

Hydrogen Safety Knowledge Tools

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Overview

Timeline

- ▶ Project start: 2003
- ▶ Continuing

Budget

- ▶ FY10 Funding: \$200K
for both **Best Practices**
and **Incident Reporting**
- ▶ FY11 Funding: \$250K
for both **Best Practices**
and **Incident Reporting**

Barriers

- ▶ Limited Historical Database
- ▶ Proprietary Data

Partners

- ▶ **Best Practices** – Hydrogen Safety Panel, NASA, Nuvera Fuel Cells, and NREL
- ▶ **Incident Reporting** – Hydrogen Safety Panel and NASA



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Relevance --- Objectives

H2 Safety Best Practices (H2BestPractices.org)

Capture vast and growing knowledge base of hydrogen experience and make it publicly available. The Hydrogen and Fuel Cells Program Multi-Year Program Plan says, “This living document provides guidance for ensuring safety in DOE hydrogen projects, while serving as a model for all hydrogen projects and applications.”

H2 Incident Reporting and Lessons Learned (H2Incidents.org)

Collect information and share lessons learned from hydrogen incidents and near-misses, with a goal of preventing similar incidents from occurring in the future.



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Relevance --- Goals

▶ H2 Safety Best Practices

■ Update Hydrogen Safety Best Practices Online Manual (9/30/11)

- Update existing content based on recommendations from the Hydrogen Safety Panel
- Add new content after Hydrogen Safety Panel review/approval

▶ H2 Incident Reporting and Lessons Learned

■ Achieve Target of 220 Records in Database (9/30/11)

- Currently 194 records
- 26 more in progress

■ Analyze Lessons Learned from Incidents (9/30/11)

- Publish thematic “Lessons Learned Corner” quarterly



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Approach

H2 Safety Best Practices

Best practice = a technique or methodology that utilizes available knowledge and technology to achieve success

- ▶ Best practices are compiled from learnings and observations from Hydrogen Safety Panel site visits, safety plan reviews and other work, and available reference materials tailored specifically to working with hydrogen.
- ▶ Proposed new content is discussed at Panel meetings.
- ▶ PNNL staff create draft strawman materials.
- ▶ Panel members and PNNL subject matter experts review the drafts and provide comments.
- ▶ PNNL staff revise drafts based on reviewers' comments and then publish materials on website.
- ▶ Respond quickly to user questions submitted from the website.



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H₂ Safety Best Practices

Welcome!

[H₂BestPractices Home](#)

What is a best practice?

A best practice is a technique or methodology that has reliably led to a desired result. Using best practices is a commitment to utilizing available knowledge and technology to achieve success.

[Introduction to Hydrogen](#)

What is H₂BestPractices.org?

A wealth of knowledge and experience related to safe use and handling of hydrogen exists as a result of an extensive history in a wide variety of industrial and aerospace settings. Hydrogen is gaining increasing attention worldwide as a possible energy storage medium, for later conversion to electricity through fuel cells or for use as a combustion fuel. This focus has introduced many new participants to research, development, demonstration, and deployment of hydrogen technologies (e.g., fuel cell vehicles and stationary fuel cells).

The purpose of the Hydrogen Safety Best Practices online manual is to share the benefits of extensive experience by providing suggestions and recommendations pertaining to the safe handling and use of hydrogen. Best Practices have been compiled from a variety of resources, many of which are in the public domain and can be downloaded directly from the References section. Many others can be obtained via reference links found at various places within the manual.

[Best Practices](#) are organized under a number of hierarchical categories in this online manual, beginning with those displayed down the left-hand column. Because of the interdependence of the topical areas, however, individual pages are often accessible via multiple internal links. A web-based electronic document format lends itself well to this type of overlapping content.

Website features

Please notice the [mouse-over feature](#) on this website. When a word in the text appears in [blue font](#), you can see its definition by placing your cursor over the word. All the definitions are compiled into a [Glossary](#) that can be accessed from the References section of every page. There is also an [Acronyms](#) list and a [Bibliography](#) that can be accessed from every page. When you click on the link to the Bibliography, it will take you to the alphabetized list of references for the particular section from which you accessed it. Please contact us if you notice any definitions, acronyms, or references that should be in these lists but aren't.

A word about safety

Following the best practices contained in this online manual represents a commitment to the safe use and handling of hydrogen, but it should be recognized that no information resource can provide 100% assurance of safety. Personnel with applicable expertise should always be consulted in designing and implementing any system carrying a potential safety risk. Additionally, since following these best practices does not guarantee compliance with local codes, standards, and regulations, users should check with their local [Authority Having Jurisdiction](#) to ensure that those requirements are adequately addressed.

