



FUEL CELLS and HYDROGEN 2 JOINT UNDERTAKING (FCH 2 JU)

Assessment and lessons learnt from HIAD 2.0 – Hydrogen Incidents and Accidents Database

20 September 2019

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TABLE OF CONTENTS

1.INTRODUCTION.....	4
2.THE EVENTS CONTAINED IN HIAD 2.0 – OVERVIEW	5
3.THE EHSP ANALYSIS – THE PROCEDURE.....	8
4.LESSONS LEARNT AND RECOMMENDATIONS.....	9
4.1 Inspection and maintenance	10
4.2 Personnel	10
4.3 Process/plant modifications.....	11
4.4 Miscellaneous cases	12
5.CONCLUSIONS.....	13

1. Introduction

The Hydrogen Incidents and Accidents Database (HIAD) is an international open communication platform collecting systematic data on hydrogen-related undesired events (incidents or accidents). It was initially developed in the frame of the project HySafe, an EC co-funded NoE of the 6th Frame Work Programme by the Joint Research Centre of the European Commission (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.

Starting from June 2016 JRC has been developing a new version of the database (HIAD 2.0¹). With the support of the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU), 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 learnt and other relevant information related to hydrogen technology; the database is publicly released, and the events are anonymized. The database currently contains over 250 events. It aims to 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.

The FCH 2 JU launched the European Hydrogen Safety Panel (EHSP²) initiative in 2017. The mission of the EHSP is to assist the FCH 2 JU at both programme and project level in assuring that hydrogen safety is adequately managed, and to promote and disseminate hydrogen safety culture within and outside of the FCH 2 JU programme. Composed of a multidisciplinary pool of experts – 16 experts in 2018 - the EHSP is grouped in small ad-hoc working groups (task forces) according to the tasks to be performed and the expertise required. In 2018, Task Force 3 (TF3) of the EHSP has encompassed the analysis of safety data and events contained in HIAD 2.0 operated by JRC and supported by the FCH 2 JU. In close collaboration with JRC, the EHSP members have systematically reviewed more than 250 events.

This report summarizes the lessons learnt stemmed from this assessment. The report is self-explanatory and hence includes brief introduction about HIAD 2.0, the assessment carried out by the EHSP and the results stemmed from the joint assessment to enable new readers without prior knowledge of HIAD 2.0 to understand the rationale of the overall exercise and the lessons learnt from this effort. Some materials have also been lifted from the joint paper between JRC and EHSP, which will also be presented at the International Conference on Hydrogen Safety (ICHS 2019)³ to provide some general and specific information about HIAD 2.0.

¹ <https://odin.jrc.ec.europa.eu/giada/Main.jsp>

² <https://www.fch.europa.eu/page/european-hydrogen-safety-panel>

³ Melideo, D., Wen, J. and Moretto, P., HIAD 2.0 - HYDROGEN INCIDENT AND ACCIDENT DATABASE, International Conference on Hydrogen Safety 2019, 24-26 September, Adelaide, Australia.

2. The events contained in HIAD 2.0 – Overview

The events contained in HIAD 2.0 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 1).

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JOINT RESEARCH CENTRE

European Commission

HIAD : Event Selection

European Commission / EU Science Hub / ODIN / HIAD / Event Selection

SELECT LIST OF EVENTS EVENT DETAILS

Event classification

Physical Consequences

Application

Hydrogen system initiating event
Non-Hydrogen system initiating event
False positive

Jet Fires and Explosions
No Hydrogen Release
Unignited Hydrogen Release

Chemical/Petrochemical industry
Hydrogen production
Hydrogen refuelling station
Hydrogen transport and distribution
Laboratory / R&D
Non-Road vehicle

CURRENT EVENT COUNT: 272

ADVANCED SELECTION RESET SELECTION GENERATE REPORT

Figure 1: The front-end retrieval page

The first main category “Event classification” is grouped in the following three 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 second main category “Physical consequences” is sub-divided three sub-categories: jet fire and explosions, no hydrogen release and unignited hydrogen release; while the third main category “Application” category has several sub-categories such as hydrogen production, hydrogen transport and distribution, hydrogen refuelling station, road vehicles, etc.

