

HIAD 2.0 - HYDROGEN INCIDENT AND ACCIDENT DATABASE

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ABSTRACT

Hydrogen technologies are expected to play a key role in implementing the transition from a fossil-fuel-based to a more sustainable lower-carbon energy system. To facilitate their widespread deployment, the safe operation and hydrogen systems needs to be ensured, together with the evaluation of the associated risk.

HIAD has been designed to be a collaborative and communicative web-based information platform holding high quality information of accidents and incidents related to hydrogen technologies. The main goal of HIAD was to become not only a standard industrial accident database but also an open communication platform suitable for safety lessons learned and risk communication as well as a potential data source for risk assessment; it has been set up to improve the understanding of hydrogen unintended events, to identify measures and strategies, to avoid incidents/accidents and to reduce the consequence if an accident occurs.

In order to achieve that goal the data collection is characterized by a significant degree of detail and information about recorded events (e.g. causes, physical consequences, lesson learned). Data are related not only to real incident and accidents but also to hazardous situations.

The concept of a hydrogen accident database was generated in the frame of the project HySafe, an EC co-funded NoE of the 6th Frame Work Programme. HIAD was built by EC-JRC and populated by many HySafe partners. After the end of the project, the database has been maintained and populated by JRC with publicly available events. The original idea was to provide a tool also for quantitative risk assessment, able to conduct simple analyses of the events; unfortunately that goal could not be reached because of a lack of required statistics: it was not possible to establish a link with potential event providers coming from private sector, not willing to share information considered confidential. Starting from June 2016 JRC has been developing a new version of the database (i.e. HIAD 2.0); the structure of the database and the web-interface have been redefined and simplified, resulting in a streamlined user interface compared to the previous version of HIAD. The new version is mainly focused to facilitate the sharing of lessons learned and other relevant information related to hydrogen technology; the database will be public and the events will be anonymized. The database will contribute to improve the safety awareness, fostering the users to benefit from the experiences of others as well as to share information from their own experiences.

1.0 INTRODUCTION

Current trends in energy supply and use are environmentally and socially unsustainable. Without decisive action, energy-related emissions of carbon dioxide (CO₂) will more than double by 2050 and increased fossil energy demand will heighten concerns over the security of supplies. Against the background of the UN Paris agreement on green-house gases emissions mitigation and adaptation, the European Union has adopted a strategic long-term vision for a competitive and climate-neutral economy by 2050¹. From a technological viewpoint, low-carbon energy technologies have a crucial role in this strategy, together with electrification of the majority of the whole energy system. Hydrogen and the related fuel cell and water electrolysis technologies have also the potential of supporting the long term strategy and answering energy security needs in several sectors of the energy system, such as heavy goods transport, heavy industry, residential

¹ https://ec.europa.eu/clima/policies/strategies/2050_en

sectors. They are also enabler for sector coupling , i.e. in connect different energy sectors and energy transmission and distribution networks, and thus increase the operational flexibility of future low-carbon energy systems [1-3].

Hydrogen technologies and applications should provide the same level of safety, reliability and comfort currently experienced by consumers for established technologies. Compared to the fossil energy carriers used at present, hydrogen introduces different safety and regulatory issues which need to be understood and tackled. Hydrogen has already been used and safely handled for many years in several application areas (e.g. in aerospace technology, chemical processing, fertilisers, food and electronic industries). However, to play a role as energy vector for the decarbonisation goals, the fuel cells and hydrogen technologies need to be deployed broadly outside the industrial frame and the aspect of public safety need to be addressed, to guarantee the same (or better) level of safety then the incumbent technologies. In the past 10 years, hydrogen-based solutions have been deployed in Europe in the frame of various demonstration projects of the European Joint Technology Initiative on Fuel Cells and Hydrogen FCH JU (2008-2013) and FCH 2 JU (2014-2020)². Lessons learned from technology glitches occurring during these initial deployments are extremely valuable to understand hazards and develop preventive and mitigating measures. Unfortunately the information related to hydrogen incidents available on the internet and in the literature is scarce and does not contribute to useful knowledge on hydrogen safety. To make sense of this fragmented experience and allow for lessons learned, both the US and the European Commission developed at the begin of the new century structured repositories of data describing safety-related events occurring along the whole fuel cells and hydrogen technology chain. The US database has evolved along the year to become part of the series of support tools with the general names of H2Tools³. The European Hydrogen Incident and Accident Database HIAD had originally been developed in the frame of the HySafe EC co-funded Network of Excellence (NoE)⁴. While the structure and the original objectives of the two databases were partially different, both tools have been developed to assist stakeholders in better understanding hydrogen-related undesired events.

The goal of this paper is to describe the recent evolution of the European database HIAD in term of objectives and structure.

2.0 THE HYDROGEN INCIDENT AND ACCIDENT DATABASE (HIAD)

The Hydrogen Incident and Accident Database (HIAD) has been designed to hold high quality information on accidents and incidents related to hydrogen production, transport (road/rail/pipeline), supply and commercial use. The database is updated with the latest information concerning each event in order to take advantage of the most recent outcomes of accident investigations.

