled areas and involving well trained people. In case of the hydrogen spreading to a large and domestic public, people would have to be informed (or even better, trained) about how to avoid incidents in handling hydrogen.
As a general conclusion, the appropriate formation and training about hydrogen handling is essential as for any other similar technology to be implemented. Moreover, the formation through seminars, courses, school lessons, etc. is considered important not only to train people to reduce the risk of hydrogen mishandling but also to improve the acceptance of hydrogen introduction in everyday life. People in general seem ready to use new technologies but hydrogen sometime is still connected to fire and explosion, often without a rational explanation. For this reason, explaining and showing the differences and similarities with other fuels can increase the level of hydrogen acceptance in the society. Moreover, in order to improve the awareness of hydrogen technologies and their potential, in addition to dissemination of information, a higher number of demonstration projects focused on applications and also specifically on safety, like fire or crash tests, are needed.
Related with safety aspects, although a critical point could be the leakage of hydrogen in closed environments (e.g. a parking for a FC vehicle), the stakeholders, especially the industries, do not consider the safety aspects related to hydrogen as a limiting factor for market introduction. However, the lack of knowledge leads oversizing the safety measures increasing the installations of equipments working with hydrogen.
The industry is mainly facing other problems such as the high cost of the technology, the lack of infrastructure and, especially, the lack of a common and simple legislation.
Very often the safety rules for new type of installations are not clear, or who is the responsible for giving the permissions is not well defined. Likewise, there are different rules in the EU countries, being an additional obstacle. For this reason, it is important that the safety codes are well defined and balanced, without introducing an excess of safety measures, in order to avoid the unnecessary increase of cost as well as a not justified alarm in the public perception.

WP4: Preparedness Mapping, Assessment, Recommendations (led by CTECH)

This chapter describes the main results of the WP4 “Preparedness Mapping, Assessment,

Recommendations” within the H2TRUST project. This WP was coordinated by CTECH and supported by specialist experts (from MATGAS, AIRP, SPPI, POLIMI, MCPHY, SOL, TU/e).
The main aim of WP4 was to integrate all of the research and info gathering performed previously in the project (especially in WP3, using methodologies developed in WP2) and to undertake comprehensive analysis of the FCH safety environment. A clear picture emerges of the state of the industry and its readiness to further industrialize FCH infrastructure and processes.
More specifically, the main outcomes achieved in WP4 are:
- The mapping of the regulatory and safety state of the art.
- The definition of the recommended actions and best practices that will be required to assure the successful and incident free development of the industry. There outputs are the most important for the dissemination phase.
The defined WP4 tasks were:
Task 4.1 Mapping safety issues (CTECH).
Task 4.2 Identify best practices (CTECH).
Task 4.3 Safety Risk Assessment (TU/e).
Task 4.4 Public Safety Assessment (CTECH).
Task 4.5 Recommendations (CTECH).
Main results/Foreground
We discuss here the main results obtained by each task in more detail than the previous ones, taking into account that those are the main outcomes and conclusions of the project.

Task 4.1 Mapping safety issues (CTECH)
This task led to a comprehensive 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 and where they lie.
A comprehensive map (included in Annex I of Deliverable 4.1) was built to have a clear understanding of the safety issues.
Following the categorization developed in H2TRUST (with the 5 categories), the same approach was used for each area of application to describe:
1. The most common incidents.
2. Lessons learnt from the incidents.
3. Recommended protection systems.

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

Task 4.2 Identify best practices (CTECH)
In this task, best practices of similar industries were considered and, where possible, taken as a guiding reference to be translated into hydrogen. In general, safety aspects were taken into account in terms of impacts to:
- Personnel.
- Equipment.
- Business Interruption.
- Environment.
In addition to hydrogen plants, Liquefied Petroleum Gas (LPG) and Natural Gas (NG) industries were also studied to find best practices in the way safety aspects are addressed and handled. As result, the fundamental principles of reducing explosion risk for hydrogen industry have been depicted 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 long wall 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.

Another important finding of this task was that consumer safety awareness campaigns are an essential part of gas safety principles which could be translated to the hydrogen case. Summarizing, the main findings/best practices found are:

- 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 specifically, for adequate ventilation.
- How to recognize the risks and the action to take when gas is used and an incident occurs.