Overall, 233 events were initiated by hydrogen systems while 42 were initiated by non-hydrogen systems. Table 1 provides an overview of the number of events in each of the above sub-categories.

Table 1: HIAD 2.0 events classification- Overview

	Number of events	Application								
		Chemical/Petrochemical industry	Hydrogen production	Hydrogen refuelling station	Hydrogen transport and distribution	Non-road vehicle	Road vehicle	Stationary fuel cell	Laboratory/R&D	Other
Hydrogen system initiating event	230									
Jet fires and explosions	191	137	13	1	8	5			7	20
No hydrogen release	3	3								
Unignited hydrogen release	36	24	1	3	4	2		1		1
Non-hydrogen system initiating event	42									
Jet fires and explosions	10	6	1		2					1
No hydrogen release	28			3	4		18			3
Unignited hydrogen release	4	1			2					1

In terms of “Physical consequences”, the majority of the events were initiated by hydrogen system: almost all of them had as a consequence the release of hydrogen (see Figure 2). 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) did not produce any hydrogen release.

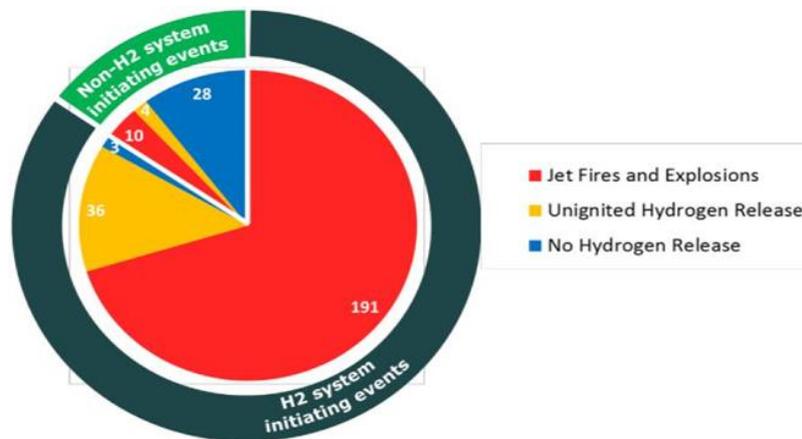


Figure 2: HIAD 2.0 events grouped in categories

In terms of “Application” (see Figure 3), 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 production⁴.