HIAD had originally been developed in the frame of the HySafe EC co-funded Network of Excellence (NoE), which aimed at filling the lack of structured information clearly identified by the scientific community [4]. HySafe NoE (2004-2009) aimed at facilitating the safe introduction of hydrogen as an energy carrier, contributing to the safe transition to a more sustainable development in Europe [5]. The HySafe NoE network brought together competencies and experience of 24 partners from 12 European countries and one partner from Canada, representing private industries (automotive, gas and oil, chemical and nuclear), universities and research institutions; more than 100 scientists performed integrated research activities related to hydrogen safety issues. The main objective of the HySafe NoE network was to strengthen, integrate and focus fragmented research efforts to provide a basis allowing the removal of safety-related barriers to the deployment of hydrogen as an energy carrier. Synthesis, integration and harmonization of these efforts aimed at breaking new ground in the field of hydrogen safety and at contributing to the increase of public acceptability of hydrogen technologies within Europe by providing a basis for communicating the risks associated with hydrogen. One of the means to achieve those objectives was the development and establishment of the Hydrogen Incident and Accident Database, HIAD. After the end of HySafe NoE in 2009, a new legal entity was founded to continue the activities such as HIAD and the biannual International Conference on Hydrogen Safety. The new legal entity is a non-profit organization, the International Association for Hydrogen Safety (IA HySafe), whose mission is to facilitate the international coordination, development and dissemination of hydrogen safety

² <https://www.fch.europa.eu/>

³ <https://h2tools.org/lessons>

⁴ <http://www.hysafe.org/>

knowledge

The Hydrogen Incidents and Accidents Database HIAD had originally been designed as a multi-tasking tool: a communication platform suitable for risk and safety lessons as well as a potential data source for risk assessment [6]. The tool had the ambition to promote both the safety performance of existing hydrogen technologies and safety actions after events involving hydrogen.

Specifically, HIAD was originally intended to:

- contribute to the integration and harmonization of fragmented experience and knowledge on hydrogen safety;
- contribute to the progress in common understanding of hydrogen hazards and risks;
- constitute a reliable tool that provides inputs for safety and risk assessment [7];
- enable generation of common generic accident and incident statistics;
- serve as a common reference database for ongoing data collection and storage;
- keep the industry updated with recent hydrogen events, along with trend analyses;
- represent a reference source for the understanding and experience transfer of hydrogen accident phenomena, scenarios and hazard potential.

In order to achieve those objectives, HIAD data collection was and still is characterized by a significant degree of detailed information about recorded events (e.g. causes, releases, fires, explosions, consequences). The data are related not only to real incident and accidents but also to hazardous situations and false positive events.

The partners in the NoE HySafe collected and entered a considerable amount of data into HIAD. A quality assurance plan was developed to ensure a sufficient level of quality for all entered data. Each event submitted by a provider to HIAD was therefore subjected to a quality assurance process managed by a group of experts. This process was in place till the end of the HySafe project (2009).

The experience of the past years has revealed some shortcomings and generated improvement needs for HIAD. The goal of HIAD to become a tool for quantitative risk assessment was too ambitious, due to the limited number of events made available by a technology which has not yet attained full market maturity and is not yet deployed extensively. Available statistics on failures and failure modes of individual components belonging to the hydrogen technology chain are still not enough to allow for reliable quantitative analysis. This is the reason why activities on Quantitative Risk Assessment (QRA) of hydrogen technologies still now make use of failure statistics from different, though partially equivalent, technologies such as off-shore gas industry data. Finally, another identified issue was that after the end of NoE HySafe the database has not been supported financially by the community of hydrogen stakeholders. This had as a consequence that the pool of international experts which were providing quality assurance was not available anymore and that the communication channels linking potential event providers with the database had disappeared together with the network. After the end of the project, JRC became the only data provider, only publicly reported events have been collected and the quality assurance process had to be organised relying only on internal expertise. [8].

Based on the experience gained from HIAD operation of the previous years, JRC performed in 2016 a thorough analysis of the database functions, from a strategic as well as operative point of view. As a consequence, it was found that a complete overhaul of the database was required, addressing shortcomings in several areas.

The specific objectives of the database has been reviewed and assessed on the basis of their achievements and their impact. Among them, the one aiming at making HIAD an input tool for QRA was far from being achieved, for the reason mentioned above. To maximise the impact of the database it was necessary to focus on what could be learned from events. These lessons learned could result from the analysis of each individual event and/or from summarising conclusions from a cluster of similar events specific to each sub-technology. The dissemination of these lessons to the whole hydrogen technology community had to become the overarching goal of the tool; as a matter of fact, the analyses of the incidents and accidents recorded in the database will help to identify lessons learned, which then can be disseminated throughout the community to prevent a recurrence of similar accidents. The detailed assessment will be of high value in terms of establishing improvement needs in safety, health and environmental protection. This shift in focus is very similar to the one experienced by a comparable database developed by the US Department

of Energy [9]. To allow for this strategic re-focussing, the structure of HIAD had to be reviewed. The need of providing a tool for QRA required an extremely high level of detail for the description of events. The thorough analysis mentioned above identified a considerable number of fields which had remained empty for all the events. The re-structuring of HIAD started with the simplification of the events descriptors by merging several fields and reducing the level of detail for fields in which data were non-existent. In addition a qualitative description of the event is now encouraged, rather than the previously compulsory quantitative data entries which are now optional.