Task 4.3 Safety Risk Assessment (TU/e)

As part of WP4, risk assessment methodology was developed to establish the level of preparedness of industry for the introduction of FCH technology. For this purpose, different hazard identification methods were screened and compared. Taking into consideration the advantages and disadvantages of each hazard identification method, the selected method is a combination of the Hazard Identification (HAZID) analysis with the Fault Tree Analysis (FTA) and the Event Tree Analysis (ETA) as the most appropriate methodological approach providing complete data for each case. This study covers the hazard identification, the consequences, the consequence assessment and the risk characterization and goes beyond the topics of the physical plant, equipment and materials, including emergency and health service readiness. The H2TRUST work was built upon the work done by the Hydrogen Incident and Accident Database (HIAD, https://odin.jrc.ec.europa.eu/engineering-databases.html) and H2 Lessons Learnt (http://energy.gov/ehss/policy-guidance-reports/databases/lessons-learned-database), taking into account their reports and lessons learnt.

The followed procedure was: the first stage in assessing the risk was to describe the system in terms of its equipment and product characteristics, safety systems, procedures and relevant assumptions. The next step was to identify the possible hazards and to select a set of accident scenarios. In fact, one of the outcomes of the project was the definition of comprehensive tables reporting the various hazard types, possible scenario, possible causes and mitigation measures. Each of these hazards can be further evaluated with the methodology developed, via a risk estimation, where models have been used to identify the frequency of each possible event and the number of fatalities associated to each event. Once these two parameters are known, the rest can be compared with risk tables and diagrams in order to check if the risk associated to the event is acceptable or a mitigation measure has to be applied. In Table 2 a risk matrix is shown, where the letters H, M and L denote risk levels “High”, “Medium” and “Low”, respectively. The descriptions of the risk levels are given in Table 3.

The methodology developed was applied to the 4 mean areas of hydrogen production and distribution as well as to novel production technologies as membrane reactors (more detailed information can be found in the deliverable 4.2). This methodology was also translated in a simplified online tool in WP5, as will be explained in task 5.1.

Task 4.4 Public Safety Assessment (CTECH).

This task studied the extent to which the general public knows and understands what is happening concerning FCH applications, how they will change with time, how they will influence them as regards safety and a zero incident hydrogen economy, as well as to build public confidence based on sound shared evidence. As part of this activity proposals were developed for a risk assessment on behalf of the public interest and advice on risk mitigation measurements, guidelines, benchmarks, training of officials and regulations that improve the safe production, transportation and use of FCH.

The main activities considered in this task were:

- Qualitative analysis of open access data (data gathering, risk assessment).
- Investigation of surveys and interviews related with public's perception on FCH.
- Analysis on stakeholder level (FCH Sites, NGO's, policymakers, etc.).
- Investigation of surveys and publications on large scale transportation and safety issues.

The main results of this task can be summarized as follows:
- Identification of current regulations, standards and codes on FCH.
- Determination of FCH public safety issues.
- Determination of public's understanding regarding FCH applications.
- Assessment of public safety of FCH.
- Preparation of guidelines related to public safety issues for training and inspection.

T4.5.Recommendations
CTECH, as leader of this task gathered all of the work to date (data gathering, desk studies, etc.) in a comprehensive report (deliverable 4.1) that includes the recommendations for the FCH deployment, as well as the further safety efforts by FCH community required to form the basis of a zero incident hydrogen economy and build public confidence based on sound shared evidence.
The work of this task can be summarized as following:
- Analysis of data gathered in WP3 (final version of 3.1).
- Multilayer (Meta-) Analysis of data gathered in Task 4.1, 4.2, 4.3, 4.4.
- Additional (desk) research on several sources (Scientific Papers, Technological/R&D/Policy roadmaps, web platforms, etc.).
- Gap analysis study, also taking into account the JRC comments and inputs.
- Re-contact consortium partners from WP3 to fill gaps (short focused interviews).
- Highlight strengths and weaknesses.
- Specific attention to RCS strategies, training, permits, inspections, crisis management.
The output of this task was one of the most important work in WP4, and it represents the main part of the deliverable D4.1. The report with recommendation was structured in 3 categories: i) technology and research, ii) Regulations, Codes and Standards (RCS), and iii) training, education and public communication as it can be seen in tables 4-6.

