# LESSONS LEARNED FROM SAFETY EVENTS

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**ABSTRACT**

The Hydrogen Incident Reporting and Lessons Learned website (www.h2incidents.org) was launched in 2006 as a database-driven resource for sharing lessons learned from hydrogen-related safety events to raise safety awareness and encourage knowledge-sharing. The development of this database, its first uses and subsequent enhancements have been described at the Second and Third International Conferences on Hydrogen Safety. [1,2] Since 2009, continuing work has not only highlighted the value of safety lessons learned, but enhanced how the database provides access to another safety knowledge tool, Hydrogen Safety Best Practices (http://h2bestpractices.org). Collaborations with the International Energy Agency (IEA) Hydrogen Implementing Agreement (HIA) Task 19 – Hydrogen Safety and others have enabled the database to capture safety event learnings from around the world. This paper updates recent progress, highlights the new "Lessons Learned Corner" as one means for knowledge-sharing and examines the broader potential for collecting, analyzing and using safety event information.

## 1.0 INTRODUCTION

The primary purpose of safety event reporting, analysis and use is to facilitate the sharing of lessons learned and other relevant information gained from actual experiences, with the goal of preventing similar events from occurring in the future. As one example in the industrial sector, the Process Safety Incident Database (PSID) of the American Institute of Chemical Engineers' Center for Chemical Process Safety allows participating companies to collect and share safety incident experiences to enable learning based on the experience of others. [3]

The magnitude of safety events can vary widely and impact personnel, equipment, business operations and the environment. By learning about the likelihood, severity, causal factors, setting and relevant circumstances of safety events, one is better equipped to prevent similar incidents in the future and at other facilities.

These same principles have been applied to the development and use of a database-driven website, Hydrogen Incident Reporting and Lessons Learned (www.h2incidents.org). The development of this database, its first uses and subsequent enhancements were described at the Second International Conference on Hydrogen Safety (ICHS). [1] At the Third ICHS, the lessons learned from three example safety events in the database were described and the linkage to specific resources in another safety knowledge tool, Hydrogen Safety Best Practices (http://h2bestpractices.org), was illustrated. [2]

From the outset, we have hoped that users of this publicly accessed website will both learn valuable lessons from others and share their own experiences. Ensuring anonymity for those who submit safety event records is an important principle in this work. Therefore, all identifying information, including the names of companies or organizations, locations, equipment brands and the like, are removed to ensure confidentiality and to encourage the unconstrained future reporting of events. Adherence to this approach will help ensure the future viability of this tool and enable additional enhancements such as the one which is the principal topic of this paper.

## 2.0 ENHANCING "H2INCIDENTS.ORG"

Our goal has always been to ensure technically accurate safety event records. Over the past three years, we have made significant technical enhancements to the safety event records stored in the database, which currently contains 195 records. The 114 safety event records entered during 2006 and 2007 were mainly obtained from databases and journal articles, many of which were from the 1980s and even earlier. Only about 25% of these incidents occurred since 2000, and about 40% of them occurred in the 1990s. For most of the initial efforts to collect lessons learned, the information that could be extracted directly from the database sources and other documents was limited. Access to points of contact for detailed discussions of these events, their probable causes, contributing factors and lessons learned was also significantly limited. As would be expected for growing hydrogen-related research and development (R&D) and applications, hydrogen safety best practices have evolved to an enhanced state of knowledge compared to 30-40 years ago, and these early incidents may be less relevant to current hydrogen-related work.

Among the 81 safety event records entered into the database since 2008, about 85% occurred between 2001 and the present, making those lessons learned more relevant to those who are working with hydrogen today. Recent safety events were brought to our attention by organizations such as the U.S. Department of Energy (DOE) and the Fuel Cell and Hydrogen Energy Association (FCHEA), through Google alerts searching for "hydrogen" or "fuel cell vehicle" stories in the news media and through self-reporting. We ask the "incident owner" to review and approve each record to ensure that the incident details and the lessons learned are complete and accurate. We try to obtain more detailed descriptions of the safety events and lessons learned from the owners and include photos whenever they are available to enhance the knowledge-sharing process.