The need for improvement of the data collection process is another of the strategic aspects emerging from the mentioned analysis. Getting access to information on safety related events is a challenge, as facility owners or project coordinators, with some exceptions, do not have any obligation to provide data to HIAD. Several publically funded projects are mandated to report any incidents to HIAD, but this does not apply for all European and nationally funded projects. Establishing a requirement for any publically funded project to report any incident to HIAD would improve the data collection process considerably. Another option to get better access to safety related information is to have a commitment to report to HIAD as a requirement by permitting authorities. These measures would ensure a robust and distributed, European-wide network of data providers.

As to the event data itself, the attainability of accurate event reports is also a concern. The providers of an event description tend to give only a minimal amount of information, which limit any further analysis and lessons learned from the event. Relying on publically available information is not an option, as public press journal articles almost never provide data with the required quality and resolution. HIAD would profit from full accident reports made available by internal investigators, local authorities and/or first responders. Contacts with associations of first responders are on-going.

Finally, the interface of HIAD for entering event data was not easy to use as it had been developed for expert operators, not for end users. As mentioned above, the ambitious goal to serve as quantitative risk assessment tool had as a consequence that the level of details for a full event description was rather daunting and involuntarily encouraged misreporting and incomplete event description. Experience showed that the amount of detailed data required must be balanced with the average availability of information provided for a typical event. Therefore a simplification of HIAD users' interface was deemed critical, from event input to data selection and retrieval.

3.0 THE NEW VERSION OF HIAD

The upgrade work on HIAD was started by the JRC with close collaboration of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). The development of a new version of the database in order to specifically collect incidents from FCH JU projects (namely HELLEN) began in 2016. The new database has a significantly simplified structure: based on an in-depth analysis of the data quality collected in the previous years, entry fields were redefined and reduced, resulting in a more streamlined user interface compared to the older HIAD version. The front-end and back-end of the database were completely redesigned: a new database structure and a new user interface has been redesigned. In addition, a template for data collection was developed; it includes explanations for each entry field and guides the reporting activities. The access to the HELLEN database is limited only to staff of the FCHJU and to the HIAD team.

At the same time JRC will maintain a public database which will be further developed in the future (namely HIAD 2.0) [10]. This database will only contain publically available reports on events and incidents. The HELLEN database and HIAD 2.0 will be completely independent from each other. Both databases will share the same graphical front-end user interface (see Figure 1).

The FCH JU launched the European Hydrogen Safety Panel (EHSP) initiative in 2017. The mission of the EHSP is to assist the FCH 2 JU both at programme and at project level in assuring that hydrogen safety is adequately managed, and to promote and disseminate H2 safety culture within and outside of the FCH 2 JU programme. Composed of a multidisciplinary pool of experts – 17 experts on 2018 - the EHSP is grouped in small ad-hoc working groups (task forces) according to the tasks to be performed and to expertise. In 2018, the EHSP tasks under this category have encompassed the analysis of safety data and events contained in HIAD 2.0 operated by JRC (Joint Research Centre of the European Commission) and supported by the FCH JU. In close collaboration with JRC, the EHSP members have systematically reviewed more than 250 events

and the lessons learned stemmed from this assessment will be released in a report that will provide a clear view about the current situation with regards to the Hydrogen Safety Reference Database, while providing the foundations for future research in this field.