As it can be seen, the recommendations cover a broad range of topics and actions, from proposals for further technical research and development in FCH technologies, to regulatory, codes and standards advice, to public communications initiatives. Recommendations have been made for the implementation of an industry-led RCS strategy coordination function to ensure that the needs of the European stakeholders are well addressed by international standards, and to support the establishment of an efficient regulatory framework calling out these standards where appropriate. Recommendations include guidelines for training materials, procedures for permit granting and inspections and preparative action recommendations for crisis management planning.
A comprehensive roadmap with relevant recommendations was also prepared (See Table 7) , starting from relevant existing roadmaps developed at EU level (ECF Roadmap 2050, Hyways project, etc.), gap analysis, and projecting over time (up to 2050) the main findings of this Task for future FCH uptake.

Conclusions:
Lessons learnt and general recommendations from the project were discussed at the final meeting of H2TRUST in Barcelona and validated by all consortium partners. As a result, we want to highlight the following ones:
Lessons Learnt
- Regarding the questionnaires:
o It is essential to involve stakeholders during their preparation.
o The structure of the questionnaire need to be carefully designed taking into account the following items:
Open vs. closed Questions.
Number of questions: not too many to avoid disincentive to fill in by stakeholder, not too little so that enough information is collected.
Include a stakeholder mapping and engagement strategy as part of project's activities before sending out the questionnaires.
o It is important to have a well structured "preparation work" (stakeholders mapping, preparation of

the questionnaires with contributions from all partners and a first group of stakeholders that act as “validators” of the questionnaires before sending out, etc.). Moreover, it is important to allow enough time to meet and call the stakeholders to get the right information.

o Questionnaires can be done by an online tool and by phone (if required), always being closer and understandable, in order to have a first contact to be complemented with personal meetings/interviews. For this purpose, some additional activities and budget would be beneficial, since considerable resources are required.
- Although the interviews require more time, they are more useful than the questionnaires. They have to be more opened, and done face to face or by phone.
- The availability of data (p.e. HIAD) is essential to provide the corresponding risk assessment.
General recommendations
- To have a permanent reference body or structure inside FCH-JU that collects, monitors and makes available this knowledge for all EU projects and their implementation.
- To establish a permanent group of experts in Europe checking, approving and validating safety related issues, giving recommendations, etc.
- Necessity to continuously gather and analyze data related to hydrogen safety.
- To take into account the recommendations from the finished projects in order to avoid the same error in the future works (knowledge management). Taking this into account, probably a thorough analysis of the existing knowledge base at FCH and EU level at the beginning of the project could help.
These recommendations are seen by the H2TRUST consortium as a valuable result to be shared with FCH-JU to inform future decision taking, with a specific focus on safety aspects linked to FCH technologies and the way hydrogen is perceived by practitioners, stakeholders and the general public.
The H2TRUST partners hope that the work done in the project, the valuable information gathered and the results of the final analysis would help to FCH-JU as a good knowledge base that would serve the hydrogen community at large.

WP5: DISSEMINATION (led by FAST/EHA)
In the general scope of H2TRUST to offer a safety perspective in the field of FCH applications, the dissemination activities are particularly important, since they are the tool through which the industry stakeholders and the public are informed and prepared to accept the technologies related to hydrogen use both as energy source and carrier.
The main objective of this WP was to disseminate the findings, recommendations and follow up the initiatives of the H2TRUST project to an audience as wide as possible through events, seminars, conferences and presence on third parties websites. These efforts include the development of an online portal of FCH safety resources, demo-set ups for safety demonstrations and an online safety assessment tool, among others.
The defined WP5 tasks were:
Task 5.1 Develop online best practice portal (CTECH).
Task 5.2 Develop H2 safety due-diligence methodology (CTECH).
Task 5.3 Develop demo-set ups for safety demonstrations (FAST/EHA).
Task 5.4 Stakeholder workshops, publications, and dissemination (FAST/EHA).

