



Pacific Northwest
NATIONAL LABORATORY

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PNNL-SA-86587

Hydrogen Safety Knowledge Tools

LINDA FASSBENDER

Hydrogen Program Annual Merit Review and Peer Evaluation Meeting

Arlington, VA

May 15, 2012

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Project ID # SCS006

Timeline

- ▶ Project Start: 2003
- ▶ Continuing

Budget

- ▶ Funding received in FY11: \$175K
- ▶ Planned funding for FY12: \$125K

Partners

- ▶ Hydrogen Safety Panel
- ▶ IA HySafe's Hydrogen Incident and Accident Database (HIAD)

Barriers

- ▶ A. Safety Data and Information: Limited Access and Availability
- ▶ C. Safety is Not Always Treated as a Continuous Process
- ▶ D. Lack of Hydrogen Knowledge by AHJs

Technical Plan – Safety, Codes and Standards, Section 3.7.5,
Multi-Year Research, Development and Demonstration Plan, 2011.

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 safety events from occurring in the future.
- ▶ Increase number of records in database by encouraging “incident owners” to share lessons learned with the hydrogen community.
- ▶ Analyze and summarize lessons learned from incidents and near-misses.

H₂ Safety Best Practices (“H₂bestpractices.org”)

- ▶ Capture vast and growing knowledge base of hydrogen experience and make it publicly available.
- ▶ Update existing content and add relevant new content based on Hydrogen Safety Panel guidance and other means.

Approach – “H₂incidents.org”

- ▶ Establish and maintain a mechanism for online submission of records.
- ▶ Encourage all DOE projects to submit records of incidents and near-misses with clear descriptions of lessons learned.
- ▶ Pursue addition of new records by actively reviewing media reports of hydrogen incidents.
- ▶ Contact private-sector companies who experience hydrogen incidents and near-misses to solicit permission to publish records.
- ▶ Publish quarterly Lessons Learned Corner to analyze, summarize, and expand upon lessons learned for specific hydrogen safety vulnerabilities.
- ▶ Add links to “H₂bestpractices.org” to correlate between each incident and the relevant safe practices for working with hydrogen.
- ▶ Provide expert review of all incident records and lessons learned by Hydrogen Safety Panel and other subject matter experts.

Approach – “H₂bestpractices.org”

- ▶ 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 and with other subject matter experts.
- ▶ PNNL staff compile draft materials.
- ▶ Panel members and other subject matter experts review drafts and provide comments.
- ▶ Draft material is revised based on the comments before posting online.
- ▶ PNNL staff, with assistance from Panel members, respond to user questions and comments submitted through the website.



“H₂incidents.org” Emphasizes Lessons Learned from Incidents and Near-Misses

H₂ Incident Reporting and Lessons Learned
About H₂Incidents | Advanced Search

Welcome!

Navigation ?

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

Settings

- Laboratory (70)
- Fueling Station (20)
- Commercial Facility (17)
- Power Plant (15)
- [Show All Options](#)

Equipment

- Piping/Fittings/Valves (96)
- Hydrogen Storage Equipment (49)
- Vehicle & Fueling Systems (40)
- Safety Systems (25)
- [Show All Options](#)

Damage and Injuries

- Property Damage (105)
- Noise (81)
- Minor Injury (27)
- Lost Time Injury (16)
- [Show All Options](#)

Probable Causes

- Equipment Failure (82)

What is H₂Incidents?

This database is supported by the U.S. Department of Energy. The safety event records have been contributed by a variety of global sources, including industrial, government and academic facilities.

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 form 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

- Hydrogen Explosion and Iron Dust Flash Fires in Powdered Metals Plant
- H₂/N₂ Mixture Incorrectly Connected to Infrared Spectrometer

TOTAL EVENTS REPORTED: 201 ([SHOW ALL](#))

New! Lessons Learned Corner

- Hydrogen Compatibility of Materials
- Learning from Burst Disk Failures

[LESSONS LEARNED ARCHIVES](#)

Lessons Learned Corner Archives

- Hydrogen Compatibility of Materials
- 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

H₂ Safety Snapshot Added to “H₂bestpractices.org” References

Welcome!

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.

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.

Search H₂BestPractices

Enter a search term below.