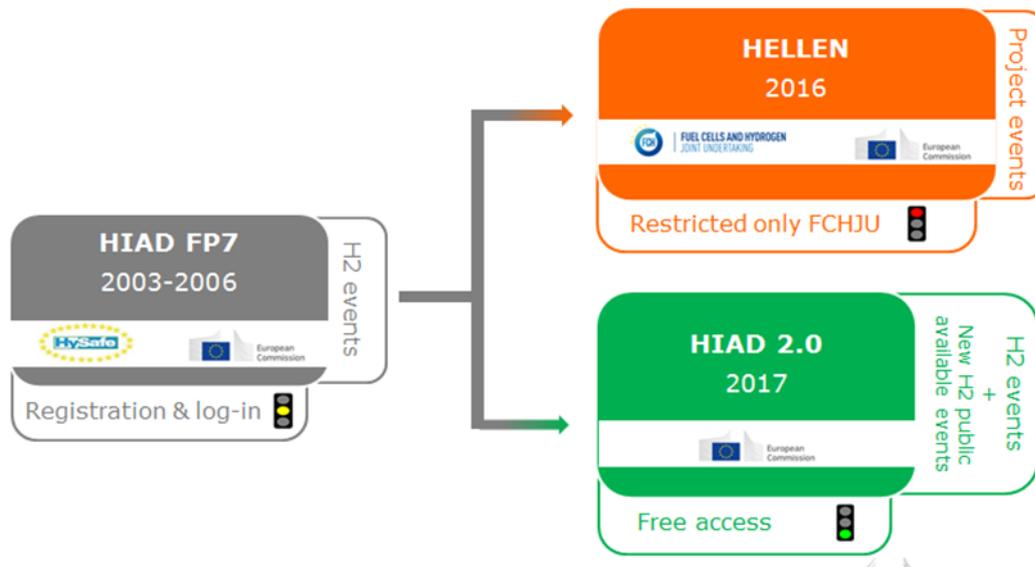


Figure 1. New databases and their relation with HIAD

4.0 THE STRUCTURE OF THE NEW DATABASES

The events inserted into the new databases are divided into three main categories, giving the first quick piece of information about the full event scenario: “Event classification”, “Physical consequences” and “Application” (see Figure 2). The “Event classification” is grouped in the following sub-categories:

- Non-hydrogen system initiating event: event not directly caused by the hydrogen system (e.g. sudden, unintended damage to hydrogen vehicles, installations or plants caused by impact, high voltage, failure of conventional components, etc.)
- Hydrogen system initiating event: event triggered directly by system containing hydrogen (e.g. rupture of hydrogen pipe, valve, tank)
- False positive: emergency alarm or procedure triggered in the absence of any actual problem; a hydrogen sensor giving a false alarm, for instance, falls in this category.

The “Physical consequences” category is sub-divided in jet fire and explosions, no hydrogen release and unignited hydrogen release; while the “Application” category has several subcategories such as hydrogen production, hydrogen transport and distribution, hydrogen refuelling station, road vehicles, etc.

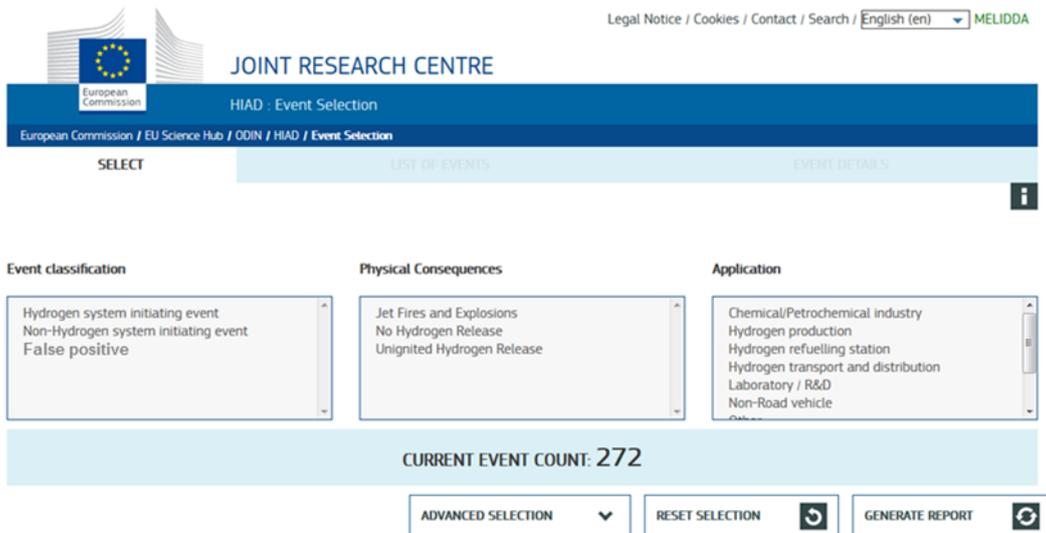


Figure 2. The front-end retrieval page.

An advanced selection process allows the possibility to filter the event search results using additional fields such as year of the event, cause, etc. (see Figure 3)