We take a flexible approach to developing new safety event records for the database. First, a PNNL staff member contacts the national laboratory, university or private-sector firm that experienced the event to discuss it with them. The discussion is focused on sharing lessons learned with the hope of preventing future incidents. We assure the owner that all identifying information (e.g., individual and organization names, locations) is confidential and will not be published on the public website, and that no safety event records are published without the owner's review and approval. Once we build a level of trust, we encourage the owner to either submit a draft safety event record using the submission form on the website, or let us create a draft record for their review and approval.

The online incident submission form was used extensively by members of the IEA HIA Task 19 who submitted safety event records for our database during 2009 and 2010. Records were submitted by members from Canada, France, Germany, Italy, Japan, the Netherlands, Switzerland, the United Kingdom and the United States. The inclusion of international hydrogen safety event records has greatly enriched the database content and expanded the pool of lessons learned information.

The most significant and recent technical enhancement to the website is the addition of the quarterly Lessons Learned Corner (LLC) to analyze lessons learned in specific thematic areas of hydrogen safety. This analytical enhancement, described in detail in Section 3.0, provides valuable insights that might not be evident from just looking at individual safety event records.

In addition to the technical enhancements discussed above, we updated the website design and features to make it more user-friendly. Figure 1 displays a screen shot of the welcome page of the "H2incidents.org" website. Several improvements have been made since the website was launched in May 2006, including streamlining the welcome page, improving the advanced search function, and enhancing the graphical presentation of the database contents.