References

- Glossary
- Acronyms
- Bibliography
- Codes & Standards
- NFPA 2, Hydrogen Technologies Code, 2011 Edition
- New! Bulletin Archives

H₂ SAFETY Snapshot

Related Sites

- H₂Incidents Database
- FCHEA Hydrogen and Fuel Cell Safety
- DOE Hydrogen Program
 - Hydrogen Safety Bibliographic Database

Contact Us

✉ h2bestpractices@pnl.gov

- Identifying Safety Vulnerabilities
- Handling Compressed Hydrogen Gas Cylinders
- Hydrogen Safety Knowledge Tools

H₂ Safety Snapshot



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► Cylinder Safety

- Good practices for safe handling of gas cylinders
- Specific “Dos” and “Don’ts” for
 - Training personnel who handle cylinders
 - Transporting, receiving, and staging cylinders
 - Connecting a cylinder to piping or tubing
 - Storing cylinders
- References for handling compressed gas cylinders

► Identifying Safety Vulnerabilities

- How to perform a hazard analysis
- Tips for a successful hazard analysis
- Hazard analysis methodologies
- Hydrogen hazards to consider
- Helpful resources for further information

H₂ SAFETY Snapshot
Vol. 1, Issue 1, Fall 2010

HANDLING COMPRESSED HYDROGEN GAS CYLINDERS

Proper training and procedures are key elements of a safe work environment. Compressed gas cylinders, as with other equipment, pose risks if they are not handled properly. This issue outlines good practices for the safe handling of gas cylinders. The information will help you create a safer environment by minimizing the likelihood of an accident involving a gas cylinder.

For more information on compressed hydrogen gas cylinders, visit the **Process Safety Institute's "Hydrogen Safety Training for Researchers"**, a Web-based class developed by Lawrence Livermore National Laboratory. This module will assist you in recognizing general process safety issues and introduce considerations specific to system components exposed to hydrogen.
www.llnl.gov

Personnel Handling Gas Cylinders

DO ensure that cylinders are handled only by trained personnel knowledgeable in the handling and use of compressed hydrogen gas. The training should cover compressed gas safety, storage and connections, and how to safely attach a regulator to the top of a cylinder. For compressed hydrogen, the specific names and labels associated with hydrogen should also be discussed.

DO NOT allow untrained personnel to handle gas cylinders.

Transporting, Receiving and Staging Cylinders

DO ensure that gases are delivered with a valve protection cap on the top of each cylinder. This protective cap should remain on until the cylinder is delivered to its point of use, where a valve regulator is attached. See related issues found at: www.llnl.gov/energy/essentials/article/2010/09/01

DO NOT accept any cylinder that is rusted or has conflicting markings or labels regarding its contents. Never rely on the color of the cylinder to identify the contents. If there is any conflict or doubt concerning the contents, do not use the cylinder. Return it to the vendor.

DO use a cylinder cart with a restraining device to secure large cylinders and specially designed cylinder holders to carry small cylinders.

DO NOT transport a cylinder of compressed gas with a regulator attached to it.

DO secure cylinders from tipping over by using blocks or restraints designed for each service. Double cylinder containers (high and low) should be secured as if a normally secure one.

DO NOT pick up a cylinder by its cap.

References for Handling Compressed Gas Cylinders

H₂ Safety Best Practices
www.llnl.gov/energy/essentials/article/2010/09/01
Air Products Safetygases #10, Handling, Storage, and Use of Compressed Gas Cylinders
www.airproducts.com/resources/technicalpublications/10.pdf
Matheson Tri-Gas, Safe Handling of Compressed Gases in the Laboratory and Plant
www.matheson.com/~/media/Files/TechnicalPublications/Safety/2010/09/01/20100901.pdf
Matheson Tri-Gas, Guide to Regulators
www.matheson.com/~/media/Files/TechnicalPublications/Safety/2010/09/01/20100901.pdf

H₂ SAFETY Snapshot
Vol. 1, Issue 1, Fall 2010

IDENTIFYING SAFETY VULNERABILITIES

What is it?
Identify areas of higher vulnerability (HV) is an organizational or facility-level effort to identify and analyze the implications of hazards associated with process activities (i.e., a hazard analysis). Using a hazard analysis to identify areas of higher vulnerability (HV) can help you understand the potential consequences of a hazard analysis.