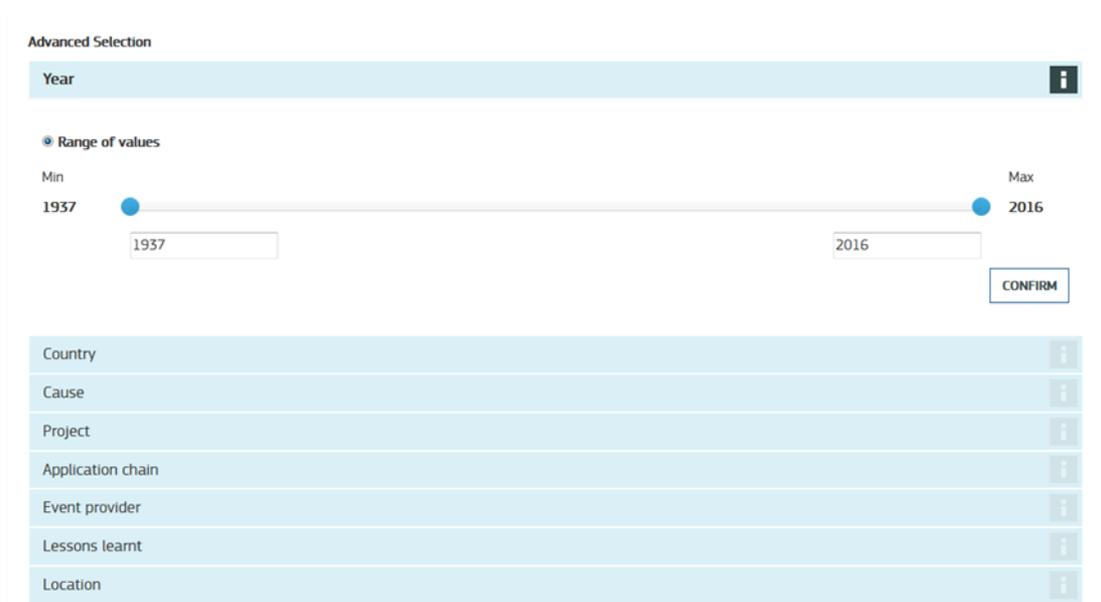


Figure 3. Advanced selection criteria page.

5.0 DATA COLLECTION

A dedicated on-line form will be used for reporting any safety-related event. The on-line form welcome page is shown in Figure 4; the form is divided into sub-sections (some of which are mandatory):

- Provider information: the contact information will only be used by the JRC for requesting clarifications on information provided, but will not be disclosed any further and will not be entered in the database.
- General information: together with the event category (i.e. “Non-Hydrogen system initiated event”, “Hydrogen system initiated event” and “False positive”) a summary of the key

aspects of the event has to be reported. This summary should specify the causes of the event and the context, the event dynamics, the technical details of the accident and a quantitative description of the effects.

- Initial situation (pre-event): it is a description of conditions prior to the event; it should be mentioned if the event occurred during planned or routine operation; there is also the possibility to specify information on the weather conditions, if considered important for understanding the event
- Application: it is the category related to the type of operation during which the event occurred (such as hydrogen production, hydrogen transport and distribution, hydrogen refuelling station, road vehicle, non-road vehicle, stationary fuel cell, portable fuel cell, laboratory / R&D and chemical/petrochemical industry). By selecting one category, relevant sub-category will appear allowing further specification of the type of application.
- Consequences: it is the description of the physical consequence (i.e. no hydrogen release, unignited hydrogen release and hydrogen release with jet fires and explosions) after the event; it is optionally possible to specify which part failed or was most affected in the event (e.g.: tank of a road vehicle, compressor of a hydrogen refuelling station, etc.); in addition a description of the consequences to people, equipment and environment (e.g.: which kind of injury, damage, etc.) is requested.
- Cause of the event: it is a description of which causes were identified or are deemed most likely (e.g.: human error, lack of maintenance, untrained personnel, etc.)
- Corrective actions taken (if any): the description of the corrective actions already taken to avoid recurrence of the event and if the event required further investigation (for instance official investigation) has to be reported.
- Lessons learned: it is related to any lessons learned from the event; this could consist in improved procedures, new preventive and/or mitigating measures, better training, etc.
- Reference: it is also possible to upload reference documents or pictures of the event, if available.

Figure 4. Advanced selection criteria page.

Previous experience has shown that in some cases the information given in a report form is not sufficiently detailed or that clarifications are necessary. Therefore a direct contact with the event provider is crucial, to prevent misunderstandings and to ensure that a complete picture of the event is available. This will be also necessary in the case of a complex accident, where the description may need further details to enable understanding of the event circumstances and consequences. Once the additional needed information is received, the event will be formatted, entered in HIAD and validated by the HIAD team.

In the specific case of the HELLEN, if needed, the acquired information will be processed, analysed and reported with the external support of selected FCHJU European Hydrogen Safety Panel (EHSP) members (see Figure 5), consisting of a group of recognized hydrogen safety experts. In this case, the experts of the EHSP will have access to individual events within HELLEN for further analysis and for obtaining the lessons learned together with the JRC HIAD team. This will take place under a confidentiality agreement with the selected EHSP experts.