This online manual is linked to a companion website, [H₂Incidents.org](#), to provide unambiguous illustration of the importance of following safe practices and procedures when working with and around hydrogen. Like virtually all energy forms, hydrogen can be used safely when proper procedures and engineering techniques are followed, but its use still involves a degree of risk that must be respected. The importance of avoiding complacency and/or haste in the safe conduct and performance of projects involving hydrogen cannot be overstated.

Search H₂BestPractices

Enter a search term below.

References

[Glossary](#)

[Acronyms](#)

[Bibliography](#)

[Codes & Standards](#)

[NFPA 2, Hydrogen Technologies Code, 2011 Edition](#)

Related Sites

- [H₂Incidents Database](#)
- [NHA Hydrogen and Fuel Cell Safety](#)
- [DOE Hydrogen Program](#)
 - [Hydrogen Safety Bibliographic Database](#)

Contact Us

✉ h2bestpractices@pnl.gov

[Facility Design Considerations](#)

[Storage & Piping](#)

[Operating Procedures](#)

[Equipment Maintenance](#)

[Laboratory Safety](#)

[Indoor Refueling of H₂ Forklifts](#)

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A collaboration of the
[Pacific Northwest National Laboratory](#)
and [Los Alamos National Laboratory](#)
with funding from the [U.S. Department of Energy](#).

Technical Accomplishments

H2 Safety Best Practices

- ▶ Added new section on Hydrogen Properties, focused on combustion and liquid hydrogen expansion
- ▶ Added new section for students, technicians, and young engineers not familiar with hydrogen called “So You Want To Know Something about Hydrogen”
- ▶ Added new section on Indoor Refueling of Hydrogen-Powered Forklifts with team of industry experts
- ▶ Added new section on Chemical Hydrogen Storage
- ▶ Added more photos to enhance website appearance



Hydrogen Overview

- Properties and Behavior
- Applications
- Systems and Controls

Hydrogen Hazards

- Leaks
- Flames
- Explosions



Proposed Future Work

H2 Safety Best Practices

- ▶ Add new content
 - Brainstorm with Hydrogen Safety Panel to identify gaps in content that should be addressed
- ▶ Enhance website utility
 - Continue to link content to safety event records in H2Incidents.org
 - Add more photos, graphics, and videos
- ▶ Encourage use of website and respond quickly to user questions with assistance from Hydrogen Safety Panel, NASA, and PNNL staff



Alarm System in a PNNL Laboratory



Fume Hood in a PNNL Laboratory

Collaborations

H2 Safety Best Practices

Since 2010 AMR

- ▶ Hydrogen Safety Panel
 - Addison Bain
 - Dave Farese
 - Don Frikken
 - Richard Kallman
 - Andy Sherman
- ▶ NASA White Sands Test Facility
 - Steve Woods
- ▶ Nuvera Fuel Cells
 - Aaron Harris
- ▶ NREL
 - Carl Rivkin



Thanks to my PNNL colleagues:

- Nick Barilo
- Andy Minister
- Kathleen Quick
- Steve Weiner



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Approach

H2 Incident Reporting and Lessons Learned

Purpose: Facilitate sharing of lessons learned from hydrogen incidents to help avoid similar future incidents, without attribution to organization, location, or date of occurrence

- ▶ Success requires that people use the database and not fear negative consequences from reporting incidents. We encourage all DOE projects to submit incidents and near-misses with lessons learned.
- ▶ Pursue addition of new records by actively seeking news reports for hydrogen incidents and searching existing databases for hydrogen events.
- ▶ Contact private-sector companies who experience hydrogen incidents and near-misses to solicit permission to publish records.
- ▶ Establish and maintain a mechanism for online submissions of records.
- ▶ Add links to H2BestPractices.org to emphasize safe practices for working with hydrogen.
- ▶ Provide expert review of all incidents and lessons learned by Hydrogen Safety Panel and PNNL subject matter experts.



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Approach

H2 Incident Reporting and Lessons Learned

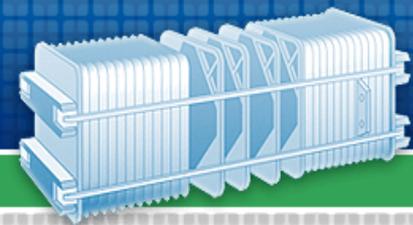
Each safety event record contains:

- ▶ Description
- ▶ Severity (Was hydrogen released? Was there ignition?)
- ▶ Setting
- ▶ Equipment
- ▶ Characteristics (High pressure? Low temperature?)
- ▶ Damage and Injuries
- ▶ Probable Cause
- ▶ Contributing Factors
- ▶ Lessons Learned and Mitigation Steps
- ▶ **Some records include photos**



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H₂ Incident Reporting and Lessons Learned

About H₂Incidents | Advanced Search

Welcome!