Why Do I Need It?
Hazard analysis can show a spotlight on facility design problems and weak hydrogen operations that could cause process damage, injury, or loss of life. Check for problems and leverage to light you can identify risk management strategies to address them. These concepts, hazard analysis helps a project team identify potential safety issues. Hazard analysis helps the probability of an occurrence, and estimates the associated consequences.

Who Should Be Involved?
The hazard analysis team should have sufficient expertise in all aspects of the work being analyzed. It should also include representatives from design, project, process, operations, and safety. The hazard analysis team should be trained in the hazard analysis methodology used.

How Do I Perform a Hazard Analysis?
Perform the hazard analysis at the project initiation stage using one of the available safety methods described on page 2.

A hazard analysis typically consists of the five major steps shown in the graphic to the right: risk ranking, Planning, Linkage for Redesign and Fuel Cell Progress in the Use of Hydrogen Events on page 2 for more information.

Once the hazards are identified, they can be identified by comparing the probability of occurrence (frequency) and potential impact (consequence) and probability of occurrence (frequency).

For example, a very low probability risk might be a low probability risk, but a high potential impact (consequence) of the process, and a low probability risk might be a high potential risk. For example, a high probability risk might be a high potential risk, but a low potential impact (consequence) of the process, and a high probability risk might be a high potential risk.

After the risks are categorized, hazard controls should be developed to eliminate or reduce the probability, consequence, or both. The higher risk should receive the most attention.

Tips for a Successful Hazard Analysis

- When using risk ranking matrices, don't rely on them.
- Being overly conservative does not guarantee design and operation, required change of operating parameters, starting and shutdown procedures, and required maintenance operations.
- Don't get bogged down by too difficult-to-control or reduce risks. Prioritize completion of the work to reduce risks with additional process operations and maintenance (and possibly further participation) because it is viable.
- Being phony doesn't help either stakeholders or the process.
- Involve a group of experienced and competent facility design and operations staff.

Light work with planning, and planning work with hazard analysis

Linking “H₂incidents.org” and “H₂bestpractices.org” Enhances the Value of Both



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H₂ Incident Reporting and Lessons Learned
About H₂Incidents | Advanced Search

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Navigation
Clear Find Records >>

Settings
Laboratory (67)
Fueled Station (20)
Commercial Facility (17)
Power Plant (16)
[Show All Options](#)

Equipment
Piping/Process/Valves (93)
Hydrogen Storage Equipment (47)
Ventilator & Fueling Systems (25)
Safety Systems (24)
[Show All Options](#)

Damage and Injuries
Property Damage (101)
Hose (79)
Minor Injury (26)
Lost Time Injury (14)
[Show All Options](#)

Probable Causes
Equipment Failure (81)
Human Error (30)
Design Error (24)
Failure to Follow Standard Operating Procedures (20)
[Show All Options](#)

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: 198 (SHOW ALL)

New! Lessons Learned Corner
Adequate Ventilation of Battery Charging Facilities
Hydrogen Use in Anaerobic Chambers
LESSONS LEARNED ARCHIVES

Safety event lessons learned content enhanced by links to best practices and/or LLC content.

Safety event links illustrate what can go wrong if best practices are not followed.

H₂ Safety Best Practices

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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.

Latest Updated March 11, 2011
A collaboration of the
Pacific Northwest National Laboratory
and Los Alamos National Laboratory
with funding from the U.S. Department of Energy

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

Site Map | Security | Privacy

Accomplishments – “H₂incidents.org”

Year	Total Visitors	Max Visitors in 1 Month
2006	3,357	751
2007	15,797	1,928
2008	25,539	4,568
2009	17,081	2,084
2010	17,502	1,954
2011	20,936	2,339

Visitors = unique visits as tracked by PNNL on a monthly basis. Regardless of how many times a particular individual may access a website during a particular month, they are counted as one unique visitor.

Lessons Learned Corner is the most popular website feature, especially:

- ▶ Burst disk failures
- ▶ Battery charging facility ventilation
- ▶ The importance of purging

Accomplishments – “H₂bestpractices.org”

Year	Total Visitors	Visitors to “Laboratory Safety”	Max Visitors in 1 Month
2008	703	191	87
2009	1,029	555	113
2010	1,373	804	166
2011	1,373	930	167

Visitors = unique visits as tracked by PNNL on a monthly basis. Regardless of how many times a particular individual may access a website during a particular month, they are counted as one unique visitor.