Main results/Foreground
The main tool for dissemination is the web portal (h2trust.eu), developed in the mainframe of the project, where through the user interface the interested people can access to various modules:
- A crawler software scanning the web in search of relevant safety literature based on a continuously updated hydrogen safety documents repository.
- An H2 due diligence safety risk assessment tool, developed in this project and available online.
- A statistical mass of projects and databases at EU level including accidents and incidents, that can be accessed and inspected.
Beyond these gateways to specific tools, the website includes information about the project, a news area and a forum area, where experts groups, based on H2TRUST mirrors groups, may answer any question attaining the theme of safety on hydrogen application from user.
After the end of the project the H2TRUST website will be integrated into the EHA website to remain alive and updated.

Task 5.1 Develop online best practice portal (CTECH).

The H2TRUST website (h2trust.eu) includes:
- A brief introduction about the project H2TRUST and the consortium.
- The hydrogen and fuel cell safety library divided by type of application (Hydrogen Production, Storage and Distribution, Mobility and Vehicles, Non-vehicles and Residential Power, Regulators, 1st Responders and Consumers). The online library has around 145 documents classified by the type of document, authors, language, link -where the document can be found-, references, year of publication and keywords.
- The regularly updated news section of the website comes under the title ‘’Hydrogen Hits the Road’’.
- H2TRUST forum, which a free registration allows the users to participate in the forum. The forum aims to allow public, private organisation, H2TRUST mirrors group leaders and experts to have an interactive discussions.
- The “links” section is including hydrogen and fuel cells third parties websites and blogs where H2TRUST website link is published.
- Deliverables from the H2TRUST project, that will be uploaded to the website as soon as they are approved by the FCH JU.
- An online tool, that it is explained in the next section.

In order to know its impact, the H2TRUST website statistics area shown in Figure 8.
Task 5.2 Develop H2 safety due-diligence methodology (CTECH).
The online tool is part of a series of advanced features developed by the H2TRUST consortium in order to:
- Facilitate access for the user to relevant information related to H2 safety.
- Give the user guidance on the methodological framework, the main parameters involved and the steps needed to perform a risk assessment related to H2 technologies.
- Create a forum of experts able to respond to questions and remarks on safety of hydrogen.

Under the “online tool” section in the website, there are the following features:
o Advanced Search Engine: it uses modern semantic web techniques and tools based on a series of EU funded projects (TechITeasy, InSearch) to continuously crawl the web to find relevant safety related literature to be structured within categories, and a continuously updated searchable H2 safety document repository. Pages crawled are indexed and processed so that the results displayed are ordered on the basis of their relevance.

o Hazard and Consequences Tables: these tables have been structured in Task 4.2 as a result of the development of the methodology for risk assessment performed by TU/e (see deliverable D4.2 for more information). These tables are based on the identification of all possible hazard types related to the hydrogen process considered. Based on the list of hazard types, the suitable hazard identification method (e.g. HAZID + FTA, etc.) can be applied for each case. Therefore, the final tables report the list of Hazard Type, Hazardous Event, Initiating Cause, Prevention Controls, Consequences, Mitigation Controls.
o H2 due diligence safety risk assessment tool: based on the H2TRUST, FCH stakeholders and analyses model as well as the reference benchmark for production-storage-distribution technologies, a specific online tool (result from Task 5.2) is made available for whoever wants to use it to assess its safety readiness/adequacy. IT HAS TO BE NOTED THAT THE TOOL IS NOT INTENDED TO BE EXHAUSTIVE FOR RISK ASSESSMENT, BUT MORE A “GUIDING INSTRUMENT” IN THE HANDS OF USERS TO HELP THEM UNDERSTAND THE STEPS NEEDED TO PERFORM A SOLID RISK ASSESSMENT. To this end, the main parameters involved the mathematical and physical models that regulate the different hazard situation and potential consequences have been studied for several case studies, as well as how these are calculated and treated to evaluate the risk associated to a certain technology, process, plant, involving hydrogen. For a more detailed description of the H2 due diligence safety risk assessment tool, please refer to Deliverable 5.2.
The tool itself (last point) is based on a series of assumptions in order to be user-friendly and show them as well as the formulas used for the calculation, in a step-by-step flavour designed to be very handy for users. Moreover, it is based on the risk assessment methodology described in more details in the Deliverable 4.2.
The aim of the tool is to give a quick indication to the user about the level of risk for each possible