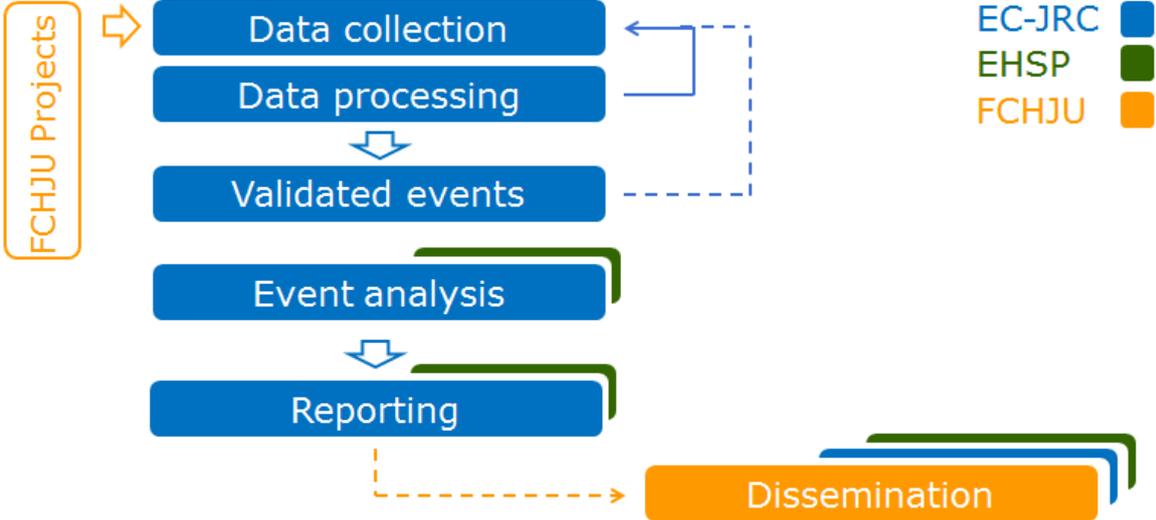


Figure 5. HELLEN: Data collection, analysis and reporting process.

6.0 HIAD 2.0 DATA ANALISYS

Currently 272 events are present in HIAD 2.0; in Figure 6 is reported the geographical distribution of them: the majority of them happened in Europe and in America (i.e. 155 and 94 events reported respectively), and 21 events happened in Asia. No reported events happened in Africa and only 2 in Oceania.

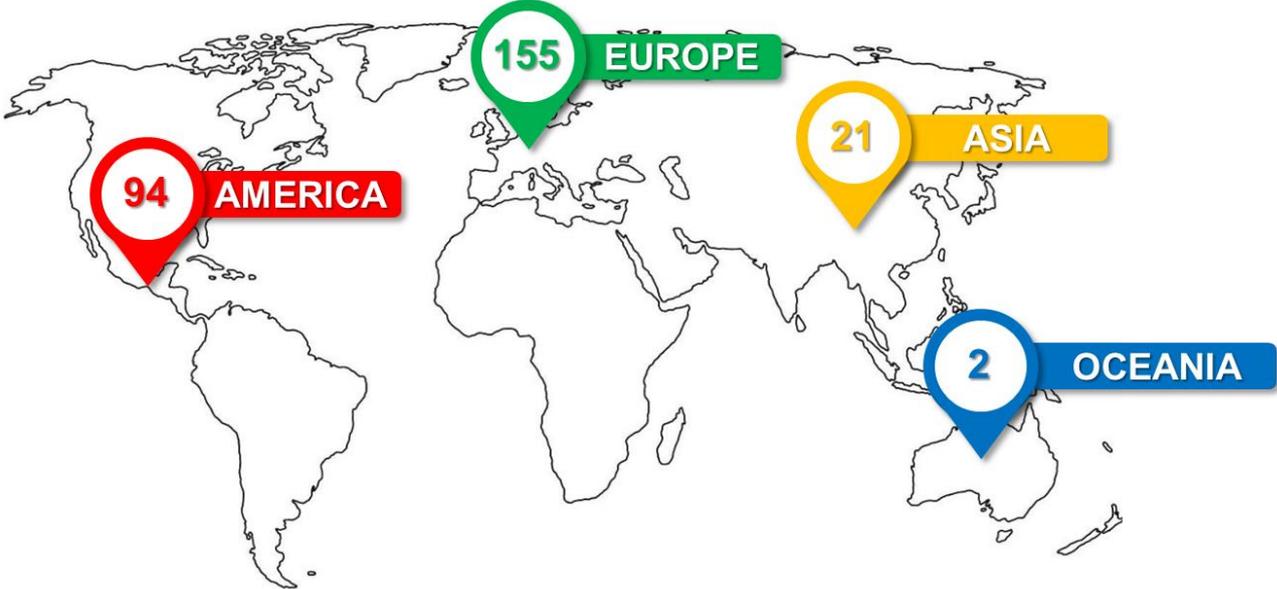


Figure 6. Geographical distribution of the events reported in HIAD 2.0

The events reported are divided in three main categories: "non-hydrogen system initiated event", "hydrogen system initiated event" and "false positive". The "non-hydrogen system initiated events" are the events not directly caused by the hydrogen system; for instance: sudden, unintended damage to hydrogen vehicles, installations or plants caused by impact, high voltage, failure of conventional components, etc. On the other hand, the "hydrogen system initiated events" are the events triggered directly by system containing hydrogen (e.g. rupture of hydrogen pipe, valve, tank). Emergency alarms or procedures triggered in the absence of any actual problem (e.g. a hydrogen sensor giving a false alarm) fall in this category "false positive". The events are also divided in three main physical consequences: no hydrogen release, unignited hydrogen release and hydrogen release with jet fires and explosions. As reported in Figure 7, the majority of the events are initiated by hydrogen system: almost all of them had as a consequence the release of hydrogen; among them, 191 events had either jet fire or explosion as physical consequences and 36 events had unignited hydrogen release as a consequence. The majority of the "non-hydrogen system initiated events" (i.e. 28 events) didn't produce any hydrogen release.