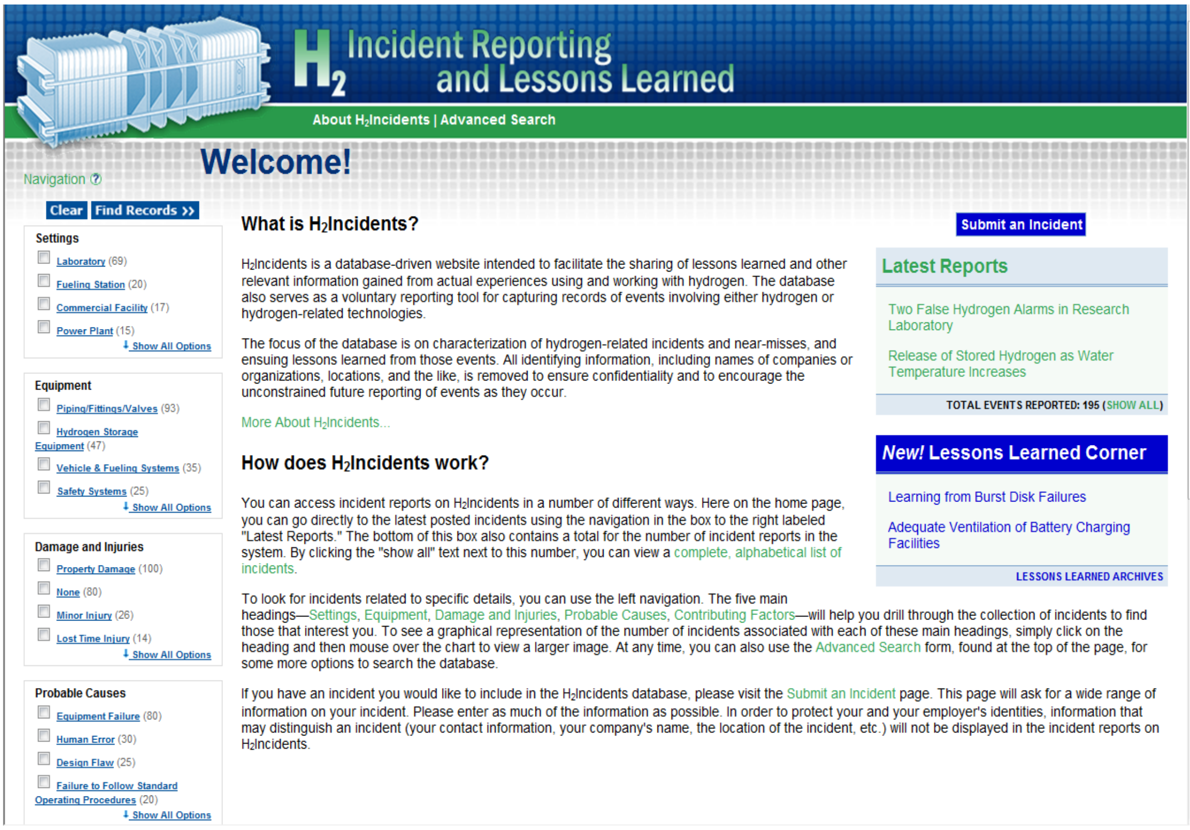


Figure 1. Hydrogen Incident Reporting and Lessons Learned Database Welcome Page

The welcome page was revised in 2010 to make the “Submit an Incident” button more visible. The button was moved to the top of the page, just above the box showing the Latest Reports.

A more powerful search feature has made it easier to find information. Now an “Advanced Search” page can be accessed by clicking the link in the green bar at the top of the welcome page. The Advanced Search will find all the places where the terms entered by the user appear in incident titles, descriptions or lessons learned. Specific settings, equipment, damage/injuries, probable causes and contributing factors can also be used as search criteria by using the “Find Records” button in the left navigation column or using the pull-down menu under “Restrict Search Categories” at the bottom of the Advanced Search page.

In response to a user request, we added the ability to graphically display the database contents in terms of settings, equipment, damage/injuries, probable causes and contributing factors. For example, when the user clicks “Settings” in the left navigation column, a page appears showing a list of all the settings included in the database, the number of incidents that occurred in each particular setting and a bar graph showing the number of incident records in each category (see Figure 2). Mousing over the bar graph provides a larger image. Similar bar graphs are available for the other major categories shown in the left navigation.

