VIII.11 Hydrogen Safety Knowledge Tools

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Fiscal Year (FY) 2011 Objectives

- Hydrogen Safety Best Practices - Capture the vast knowledge base of hydrogen experience and make it publicly available. The best practices online manual is a "living" document that provides guidance for ensuring safety in DOE hydrogen projects, while serving as a model for all hydrogen projects and applications.
- Hydrogen Incident Reporting and Lessons Learned - Collect information and share lessons learned from hydrogen incidents and near-misses, with the goal of preventing similar safety events from occurring in the future.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Safety section of the Fuel Cell Technologies (FCT) Program Multi-Year Research, Development and Demonstration Plan:

(A) Limited Historical Database

(B) Proprietary Data

Contribution to Achievement of DOE Safety, Codes & Standards Milestones

This project has already met the following DOE milestones from the Hydrogen Safety section of the FCT Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 18**: Publish safety bibliography and incident databases (3Q, 2006).
- **Milestone 19**: Publish a Best Practices Handbook (1Q, 2008).
- **Milestone 20**: Update peer-reviewed Best Practices Handbook (4Q, 2008).

FY 2011 Accomplishments

Hydrogen Safety Best Practices

- Added a new section on Hydrogen Properties, which is focused on combustion and liquid hydrogen expansion.
- Added a new section for students, technicians, and young engineers less familiar with hydrogen called "So You Want to Know Something about Hydrogen."
- Added a new section on Indoor Refueling of Hydrogen-Powered Forklifts with assistance from a team of industry experts.
- Added a new section on Chemical Hydrogen Storage.
- Added more photos to enhance the website appearance.

Hydrogen Incident Reporting and Lessons Learned

- Added 56 new safety event records from national laboratories, universities, and private-sector firms in the U.S. and other countries since the 2010 Annual Merit Review (AMR), for a total of 195 records currently in the database.
- Created quarterly postings of the Lessons Learned Corner to analyze and present hydrogen safety themes illustrated with database content.

Introduction

PNNL has developed and continues to improve two software tools to support the Hydrogen Safety, Codes and Standards sub-program. This report covers the Hydrogen Safety Best Practices online manual (http://www.H2BestPractices.org) and the Hydrogen Incident Reporting and Lessons Learned database (http://www.H2Incidents.org). The National Research Council's second report on the FreedomCAR and Fuel Partnership states that "The creation of a database on incidents involving hydrogen will be useful in promoting safety" [1]. The report also states that "The committee encourages DOE to continue to develop, publish, and update the best practices document."

Approach

Hydrogen Safety Best Practices - There are many references and resources that deal with the safe use of hydrogen, and our intent is to organize and compile relevant information in an easy-to-use Web-based manual without

duplicating existing resources. PNNL teams with the Hydrogen Safety Panel, other national laboratory staff, and other subject matter experts to compile hydrogen-specific best practices from a variety of references. Links to Web-based resources and files are provided on the website.

Hydrogen Incident Reporting and Lessons Learned - The purpose of "H2Incidents.org" is to facilitate open sharing of lessons learned from hydrogen safety events to help avoid similar incidents in the future. Our approach includes encouraging DOE-funded project teams and others to voluntarily submit incidents and near-misses and to provide specific lessons learned. We continue to pursue the addition of new records by actively seeking news reports on hydrogen incidents and searching existing databases and other sources for hydrogen-related safety event records. We contact private-sector companies who experience hydrogen-related safety events to solicit their permission to publish such records. We continue to maintain a mechanism for online submission of records. Specific safety event records are linked to Best Practices online manual content to emphasize safe practices for working with hydrogen and avoiding future incidents. Expert review of all safety events and lessons learned is provided by PNNL subject matter experts and the Hydrogen Safety Panel.

Results

Hydrogen Safety Best Practices – Existing content was supplemented with four new sections, and we added a number of photos to enhance the website appearance. A new section on Hydrogen Properties was added, which is focused on combustion and liquid hydrogen expansion. This section was developed collaboratively with members of the Hydrogen Safety Panel and the National Aeronautics and Space Administration White Sands Test Facility.

To serve the needs of students, technicians, and young engineers less familiar with hydrogen, a new section was added called "So You Want to Know Something about Hydrogen." The new section discusses properties and behavior, applications, and systems and controls, and a subsection on Hydrogen Hazards covers leaks, flames, and explosions. The Hydrogen Hazards section is not intended to dissuade anyone from working with hydrogen, but to make them aware that constant vigilance is necessary when working with or around hydrogen. In fact, hydrogen is just as safe as gasoline or any other commonly used fuel, it's just different. If you understand the differences, you will understand how to work safely with hydrogen.

Another new section on Indoor Refueling of Hydrogen-Powered Forklifts was developed with a team of subject matter experts from Air Products and Chemicals, Nuvera Fuel Cells, the National Renewable Energy Laboratory, and PNNL. This section covers design considerations, piping safeguards, leak mitigation, vehicle safety features, operations, and training.

A new section on Chemical Hydrogen Storage complements the existing material on Metal Hydride Storage and Handling. The term "chemical hydrogen storage" is used to describe storage technologies in which hydrogen is released and then later restored through chemical reactions. Many of the compounds that are being investigated for chemical hydrogen storage have never been synthesized, so material safety data sheets do not exist. Chemical hydrides present special hazards, including toxic byproducts, water and air reactivity, pyrophoricity, potential for runaway reactions with gas formation, and room-temperature gas emissions and instabilities.