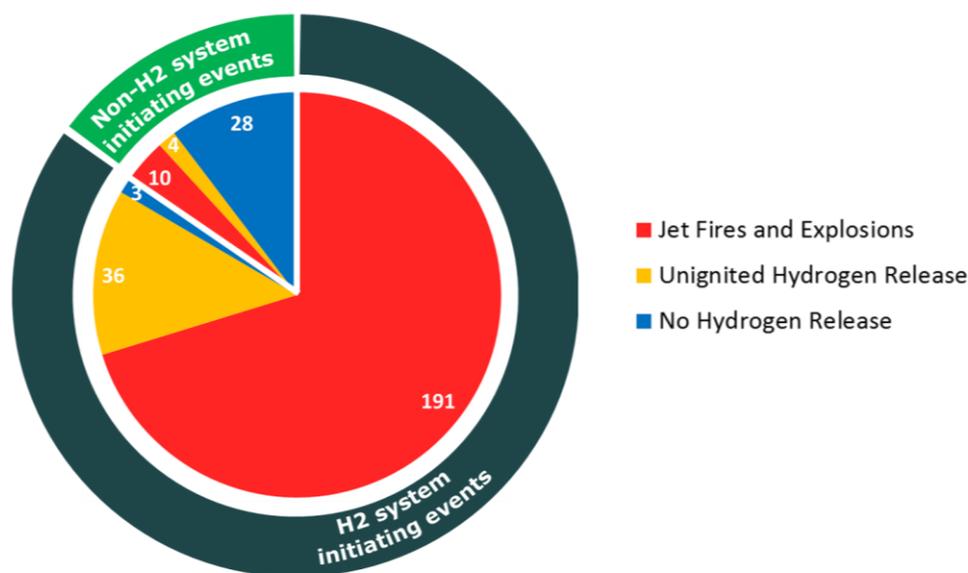


Figure 7. HIAD 2.0 events grouped in categories

The events are also divided by the type of operations in which the event occurred, as reported in Figure 8: 172 events happened in chemical/electrochemical industry (such as refining, treating metals, and food processing). That could be explained by the fact that about 55 % of the hydrogen produced around the world is used for ammonia synthesis, 25 % in refineries and about 10 % for methanol production; the other applications worldwide account for only about 10 % of global hydrogen production [11].

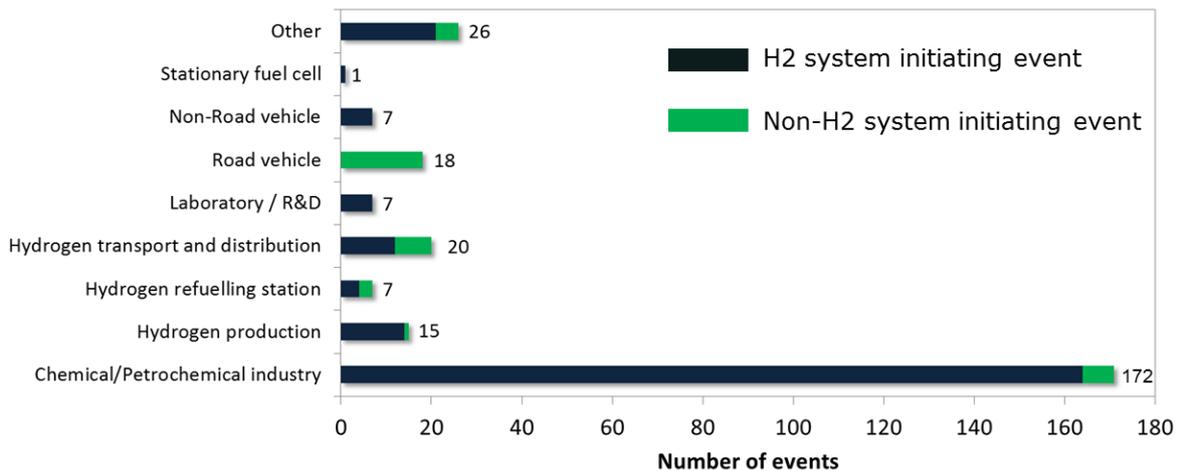


Figure 8. HIAD 2.0 events grouped by applications

7.0 RESULTS FROM EHSP ANALYSIS

Some lessons to be learned have been produced through analysis of the accidents by the experts. These can be divided into several areas as summarised below. A more detailed summary of the experts' comments will be uploaded on the EHSP website in the near future. That document also highlights some events which are useful for operators to be aware of. Those interested are also strongly recommended to consult the database for further insight and the original description of the incidents.