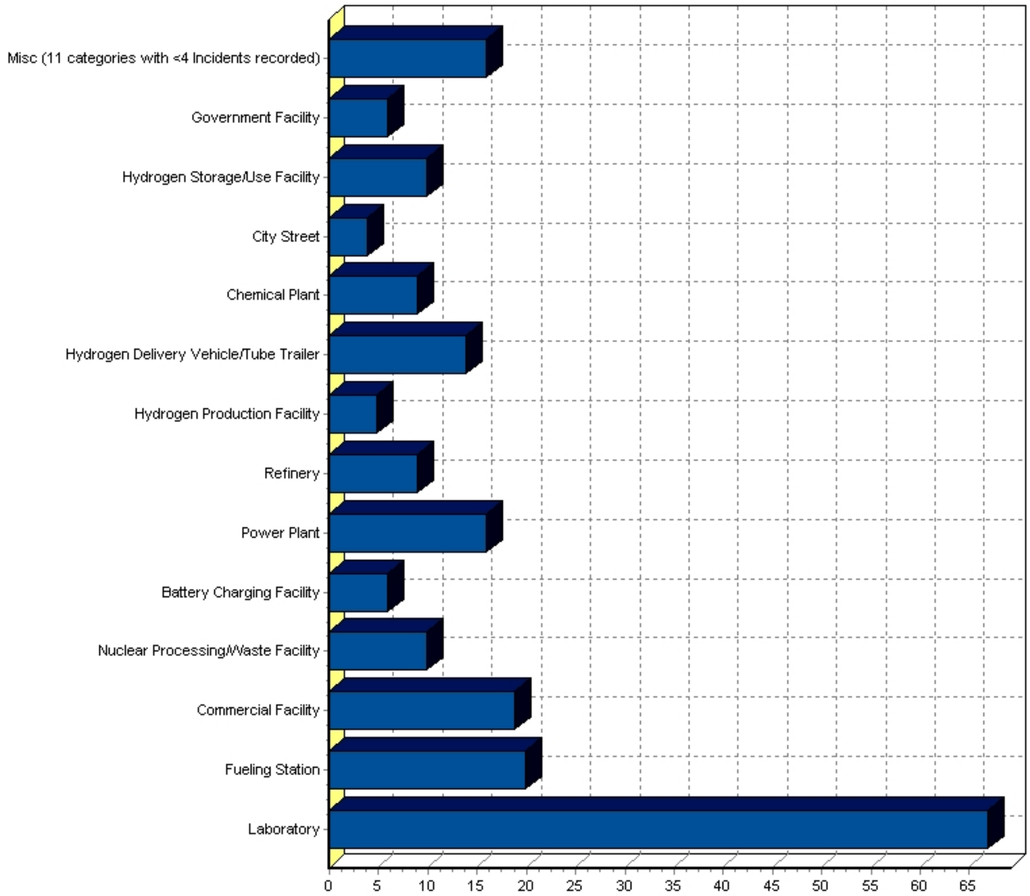


Figure 2.  Bar Graph Showing Settings of All Incidents in the Database

## 3.0 THE LESSONS LEARNED CORNER

The LLC was created to focus attention on key themes from the "H2incidents.org" database and illustrate the lessons learned from relevant safety events.  From the welcome page, the user can access each new LLC when it is posted (see Figure 3) or go to the archives where every LLC is housed.  To date, there have been six LLCs posted on the website:

- Learning from Burst Disk Failures
- Adequate Ventilation of Battery Charging Facilities
- Hydrogen Use in Anaerobic Chambers
- The Importance of Purging Hydrogen Piping and Equipment
- Working with Reactive Metal-Hydride Materials in the Laboratory
- Management of Change.