Navigation ?

[Clear](#) [Find Records >>](#)

Settings

- [Laboratory](#) (67)
- [Fueling Station](#) (20)
- [Commercial Facility](#) (17)
- [Power Plant](#) (16)

[↓ Show All Options](#)

Equipment

- [Piping/Fittings/Valves](#) (93)
- [Hydrogen Storage Equipment](#) (47)
- [Vehicle & Fueling Systems](#) (35)

- [Safety Systems](#) (24)

[↓ Show All Options](#)

Damage and Injuries

- [Property Damage](#) (101)
- [None](#) (79)
- [Minor Injury](#) (26)
- [Lost Time Injury](#) (14)

[↓ Show All Options](#)

Probable Causes

- [Equipment Failure](#) (81)
- [Human Error](#) (30)
- [Design Flaw](#) (24)
- [Failure to Follow Standard Operating Procedures](#) (20)

[↓ Show All Options](#)

What is H₂Incidents?

H₂Incidents is a database-driven website intended to facilitate the sharing of lessons learned and other relevant information gained from actual experiences using and working with hydrogen. The database also serves as a voluntary reporting tool for capturing records of events involving either hydrogen or hydrogen-related technologies.

The focus of the database is on characterization of hydrogen-related incidents and near-misses, and ensuing lessons learned from those events. All identifying information, including names of companies or organizations, locations, and the like, is removed to ensure confidentiality and to encourage the unconstrained future reporting of events as they occur.

[More About H₂Incidents...](#)

How does H₂Incidents work?

You can access incident reports on H₂Incidents in a number of different ways. Here on the home page, you can go directly to the latest posted incidents using the navigation in the box to the right labeled "Latest Reports." The bottom of this box also contains a total for the number of incident reports in the system. By clicking the "show all" text next to this number, you can view a [complete, alphabetical list of incidents](#).

To look for incidents related to specific details, you can use the left navigation. The five main headings—[Settings](#), [Equipment](#), [Damage and Injuries](#), [Probable Causes](#), [Contributing Factors](#)—will help you drill through the collection of incidents to find those that interest you. To see a graphical representation of the number of incidents associated with each of these main headings, simply click on the heading and then mouse over the chart to view a larger image. At any time, you can also use the [Advanced Search](#) form, found at the top of the page, for some more options to search the database.

If you have an incident you would like to include in the H₂Incidents database, please visit the [Submit an Incident](#) page. This page will ask for a wide range of information on your incident. Please enter as much of the information as possible. In order to protect your and your employer's identities, information that may distinguish an incident (your contact information, your company's name, the location of the incident, etc.) will not be displayed in the incident reports on H₂Incidents.

[Submit an Incident](#)

Latest Reports

[Release of Stored Hydrogen as Water Temperature Increases](#)

[Hydrogen Explosion in Battery Compartment of Dinner Cruise Boat](#)

TOTAL EVENTS REPORTED: 195 ([SHOW ALL](#))

New! Lessons Learned Corner

[Adequate Ventilation of Battery Charging Facilities](#)

[Hydrogen Use in Anaerobic Chambers](#)

[LESSONS LEARNED ARCHIVES](#)

Technical Accomplishments

H2 Incident Reporting and Lessons Learned

- ▶ Added 55 incident records since 2010 AMR
- ▶ Currently 194 records in database, and 26 more in progress
- ▶ Collaborated with national labs, universities, and private-sector firms in the U.S. and other countries to prepare/submit records of incidents and near-misses
- ▶ Significant time spent interacting with incident “owners” to extract maximum value in lessons learned from their perspectives
- ▶ Obtained hydrogen incident alerts from DOE and Google Alerts
- ▶ Created quarterly issues of “Lessons Learned Corner” to analyze hydrogen safety themes illustrated by database content



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Technical Accomplishments

H2 Incident Reporting and Lessons Learned

► Incorporated bar graphs to characterize database contents in terms of:

■ Settings

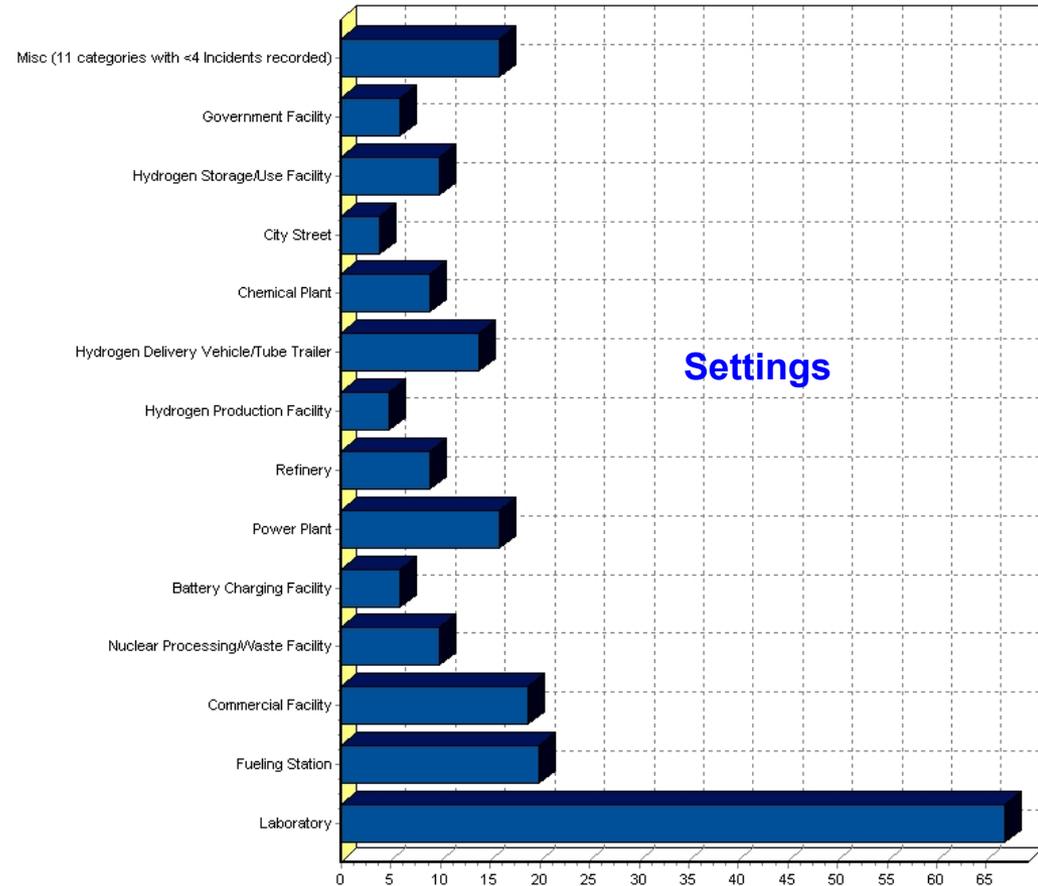
- Laboratory (67)
- H₂ Fueling Station (20)
- Commercial Facility (19)
- Power Plant (16)
- H₂ Delivery Vehicle (14)
- Others...

■ Equipment

■ Damage/Injuries

■ Probable Causes

■ Contributing Factors



Technical Accomplishments

H2 Incident Reporting and Lessons Learned

► Lessons Learned Corner (LLC)

- Publish quarterly
- Summarize lessons learned for specific hydrogen safety themes
- Illustrate with safety event records
- Themes covered to date:
 - Management of Change
 - Working with Reactive Metal Hydrides
 - The Importance of Purging Hydrogen Piping and Equipment
 - Hydrogen Use in Anaerobic Chambers
 - Adequate Ventilation of Battery Charging Facilities

Lessons Learned Corner - The Importance of Purging Hydrogen Piping and Equipment

All personnel should be trained on proper procedures for taking hydrogen systems offline and for bringing them back online.

Getting Ready for Maintenance

One should always assume that hydrogen is present and verify that the system has been purged to the appropriate level when performing maintenance on a hydrogen system. Maintenance activities that could lead to a release of hydrogen should not be initiated until the hydrogen has been purged from the system. (NOTE: In most cases, this is done by procedure, not by analysis. For purging, the approach is generally not an issue, but for large vessels, analysis is the preferred approach.) When analysis is used, make sure that the system design has adequate analysis test points so that it is possible to verify that equipment is free of hydrogen before breaking into the system. Written procedures should describe the process for establishing that purging and assays are ready for maintenance.

It is common practice in the natural gas industry to depressure a system by simply loosening a fitting. This is not advised for hydrogen systems. A flammable mixture will occur at the release point, and if that is mixing to have a fire is an ignition source. With the low ignition energy of hydrogen, an ignition source can be provided by the wrench, the fitting itself, or most likely, the operator. The gas should be depressured to a safe location away from personnel, preferably outdoors due to the buoyancy of hydrogen.