Accomplishments Since FY11 AMR

- ▶ 201 safety event records in database (6 added since FY11 AMR)
- ▶ 55 safety events currently under review in backlog
- ▶ 7 Lessons Learned Corners posted (2 added since FY11 AMR and 1 in progress)
- ▶ Collaborated on presentations and demonstrations of “H₂incidents.org” and HIAD at ICHS meeting in San Francisco in September 2011
- ▶ Participated in national dialogue on laboratory safety by providing information on “H₂incidents.org” and our efforts to capture lessons learned from hydrogen incidents and near-misses (see CSB citation noted on next slide)
- ▶ Approximately 30 new links added from safety event records to Lessons Learned Corners and/or “H₂bestpractices.org” since FY11 AMR

Positive Feedback

- ▶ U.S. Chemical Safety and Hazard Investigation Board
 - *“For an example of an online near-miss database, view the Department of Energy’s (DOE) Hydrogen Program website, which facilitates the sharing of lessons learned while working with hydrogen: <http://h2incidents.org>.”*
- ▶ FY2011 AMR reviewers
 - *“The project is effective and has improved each year.”*
 - *“...critical to deployment of new technologies, especially a technology like this one where accident consequences could be severe.”*
 - *“Additions to both websites have improved the information provided and the relevance of that information.”*
 - *“There is too limited funding to expand this work and increase its relevance.”*
 - *“The project is a good approach, although resource limited. It seems this project should have more funding since it has a great impact on safety and sustainability.”*

Collaborations

Organization	Role
Hydrogen Safety Panel	Provided input for updating/adding best practices. Reviewed incident records to ensure that lessons learned were fully captured.
IEA Hydrogen Implementing Agreement Task 31 (Hydrogen Safety)	Added safety event records to “H ₂ incidents.org” from Canada, Italy, U.K., Japan, Switzerland, France, European Commission, The Netherlands, Germany, and Norway
IEA Hydrogen Implementing Agreement Task 22 (Fundamental and Applied H ₂ Storage Materials Development)	Developed best practices for Metal Hydride Storage and Handling for “H ₂ bestpractices.org”
IA HySafe	Shared incident records between Hydrogen Incident and Accident Database (HIAD) and “H ₂ incidents.org”
LANL	Collaborated with PNNL to create the initial version of “H ₂ bestpractices.org”
SNL	Provided technical review of Lessons Learned Corner on Compatibility of Materials
NREL	Provided information on Codes and Standards for “H ₂ bestpractices.org”

Proposed Future Work

- ▶ Continue to encourage DOE projects and private-sector incident owners to submit records of incidents and near-misses to share their lessons learned with the hydrogen community
- ▶ Continue to analyze and summarize hydrogen safety themes in the Lessons Learned Corner (next is Ventilation)
- ▶ Continue to create H₂ Safety Snapshots and post on DOE website and on “H₂bestpractices.org”
- ▶ Conduct a best practices gap analysis with the Hydrogen Safety Panel
- ▶ Continue collaborations with IA HySafe by sharing records between “H₂incidents.org” and HIAD
- ▶ Conduct a stakeholder survey to obtain feedback on the utility of the two websites and suggestions for improvement
- ▶ Brainstorm ideas to increase visitors to “H₂bestpractices.org”

Summary

- ▶ Rate of progress has declined due to significant budget reductions.
- ▶ 201 safety event records in database, with a backlog of 55.
- ▶ 7 Lessons Learned Corners posted and 1 currently in progress.
- ▶ 30 new links added from safety event records to LLCs and/or best practices.
- ▶ Issues of H₂ Safety Snapshot posted on “H₂bestpractices.org”.
- ▶ Total unique visitors to “H₂incidents.org” increased by a factor of 6 between 2006 and 2011.
- ▶ Total unique visitors to “H₂bestpractices.org” doubled between 2008 and 2011, but still an order of magnitude below “H₂incidents.org”.
- ▶ Collaboration is continuing with HIAD database to share safety event records and lessons learned for the benefit of both.
- ▶ Feedback on both websites has been extremely positive.