hazardous event. In particular, the aim is to calculate, for each possible event, the frequency of occurrence and the outcome in terms of fatalities (consequence). As a result, if the risk is “High” or “Medium” the user is invited to scan the Hazard table (see Table 2), for the identification of mitigation measures to reduce the risk to a “Low” level (acceptable risk).
The algorithm at the basis of the online tool goes through the following few steps:
- Calculation of the event frequency (Number to be used in the risk table).
- Calculation of the hydrogen release.
- Calculation of the radiation release.
- Calculation of the probability function.
- Calculation of the number of fatalities (number to be used in the risk table).

IMPORTANT: the calculation scheme and equations used in the online tool are reported for a typical case. Some of the data required for the calculations are inputs of the user (such as pressures on the tubes, length of the tubes, population density etc.). The rest of the data have been taken from literature or databases (see deliverable 2.3), which is the main limitation of the tool at the moment. It is important to note that, as many data are missing, only few particular cases can be really calculated. Hence, the tool is just to give an example of calculation to the user, who should therefore conduct a more detailed safety assessment with more comprehensive available tools and expert guidance.

Task 5.3 Develop demo-set ups for safety demonstrations (FAST/EHA).
A presentation kit has been prepared by FAST/EHA with inputs from the partners (brochure, banner, presentation, and video) in order to be used in the communications events for demonstration purposes and/or for communication and presentation of FCH safety matters at conferences, trade fairs and meetings. Moreover, MATGAS has prepared a dissemination book. This dissemination kit will be also used for an event organized by FAST during EXPO 2015.
Concretely, the kit includes:
- Printed brochure (2000 copies).
- 1 printed banner printed.
- Presentation (presented during 29 events – for more details please check table “A2: list of dissemination activities”).
- H2TRUST video toward the safety aspects of hydrogen applications, addressing the general public.
- H2TRUST dissemination book (500 copies): P. Ruiz, L.F, Vega, M. M. Arxer, C. Jiménez, A. Rausa. Hydrogen: applications and safety considerations, 200 pages. ISBN: 978-84-606-5978-5, L.D: B 4702-2015.

All these documents can be found at the project website.
Moreover, the following advertising items were prepared: ballpoint pens (200 pieces) and USB flash drives (250 pieces).

Task 5.4 Stakeholder workshops, publications, and dissemination (FAST/EHA).
A series of communication and awareness actions have been carried out along the deployment of the project:
- Press releases, including general press, specialized press, presence on third parties websites.
- Organisation of workshops and seminars.
- Presence in social network, LinkedIn and Facebook:
o www.facebook.com/pages/H2trust/591641694270601?fref=ts
o
www.linkedin.com/company/4829376?trk=tyah&trkInfo=tarId%3A1421844158593%2Ctas%3Ah2trust%2Cidx%3A1
- Participation at workshops, congress and events (see table “A2: list of dissemination activities”).

Conclusions
The dissemination of the H2TRUST project is the most important stage, according to its objectives. As it can be clearly seen, this project has been widely disseminated through different workshops, publications and other dissemination activities. Moreover, the webpage plays a really important role, not only for the dissemination purpose but also for the providing of an online library as well as a risk assessment tool.

Potential impact and main dissemination activities and exploitation results

H2TRUST is at the centre of Europe’s campaign to move towards a low carbon and inclusive

economy by fostering efforts to reduce and remove potential non technical barriers FCH technologies.
- Impact 1: Support industry by providing some guidance, recommendations, and lessons learnt and best practices for the use of hydrogen from a safety point of view.
- Impact 2: Make recommendations for regulators and first responders taking into account the data gathering of Research Codes and Standards (RCS).
- Impact 3: Promote the societal acceptance through dissemination activities.

Impact 1: Support industry by providing some guidance, recommendations, lessons learnt and best practices for the use of hydrogen from a safety point of view.