- **Inspection and maintenance:** Regular inspection before and during service to detect materials/components/process defects, or faulty connections, or materials failure, etc. is required to help ensure safety operation. Some cases indicated the need for the revision of the inspection plan, increasing the inspection frequency and scope of the inspected components. Corrosion has also been the cause of several accidents and need to be given due consideration for prevention in addition to inspection on hydrogen embrittlement.
- **Personnel:** Staff training and supervision are key to safety. Quite a few incidents were caused by human error. The training procedures should be made more stringent and updated at regular intervals for the personnel responsible for plant operation, even for operation considered "routine". It is also important that process instructions are made readily available, and the necessity to follow the rule and instructions received should be emphasized. The security processes prescribed for the modification and /or improvement of the plants, especially when external companies are used, should be made more stringent when these operations take place in the vicinity of functioning plants, adopting a more stringent system for the working permits. As human errors cannot be completely prevented, it might be useful to insist that some key interventions critical for plant operation cannot be bypassed, ignored or silenced by the responsible personnel (blockage devices, alarms of extreme intervention, etc.).
- **Process/plant modification:** In some cases, post-accident investigation has resulted in modifications of the process/plant/working method. For example, when electrical and magnetic problems were the identified to be the likely causes of some incidents, recommendation was suggested for the modification of the electrical system including power load rejection and protection against electromagnetism. Some incidents led to suggestions about changing the design of various equipment to avoid cavitation and hydrogen accumulation: pump & column; changing the operational conditions to reduce the vibrations for machinery like turbine and reducing time delay of the shut off valves. Procedures for maintenance operation were modified following some cases.
- **New equipment:** Special care when commissioning new equipment.

- **Cascading events:** Some accidents might consist of several causal events which, if occurred separately, might have little consequences; but if these minor events occurred simultaneously, they could still result in extremely serious consequences.
- **Miscellaneous:** Adequate risk assessment should be conducted for relevant installations concerning potential chemical reactions leading to hydrogen gas production. Safe venting of hydrogen and installation of hydrogen sensors should be emphasized. Clear guidance should be established about the lifetime of critical components in addition to their regular inspection and replacement. Some details concerning the safety during filling a gaseous hydrogen tube trailer are also described in the summary report.

8.0 CURRENT STATUS AND OUTLOOK

Based on the experience gained from HIAD operation of the previous years, JRC has performed a thorough overhaul of the HIAD database. A strategic re-focussing was undertaken, to facilitate the sharing of lessons learned rather than providing a tool for QRA. The original goal of providing input to QRA could possibly be revisited in case the knowledge on failure modes and statistics advances to a sufficient degree. The simplification of the user interface will enable a more effective event reporting and subsequent analysis. The database is now separated into a public (HIAD 2.0) and a limited access (HELLEN) section. All reported incidents will be analysed by safety experts and the lessons learned from events will be made available to the FCH community.

The data entered into HELLEN from FCHJU Projects will be owned by the FCHJU, whereas the database itself is property of the JRC. The events already entered in HIAD during the FP6 and FP7, before the start of the collaboration with the FCH2JU are belonging to the broader technology and scientific community and have been transferred to the HIAD 2.0.

Initial contact with the FCHJU Projects required to report to HELLEN has been established. Future efforts by the JRC, assisted by the safety community, will be to encourage other funded projects to report into HIAD 2.0, and in general increase the awareness of this tool for the hydrogen and fuel cells community.

REFERENCES

1. Rifkin J, Carvalho M, Consoli A, Bonifacio M. Leading the way to the third industrial revolution. *Eur Energy Rev* December 2008;1:4-18 [Special edition].
2. Nakata T, Silva D, Rodionov M. Application of energy system models for designing a low-carbon society. *Prog Energy Combust Sci* 2010;37:462-502.
3. Carvalho M, Bonifacio M, Dechamps P. Building a low carbon society. *Energy* 2010;36:1842e7.
4. Funnemark E, Eldor JE, Haugom GP. Identification and review of database for reliability data. *HyApproval; Deliverable 4.4; 2006.*
5. Jordan T. HySafe - the network of excellence for hydrogen safety. In: *Proceedings of the Sixteenth World Hydrogen Energy Conference; 2006.*
6. M. Cristina Galassi, Efthymia Papanikolaou, Daniele Baraldi, Espen Funnemark, Erling Haland, Angunn Engebø, Gerd Petra Haugom b, Thomas Jordan c,d, Andrei V. Tchouvelev. HIAD e hydrogen incident and accident database. *International Journal of Hydrogen Energy* Volume 37, Issue 22, November 2012, Pages 17351-17357

7. Funnemark E, Engebø A. Development of tools for risk assessment and risk communication for hydrogen applications. In: Proceedings of the First International Conference on Hydrogen Safety; 2005.
8. Kirchsteiger C, Vetere Arellano AL, Funnemark E. Towards establishing an international incidents and accidents database (HIAD). J Loss Prevent Proc 2007;20:98e107
9. <https://h2tools.org/lessons>
10. <https://odin.jrc.ec.europa.eu/odin/index.jsp>
11. <https://hydrogeneurope.eu/>