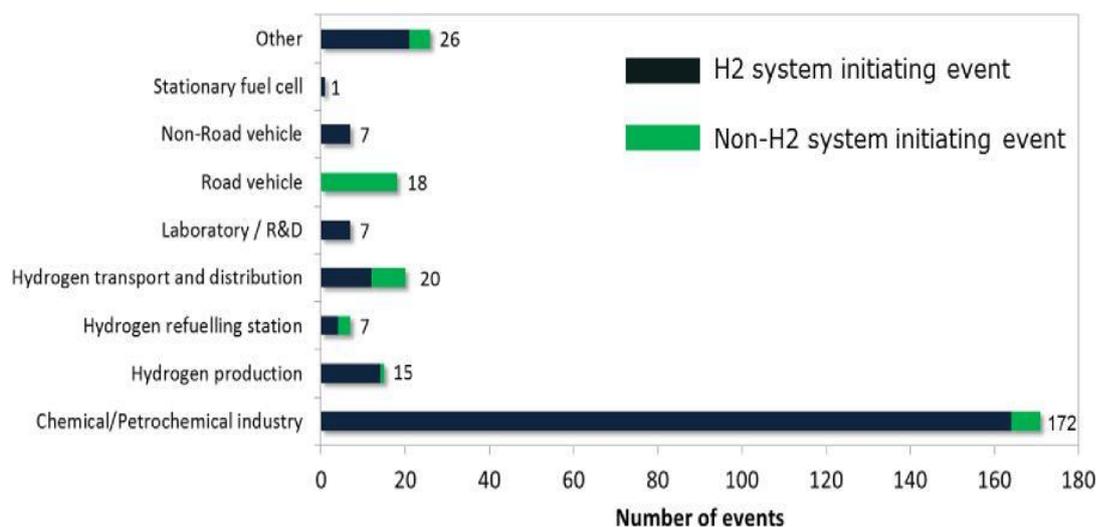


Figure 3: HIAD 2.0 events grouped in applications

Last, in terms of geographical distribution of the reported events (See Figure 4), the majority of the events were reported from Europe and USA with 21 events reported from Asia. No reported events happened in Africa and only 2 in Oceania. More specifically, events reported from Europe include 47 events in France, 20 in Germany, 16 in the United Kingdom, 5 in Norway, 3 in Italy, 3 in Spain, 2 in the Netherlands, 1 in Sweden, 1 in Poland, 1 in Finland, 5 Switzerland and an additional 49 events were reported as from the European Union without identifying the specific country. There are 126 events from elsewhere in the world including 82 in the USA, 12 in Canada, 7 in Japan, 2 in Korea and 2 in China, etc.

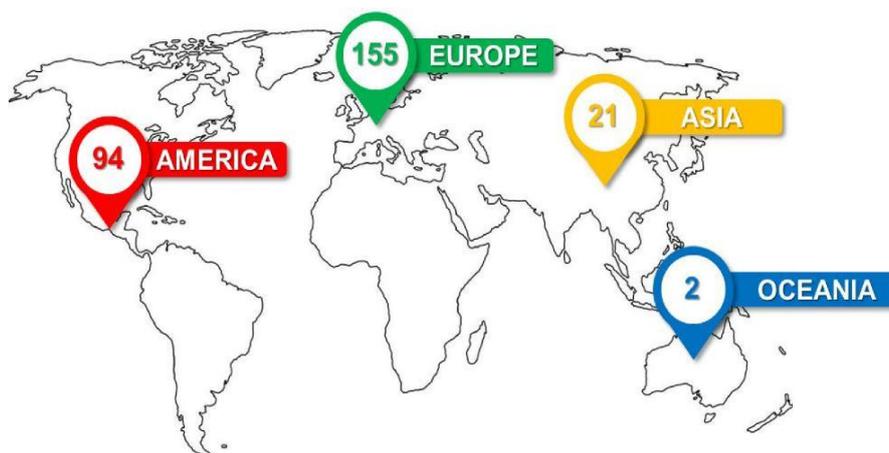


Figure 4: Geographical distribution of the events reported in HIAD 2.0.

⁴ <http://www.hydrogen Europe.eu/>

3. The EHSP analysis – The procedure

This section provides some insights about the process followed by the EHSP to perform the assessment carried out on the events contained in HIAD 2.0.

In brief, the process encompassed the following steps:

First, ten members of the EHSP were appointed to analyse the events in HAID 2.0 with the aim to identify, report and summarise the lessons learnt. To do so, a template⁵ for the event assessment was designed jointly with JRC. The structure of the template followed the descriptive analysis of the events contained in HIAD2.0. This was then implemented in the intranet online by JRC to facilitate the collection of the assessments from the experts.

Then, the 272 events contained in HIAD 2.0 in 2018 were divided among the EHSP experts, which worked in 5 groups of 2 experts per group. Each expert reviewed individually the allocated batch of events and fill the comments in the online template. Then, JRC output the information in all the completed templates into an excel file.

Next, upon the completion of the individual tasks, the two experts in each group then conducted peer-review of each other's assessment, and finally, all the EHSP experts had the opportunity to review and comment on all the individual reports generated. Comments were fed back and addressed by the original experts, if required.