The H2TRUST project results provide a mapping of safety issues that has been analyzed in order to distribute clear recommendations, best practices and lessons learnt generating a really valuable and practical knowledge.
Related to this, the impacts expected in the corresponding Annual Implementation Plan and the H2TRUST contributions are indicated in Table 8. Moreover, a risk assessment tool has been designed in order to give some indications to the experts working with hydrogen. Finally, an experts group has been formed in order to be consulted at any time through the website at the "H2TRUST forum" section.

Impact 2: Make recommendations for regulators and first responders taking into account the data gathering of Research Codes and Standards (RCS).

As part of the project, a mapping of the RCS was also carried out in the WP3. After analyzing these data, a list of recommendations was given (see Table 5).

Impact 3: Promote the societal acceptance through dissemination activities.

As happens with all new technologies, the societal acceptance of hydrogen is essential to promote its deployment. For this reason, in this project the dissemination is fundamental. The dissemination activities carried out by the consortium are included in the tables provided in section 4.2.
H2TRUST has been designed to achieve this impact by maximising the dissemination of this knowledge to the widest possible audience, as indicated in Figure 10.
Figure 10: Expected impact of H2TRUST project dissemination.

It is important to remark, as it is appreciated in Figure 10, that the dissemination of this project was focused not only on experts but also on non experts. Some of the most important outputs related to this are the video and the dissemination book aiming the understanding of hydrogen by the society, informing that the hydrogen is not more dangerous than other substances commonly used.

Notes for the FCH JU and the European Commission.

The deployment of the FCH technology needs an European effort, not only by the stakeholders, but also from the European Commission and the FCH JU, since it can be only achieved by an integrated European effort. For this reason, as outcomes of this project, we want to remark the following recommendations to the European Commission for future projects:
- It is important to provide the recommendations from the similar finished projects in order to avoid the same error in the future works (knowledge management).
- To have a reference body inside FCH-JU that collects, monitors and makes available this knowledge for all EU projects.
- To establish a permanent group of experts in Europe checking, approving and validating safety related issues, giving recommendations, etc. There is a clear necessity to continuously gather and analyze data related to hydrogen safety.

Use and dissemination of foreground:
The information gathered during the project and the findings have been widely disseminated in order to create an easily accessible knowledge base on H2 safety. This target has been addressed

consistently with the commercial interest to guarantee the maximum level of safety for an accelerated deployment of the hydrogen economy in Europe.
The dissemination has been carried out according to the following actions (see detailed information in tables A.1 y A.2):
- Presentations to conferences and workshops.
- Publications on scientific magazines.
- Use of project web site.
- Participation in exhibitions, fairs and book publication.

These activities have been carried out mainly through the FAST/EHA, since it has wide industry access and visibility (21 national H2 associations and many large industrials) with the contribution of MATGAS, as coordinator, and the rest of the partners.
The dissemination phase included the 12 communications, awareness and advocacy techniques:
1. Release of online publicly accessible portal and safety tools.
2. Modern online marketing techniques for driving people to consult with the portal, i.e. Search Engine Optimisation and “Google friendly” design of portal.
3. Professional social network positions in LinkedIn, Facebook and Industry Forums.
4. Creation of promotional and awareness collateral (banners, flyers, gadgets) to be used by the FAST/EHA at fairs, conferences and educational events, primarily intended to drive people to the H2TRUST portal (extension of www.h2euro.eu site).
5. Piggy-backing the H2TRUST agenda onto other trade fair and conference events.
6. Piggy-backing on other 3rd party websites and publications.
7. Targeted information campaign to leaders and opinion leaders, i.e. personal letters to people within each of the key stakeholder domains.
8. Submission of reports and reviews to publications and forums.
9. Presentation of papers at conferences.
10. Submission of case study and research proposals to educational and research institutions (i.e. use list EU faculties teaching safety already created by the HySAFE project).
11. Leveraging the H2TRUST partners’ own networks of people and organisations to disseminate a series of communications.
12. Execution of specific targeted awareness or info campaigns or recommendations to 3rd parties to carry out such campaigns.

Some of this actions can only be taken when the H2TRUST project have been finished. For this reason, dissemination activities will continue after the end of the project (e.g. HyPAC EXPO 2015).

Address of project public website and relevant contact details

Website: h2trust.eu

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