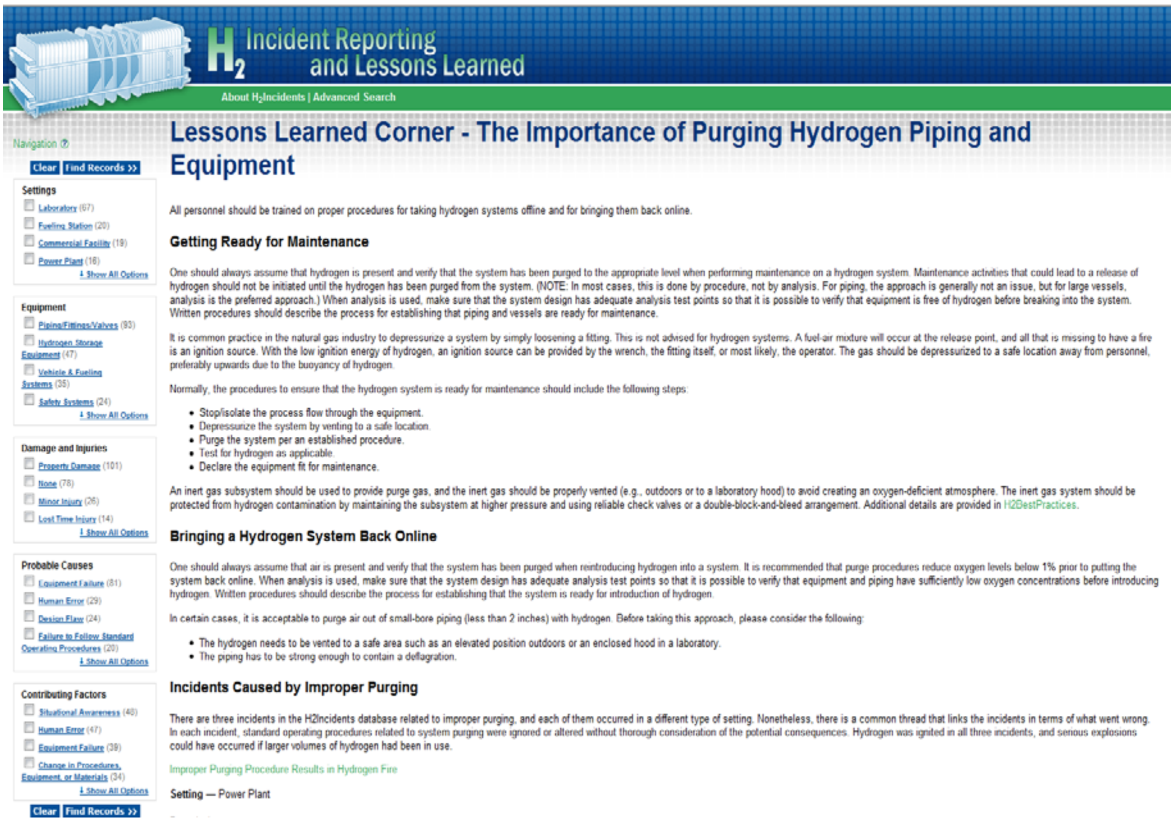


Figure 3. Lessons Learned Corner

### 3.1 The Importance of Purging Hydrogen Piping and Equipment

As an example, let's take a look at one theme: The Importance of Purging Hydrogen Piping and Equipment (http://www.h2incidents.org/ll_corner/lessonlearned_purging.asp). The key message is that all personnel should be trained on proper procedures for taking hydrogen systems offline and for bringing them back online. There are three main sections of this LLC: 1) Getting Ready for Maintenance, 2) Bringing a Hydrogen System Back Online, and 3) Incidents Caused by Improper Purging. The first section emphasizes the best practice of always assuming that hydrogen is present and verifying that the system has been purged to the appropriate level prior to performing maintenance on a hydrogen system. The typical procedures for ensuring that a hydrogen system is ready for maintenance include the following steps:

1. Stop/isolate the process flow through the equipment.
2. Depressurize the system by venting to a safe location.
3. Purge the system per an established procedure.
4. Test for hydrogen as applicable.
5. Declare the equipment fit for maintenance.

The second section discusses the best practice of always assuming that air is present and verifying that the system has been purged when reintroducing hydrogen into a system.

The following three incident records are cited to illustrate the consequences of improper purging of hydrogen piping and equipment.

- “Improper Purging Procedure Results in Hydrogen Fire” – This incident occurred in a power plant setting. During a maintenance shutdown, workers incorrectly assumed that a pipe in the cooling loop contained either carbon dioxide or air. When the welder struck an arc, a hydrogen flame developed in the pipe opening and flashed back into the generator, which caused a low-level explosion within the generator shroud.

- “Ignition of Leaking Hydrogen from Pressure Transmitter Tubing” – This incident occurred in a hydrogen production facility. While an instrument engineer was tapping a pressure transmitter containing 1900-psi hydrogen, the fitting was loosened too much and the tube accidentally got pulled out. Since the volume of hydrogen in the tapping line was small, the impact was minimal. Still, the system should have been purged prior to working on the tubing and joints.

- “Small-Scale Chemical Reaction Flash” – This incident occurred in a laboratory setting. An experiment produced a small quantity of hydride material in an enclosed reaction chamber. A small ignition flash event occurred inside the chamber, making it clear that both oxygen and an ignition source were present, even though an inert gas environment was used. Evidently a lower-flowrate argon purge was used rather than the normal nitrogen purge, which may have resulted in room air inadvertently being drawn into the chamber.

Although these safety events occurred in very different settings – a power plant, a hydrogen production facility and a laboratory – they are linked by a common thread. In all three events, standard operating procedures related to system purging were ignored or altered without thorough consideration of the potential consequences. Hydrogen was ignited in all three events, and serious explosions could have occurred if larger volumes of hydrogen had been in use.