Normally, the procedures to ensure that the hydrogen system is ready for maintenance should include the following steps:

- Stop isolates the process flow through the equipment.
- Depressure the system by venting to a safe location.
- Purge the system per an established procedure.
- Test for hydrogen as applicable.
- Declare the equipment fit for maintenance.

An inert gas subsystem should be used to provide purge gas, and the inert gas should be properly vented (e.g., outdoors or to a laboratory hood) to avoid creating an oxygen-deficient atmosphere. The inert gas system should be protected from hydrogen contamination by maintaining the subsystem at higher pressure and using reliable check valves or a double block and bleed arrangement. Additional details are provided in [H2BestPractices](#).

Bringing a Hydrogen System Back Online

One should always assume that air is present and verify that the system has been purged when reintroducing hydrogen into a system. It is recommended that purge procedures reduce oxygen levels below 1% prior to putting the system back online. When analysis is used, make sure that the system design has adequate analysis test points so that it is possible to verify that equipment and piping have sufficiently low oxygen concentrations before introducing hydrogen. Written procedures should describe the process for establishing that the system is ready for introduction of hydrogen.

In certain cases, it is acceptable to purge air out of small-bore piping less than 2 inches with hydrogen. Before taking this approach, please consider the following:

- The hydrogen needs to be vented to a safe area such as an elevated position outdoors or an enclosed hood in a laboratory.
- The purging gas to be strong enough to contain a deflagration.

Incidents Caused by Improper Purging

There are three incidents in the H2Incidents database related to improper purging, and each of them occurred in a different type of setting. Nonetheless, there is a common thread that links the incidents in terms of what went wrong. In each incident, standard operating procedures related to system purging were ignored or altered without thorough consideration of the potential consequences. Hydrogen was ignited in all three incidents, and serious explosions could have occurred if larger volumes of hydrogen had been in use.

[Improper Purging: Incident Results at Hydrogen First](#)

Setting – Power Plant



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Technical Accomplishments

H2 Incident Reporting and Lessons Learned

Sample LLC --- The Importance of Purging H₂ Piping and Equipment

All personnel should be trained on proper procedures for taking hydrogen systems offline and for bringing them back online.

- ▶ Getting Ready for Maintenance
 - Always assume that hydrogen is present.
 - Use a properly vented inert gas subsystem for purging.
- ▶ Bringing a Hydrogen System Back Online
 - Always assume that air is present.
 - Reduce oxygen levels below 1% before putting system back online.
- ▶ Incidents Caused by Improper Purging
 - Improper purging procedure in a power plant results in hydrogen fire
 - Ignition of leaking hydrogen from tubing in a hydrogen production facility
 - Small-scale chemical reaction flash in a laboratory



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Proposed Future Work

H2 Incident Reporting and Lessons Learned

- ▶ Continue to add incident records and lessons learned to the database
- ▶ Continue to publish quarterly thematic installments of Lessons Learned Corner
- ▶ Notify interested parties when new incident records and Lessons Learned Corner installments are posted
- ▶ Identify additional sources of hydrogen safety event information (e.g., other databases)
- ▶ Add links from incident records to best practices that should have been used to avoid incidents
- ▶ Encourage national labs, universities, and private-sector organizations to voluntarily submit records of incidents and near-misses to the website to share their lessons learned



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Collaborations

H2 Incident Reporting and Lessons Learned

Since 2010 AMR

- ▶ Key collaborators are organizational “owners” of the incidents and near-misses added to the database
- ▶ Hydrogen Safety Panel

- Addison Bain
- Dave Farese
- Don Frikken
- Richard Kallman
- Andy Sherman
- Ed Skolnik
- Bob Zalosh



Thanks to my PNNL colleagues:

- Nick Barilo
- Eric Berglin
- Andy Minister
- Roger Pollari
- Kathleen Quick
- Steve Weiner

- ▶ NASA White Sands Test Facility

- Steve Woods



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Summary

▶ H2 Safety Best Practices

- New content has been added
 - Hydrogen Properties
 - So You Want to Know Something about Hydrogen
 - Indoor Refueling of Hydrogen-Powered Forklifts
 - Chemical Hydrogen Storage
- **Best practices** linked to **hydrogen incidents** that illustrate the hazards of not working safely with hydrogen.

▶ H2 Incident Reporting and Lessons Learned

- Database currently contains 194 records
- Lessons Learned Corner (LLC) published quarterly
- New graphical representation of database contents
- Notices sent out when new incident records and LLCs are posted
- **Lessons learned** linked to **best practices** that would have helped avoid the incidents



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