As a result, the final peer-reviewed assessments were documented in an excel file, which lists the individual analysis with the following columns following the descriptive analysis of the events contained in HIAD2.0:

- the contributing author,
- event ID in HAID 2.0,
- the category according to Table 1,
- classification,
- cause of the event,
- searchable keywords,
- summary of the event,
- severity of the event,

⁵ <https://www.fch.europa.eu/page/european-hydrogen-safety-panel>

- lessons learnt,
- possible measures to prevent the event,
- possible measures to mitigate the event,
- information available on rescue and firefighting actions,
- if the event was caused by the failure of a specific part, what might have been done to prevent this
- what short- and long-term intervention/ solution should be put in practice to prevent and mitigate such event, and
- any lessons learnt highlighted in the above should inform the “Safety guidance and best practices document for hydrogen and fuel cell systems and fuel cell systems and infrastructure”

4. Lessons learnt and recommendations

Despite the lessons learnt from each specific event are quite specific and particular to the event conditions itself, this section aims to provide some insights about some common aspects detected in the lessons learnt compiled in the experts’ individual reports.

Overall, the overarching lesson learnt is that accidents might consist of several causal events that, if occurred separately, might have little consequences; but if these minor events occurred simultaneously, they could still result in extremely serious consequences.

In order to facilitate the reading, the lessons learnt and recommendations provided in this section are grouped into several sub-sections according to whether they were related to inspection and maintenance, personnel, or whether the events resulted in recommendation for process/plant modification. Last, any lessons outside these were group as miscellaneous cases.

The readers are recommended to consult the original event description in HIAD 2.0, where there are more details for specific events of interest.

The following sub-sections provide some insights from some of the lessons learnt stemmed from the expert’s assessment.

4.1 Inspection and maintenance

- Analysis of several cases (Event ID: 97, 101, 110, 114, 210, 212, 214, 221, 247, 252, 255, 262, 261, 411, 140, etc.) has certainly highlighted the importance of regular inspection before and during use to detect materials/components/process defects, or faulty connections, or materials failure, etc.

It is important to note that some cases indicated the need for the revision of the inspection plan, increasing the inspection frequency and scope of the inspected components. Periodic verification/audit of the structural integrity of the hydrogen tank and the use ATEX equipment close to the hydrogen tanks are also recommended.

- Regular verification of the structural integrity and maintenance of the system is also recommended.

Corrosion has also been the cause of several accidents and needs to be given due consideration for prevention. For example, Event ID 95 was caused by the corrosion of heat exchanger. Other cases caused by corrosion include Event ID: 83, 104, 122, 131. 194, 196, 208, 210, 246 and 261.

- Some accidents were related to improper maintenance (Event ID: 49, 97, 101, 106, 123, 185, 190, 192, 194, 195, 321, 156, 196, 198-199, 208, 234, 241-242, 249, 405, 410, etc.). The lessons learnt have all called for improved maintenance and the maintenance procedures to be closely followed.

As an example, in Event ID 101, the release of hydrocarbons (ethane, ethylene, methane) and hydrogen in a cryogenic unit led to the burst of a tank, which resulted in jet fires and explosions. In Event ID 150, a rupture in the furnace of an oil refinery caused it to lose 700 pounds of diesel and hydrogen resulting in a fire due to maintenance failure; and proper maintenance of the pipe and testing was particularly recommended.

It was also noted that the procedures for maintenance were modified following some events.

- Recommendations have also been made about the need for regular check of safety equipment, regular leakage tests, inspection on hydrogen embrittlement.

4.2 Personnel

- Some accidents could have been prevented if adequate process instructions were readily available.

Analysis of Event ID 321, which involved the motor of the vacuum cleaner acted as an ignition source to some accumulated combustible gases in an unnamed process, has also led to the recommendation to observe the concentration change in system and verify that purging the system is complete before using a vacuum cleaner. The use of a special ATEX vacuum cleaner was also recommended. This event was caused by human error.

- 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.
- Safety supervision should be provided during some repairing works, and extreme precautions should be exerted when soldering.
- Staff training is also a very important aspect to help ensure safe operation. Quite a few incidents were mainly 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".
- Training and recomunication of special operational conditions must be reinforced; and special care should be exerted when commissioning new equipment.

As human errors cannot be completely prevented, it is 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.).