Hydrogen Incident Reporting and Lessons Learned - We added 56 new incident records since the 2010 AMR. These records came from national laboratories, universities, and private-sector firms in the U.S. and other countries. We currently have 195 records in the database, with at least 30 more in progress. Most incident alerts were obtained from DOE or Google Alerts for hydrogen and fuel cell vehicles. Significant time was spent interacting with incident "owners" to encourage them to submit records of incidents and near-misses. We also posted quarterly installments of the Lessons Learned Corner to analyze hydrogen safety themes illustrated by database content.

We incorporated bar graphs to characterize the database contents in terms of settings, equipment, damage/injuries, probable causes, and contributing factors. The visual display makes it clear that the content is dominated by laboratory incidents (almost as many incidents as the next four highest settings combined).

Last year, we created a Lessons Learned Corner (LLC) to analyze the database content. We publish the LLC quarterly based on a specific theme that is illustrated with safety event records in the database. Themes covered to date include:

- 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
- Learning from Burst Disk Failures.

As an example, the basic theme of the LLC on The Importance of Purging Hydrogen Piping and Equipment is that all personnel should be trained on proper procedures for taking hydrogen systems offline and bringing them back online. Hydrogen Safety Panel members utilized their significant industrial experience to assist us in extracting clear lessons learned about purging systems. When getting ready for maintenance, you should always be conservative and assume that hydrogen is present and use a properly vented inert gas subsystem for purging. Likewise, when bringing a hydrogen system back online, you should always

assume that air is present and reduce oxygen levels below 1% before putting the system back online. Three very diverse incidents that were caused by improper purging are highlighted in the LLC – one from a power plant setting, one from a hydrogen production facility, and one that occurred in a laboratory. 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.

Conclusions and Future Directions

Hydrogen Safety Best Practices - Our future work includes improving existing website content as well as drafting new content. Ideas for new content come from the Hydrogen Safety Panel, other national laboratories, technical reviewers at the DOE AMR, and actual website users. We are planning a brainstorming session with the Hydrogen Safety Panel to identify any gaps in website content that should be addressed.

PNNL continues to monitor website usage and respond to user feedback. Users have submitted many requests for additional information and guidance through the website's comment submittal feature. We routinely seek guidance from one or more Hydrogen Safety Panel members in crafting our responses to these requests. Website utility is enhanced by continuing to link the content to safety event records in the Hydrogen Incident Reporting and Lessons Learned database and by adding photos, graphics, and videos to complement the text.

Hydrogen Incident Reporting and Lessons Learned - Our future work will focus on increasing the number of records in the database, in part through identifying additional sources of hydrogen safety event data and lessons learned. A significant part of our effort involves working with the national laboratories, universities, and private-sector firms that experience hydrogen incidents and/or near-misses to help them communicate what happened, what the probable causes and contributing factors were, and most importantly, what lessons were learned by their organizations that could benefit others if they were freely shared. We will continue to monitor website usage and respond to user feedback.

We will also continue to encourage all DOE-funded projects, universities, private-sector organizations, and others to voluntarily submit records of their hydrogen incidents and near-misses. Success requires that people use the database and submit information without fear of negative consequences from reporting and publicizing safety events. We will continue to maintain confidentiality for the organizations that voluntarily submit safety event records.

FY 2011 Publications/Presentations

1. Weiner, S.C., Fassbender, L.L., Blake, C., Aceves, S., Somerday, B.P. and Ruiz, A., "Web-based Resources Enhance Hydrogen Safety Knowledge," PNNL-SA-79693, HYPOTHESIS IX, San José, Costa Rica, December 12–15, 2011 (abstract accepted June 24, 2011).

2. Weiner, S.C. and Fassbender, L.L. "Lessons Learned from Safety Events," PNNL-SA-76793, International Conference on Hydrogen Safety, San Francisco, CA, September 12–14, 2011 (manuscript accepted June 1, 2011).

3. Barilo, N.F. and Fassbender, L.L. "Identifying Safety Vulnerabilities," *H2 Safety Snapshot*, Volume 2, Issue 2, PNNL-SA-77099, March 2011.

4. Weiner, S.C., Fassbender, L.L. and Quick, K.A. "Using Hydrogen Safety Best Practices and Learning from Safety Events," PNNL-SA-70148, International Journal of Hydrogen Energy, Volume 36, Issue 3, February 2011, pp. 2729-2735.

5. Fassbender, L.L. "Hydrogen Safety Knowledge Tools," PNNL-SA-77093, Hydrogen and Fuel Cell Safety, Fuel Cell and Hydrogen Energy Association, January 2011. http://www.hydrogenandfuelcellsafety.info/2011/jan/index.asp.

6. Barilo, N.F. and Fassbender, L.L. "Handling Compressed Hydrogen Gas Cylinders," *H2 Safety Snapshot*, Volume 2, Issue 1, PNNL-SA-75299, November 2010.

References

1. National Research Council, 2008, Review of the Research Program of the FreedomCAR and Fuel Partnership, Second Report, The National Academies Press, Washington, D.C.