### 3.2 Management of Change

Management of change (MOC) may be defined as the method or process that is used to review proposed changes to materials, technology, equipment, procedures, personnel and facility operation for their effect on safety vulnerabilities. Its importance in the process industries as it relates to major incidents is discussed by the U.S. Chemical Safety and Hazard Investigation Board. [4] In the example discussed in Section 3.1, taking a system offline and bringing it back online is a change worthy of detailed hazard analysis to assess potential risks.

Through a search of the database, one finds at least 25 safety event records that discuss some aspect of change per the definition noted above. These aspects of change may relate to causes, contributing factors and/or lessons learned from the incident and subsequent investigation. Also, the experience of the Hydrogen Safety Panel in conducting safety reviews of laboratory-scale work suggests that the principles of managing change should be applied more systematically to elevate the importance of safety in the research environment. [5] For these reasons, MOC was selected as a topic for the LLC for broader knowledge-sharing.

The MOC theme (http://www.h2incidents.org/ll_corner/lessonlearned_moc.asp) is presented with one specific safety event example for each aspect of change: process, equipment, procedures, materials and personnel. The text emphasizes that “management of change is usually interpreted as relating to permanent changes, but temporary changes (e.g., abnormal situations, deviations from standard operating conditions, untrained personnel filling in during an expected absence) have been contributing factors in many catastrophic events over the years and should be managed as if they were permanent changes.” See the companion safety knowledge tool, Hydrogen Safety Best Practices (http://h2bestpractices.org/safety_culture/procedures/moc.asp), for additional discussion and references on managing change.

We plan to continue to publish quarterly installments of the LLC on the H2incidents.org website based on website users' positive feedback on the five installments we have published to date. We maintain a list of interested parties to be notified each time a new installment is published, and this list keeps growing as people hear about the feature.

## 4.0 NEXT STEPS AND FUTURE PLANS

The database currently contains 195 safety event records, with approximately 25 more in progress. We continue to monitor media alerts about new hydrogen and fuel cell safety events and encourage incident owners to submit records of their experiences and lessons learned. Occasionally, users will submit incident records via the online submission form. Developing and posting a safety event record may take a long time from start to finish. Accident investigations can be very time-consuming and often the incident owner needs management approval to share the entire safety event record. Nonetheless, we continue to work with all concerned to help develop the safety event record, emphasizing the value of sharing what has been learned.

We continue to link safety event records to best practices on our companion website, Hydrogen Safety Best Practices, which might have prevented the incidents from occurring in the first place. "H2bestpractices.org" also contains numerous links to the "H2incidents.org" database that illustrate what can go wrong if best practices are not followed.

We continue to send e-mail notifications to interested parties whenever a new safety event record is added to the database or a new LLC is posted on the website. Anyone who would like their e-mail address added to our distribution list for these notices should contact one of the authors of this paper.

## 5.0 CONCLUDING THOUGHTS

Online safety knowledge tools such as the one discussed in this paper provide a mechanism for sharing, discussing and learning from the experiences of others. Developers of such tools can enhance the value of the tools by improving design features, providing data analysis and adding new content.

The sharing of safety event information and data in a publicly accessed database requires that issues surrounding proprietary, confidential and business-sensitive information be respected, addressed at the outset and dealt with in a vigilant and consistent manner. These issues are solvable. Such information from hydrogen fuel cell demonstration and deployment projects can serve as a rich resource if systematically collected, analyzed and used for several purposes: (1) to identify lessons learned from the events; (2) to develop quantitative risk assessment methodologies and models; and (3) to identify gaps in applicable codes and standards that can be addressed by R&D or further analysis.

Some initiatives, including international efforts, are in the early stages of development to expand the use of safety event information and data. For example, the International Association for Hydrogen Safety (IA HySafe) is working with the European Commission's Joint Research Center to utilize the Hydrogen Incident and Accident Database (HIAD), https://odin.jrc.ec.europa.eu/engineering-databases.html, and expand collaborations that promise to broaden the use of safety event information and data for the purposes previously noted.

## 6.0 ACKNOWLEDGEMENTS

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