- The necessity to follow the rules and instructions received should be emphasized.

4.3 Process/plant modifications

During the EHSP assessment, it was noted that some events (incidents/ accidents) resulted in the working method being changed (process modification) while others resulted in the installation being altered (plant modification). The following list provides some examples of different process/plant modifications due to some events or the recommendations made following the event analysis:

- Some accidents led to the recommendation to install extra mitigation barriers such as forced ventilation, concentration detectors and automatic closing valves, system purging and verification, developing adequate corresponding procedures to reduce the risks, eliminate ignition sources and use ATEX equipment, etc. As a result of one incident, the plant operator modified the wastewater treatment procedure to prevent any hydrogen releases.
- In general, careful design to limit hydrogen inventory, place inventory outside, protect vessels against thermal attacks, etc. is recommended. Clear separation of combustible gas and oxidizer is considered as a good practice and special attention should be taken to tightening gaskets with growing leaks. Purging of vessels after completion of hydrogen process is also recommended.
- In some cases, it was recommended to perform regular verification and update of the safety plan followed by corresponding communication and training. In others it was recommended to conduct risk assessments during the venting of hydrogen gas into the atmosphere, considering the installation of alarms and improved design of the piping system, or adequate risk assessment concerning potential chemical reactions leading to hydrogen gas production.
- Procedures should be in place for fast isolation of the release sources

- In some cases, electrical and magnetic problems were the likely causes. The post-accident analysis resulted in the recommendation for the modification of the electrical system including power load rejection and protection against electromagnetism.
- The Provision for safe venting of hydrogen is of great importance. One accident resulted in the recommendation to add a correct ventilation system and monitor the concentration with a detector which is directly linked to an automatic alarm. In another, it was recommended to consider adding a temperature controller on the pipe connected to an emergency shut down.
- The importance about the installation of hydrogen sensors was also mentioned following the analysis of several events.
- In some cases, the installation of a passive barrier between identified weak points and hydrogen pipes have been recommended.

4.4 Miscellaneous cases

The following list provides some additional examples of the lessons learnt and recommendations stemmed from the assessment performed, and from events involving devices/components, and ignition sources/fire barriers.

- Clearer guidance should be established about the lifetime of critical components in addition to their regular inspection and replacement. It is noted that the fatigue of devices needs to be properly considered; and it is recommended to have an effective mechanical integrity and frequent corrosion testing procedure. In addition, if possible, it is better to avoid flange connections. Use of redundant and diverse measurement systems is recommended as a good practice.
- Enforce fire barriers is recommended, including fires as most probable ignition source in the zoning and general risk assessment. Separation should be provided for hydrogen system such that jet fire in one system cannot affect another hydrogen system.
- It is recommended to enforce ATEX zoning for some operational / maintenance tasks like repairing, etc. and to consider zoning for hydrogen tanks and ensure that ignition source is excluded in such controlled zone. Special ignition issues in electrolysis cells; co-existing hydrogen and oxygen or chlorine gas require special care for leak tightness; choice of appropriate materials, etc.

5. Conclusions

The EHSP has encompassed the analysis of safety data and events contained in HIAD 2.0 operated by JRC and supported by the FCH 2 JU. In close collaboration with JRC, ten experts from the EHSP have systematically reviewed more than 250 events. Individual review reports summarizing the lessons learnt were firstly prepared by the individual expert and then peer reviewed by the group. This report summarizes the lessons learnt stemmed from this assessment while examples of the individual reports are included in Appendix II of this document. The readers are also recommended to consult the original event description in HAID 2, where there are more details, for specific events of interest.

The lessons learnt are grouped into several sub-sessions, but overall the review highlights the importance of regular inspection and maintenance, adequate training provision of the personnel involved, and the need to exert care when commissioning new equipment. Moreover, it is also important to note that the occurrence of some events led to the recommendation for process or plant modifications. A key takeaway message is that 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. Therefore, to ensure plant and personnel safety, it is of critical importance to follow safety principles and operating procedures strictly to avoid any event from occurring.