
Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources

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Subcontractors:

- Santa Monica Fire Department, Santa Monica, CA
- UL, Northbrook, IL
- Air Products and Chemicals, Inc., Allentown, PA
- Becht Engineering, St. Louis, MO
- CSA Group, Langley, BC, Canada
- California Fuel Cell Partnership, West Sacramento, CA
- City of Santa Fe Springs, CA
- Proton OnSite, Wallingford, CT
- GWS Solutions of Tolland, LLC, Tolland, CT
- Witte Engineered Gases, Seminole, FL
- Firexpro, Wellesley, MA

Project Start Date: 2004
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Enable the safe and timely transition to hydrogen and fuel cell technologies.
- Provide expertise and recommendations to help identify safety-related technical data gaps, best practices, and lessons learned.
- Help integrate safety planning into funded projects to ensure that projects address and incorporate hydrogen safety practices.
- Collect information and share lessons learned from hydrogen incidents and near misses to help prevent similar safety events in the future.
- Capture vast and growing knowledge base of hydrogen experience and make it publicly available to the hydrogen community and stakeholders.
- Support implementation of hydrogen and fuel cell technologies by providing technically

accurate hydrogen safety and emergency response information to first responders.

Fiscal Year (FY) 2018 Objectives

- Develop a long-term sustainability plan for the Hydrogen Safety Panel (HSP) and its resources
- Participate in outreach events on hydrogen safety aimed at a variety of stakeholder groups to emphasize available tools and resources.
- Participate in stakeholder meetings with the Connecticut Center for Advanced Technologies to identify potential HSP reviews.
- Update the Hydrogen Tools Portal content management system and user interface.

Technical Barriers

This project addresses the following technical barriers from the DOE Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration (MYRDD) Plan [1]:

Safety, Codes, and Standards

- (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 Authorities Having Jurisdiction
- (E) Lack of Hydrogen Training Materials and Facilities for Emergency Responders
- (F) Insufficient Technical Data to Revise Standards.

Education and Outreach

- (A) Lack of Readily Available, Objective and Technically Accurate Information
- (D) Lack of Educated Trainers and Training Opportunities.

Contribution to Achievement of DOE Milestones

This project contributes to achievement of the following DOE tasks and milestones from the FCTO MYRDD Plan:

Safety, Codes, and Standards

- Task 1: Address Safety of DOE Research and Development (R&D) Projects (ongoing)
- Task 5: Dissemination of Data, Safety Knowledge, and Information (ongoing)
- Milestone 5.1: Update Safety Bibliography and Incidents Databases (4Q, 2011–2020)

Education and Outreach

- Task 1: Educate Safety and Code Officials (ongoing)
- Milestone 1.1: Update “Introduction to Hydrogen Safety for First Responders” Course for First Responders (biannually)

FY 2018 Accomplishments

- Partnered with the American Institute of Chemical Engineers (AIChE) to establish the Center for Hydrogen Safety enabling long-term sustainability and broader impact of the Hydrogen Safety Panel and Safety Knowledge resources.
- Updated the National Hydrogen and Fuel Cell Emergency Response Training Resource in support of in-person training conducted in the Northeast United States in early 2018.
- Held the 24th Hydrogen Safety Panel meeting in Cambridge, Massachusetts, September 26–28, 2017, which included consideration of timely and relevant safety issues and the engagement of key hydrogen infrastructure stakeholders.
- Conducted 20 reviews (including safety plans and project designs) from July 1, 2017, to September 30, 2018, and provided timely feedback to support the safe completion of project activities.

- Provided outreach and educational sessions for a variety of audiences including the DOE Energy Exchange Conference, Green Transportation Summit and Expo, Hydrogen South Africa, and stakeholder meetings in the Northeast United States to familiarize participants with hydrogen fuel cell technologies, safe practices and safety resources, and reduce barriers to technology acceptance.

INTRODUCTION

Safety is essential for realizing the “hydrogen economy”—safe operation in all of its aspects from hydrogen production through storage, distribution, and use; from research, development, and demonstration to deployment and commercialization. As such, safety is given paramount importance in all facets of the research, development, demonstration, and deployment work of the DOE FCTO. This annual report summarizes activities associated with three project tasks: the HSP, Safety Knowledge Tools, and First Responder Training Resources.

Recognizing the nature of the DOE FCTO program and the importance of safety planning, the HSP was formed in December 2003 to assemble a broad cross-section of expertise from the industrial, government, and academic sectors to help ensure the success of the program. The panel’s experience resides in industrial hydrogen production and supply, hydrogen R&D and applications, process safety and engineering, materials technology, risk analysis, accident investigation, and fire protection. The panel provides expertise and recommendations on safety-related issues and technical data gaps, reviews individual DOE-supported projects and their safety plans, and explores ways to develop and disseminate best practices and lessons learned, all broadly benefiting the FCTO program. The panel currently has 15 members with a total of over 400 years of industry and related experience (see Table 1 for FY 2018 panel membership).

Table 1. Current Hydrogen Safety Panel Membership

| | |
|------------------------------|--------------------------------|
| Nick Barilo, Program Manager | PNNL |
| Richard Kallman, Chair | City of Santa Fe Springs, CA |
| Eric Binder | Santa Monica Fire Department |
| Ken Boyce | UL |
| David Farese | Air Products and Chemicals |
| Don Frikken | Becht Engineering |
| Livio Gambone | CSA Group |
| Aaron Harris | Air Liquide |
| Chris LaFleur | Sandia National Laboratories |
| Miguel Maes | NASA White Sands Test Facility |
| Steve Mathison | Honda Motor Company |
| Larry Moulthrop | Proton OnSite |
| Glenn Scheffler | GWS Solutions of Tolland, LLC |
| Tom Witte | Witte Engineered Gases |
| Robert Zalosh | Firexplo |

Widespread availability and communication of safety-related information are crucial to ensuring the safe operation of future hydrogen and fuel cell technology systems. The entire hydrogen community benefits if knowledge on hydrogen safety is openly and broadly shared. To that end, PNNL continues to improve the safety knowledge software tools and develop new techniques for disseminating this information. This report covers the Hydrogen Tools Portal (<http://h2tools.org>), the Hydrogen Lessons Learned database (<http://h2tools.org/lessons/>), and the Hydrogen Safety Best Practices online manual (<https://h2tools.org/bestpractices>). These resources are key to reaching, informing, and educating users and stakeholders whose contributions will help enable the deployment of new hydrogen and fuel cell technologies.

Suitably trained emergency response personnel are essential to a viable infrastructure. FCTO has placed a priority on training emergency response personnel, not only because these personnel need to understand how to respond to a hydrogen incident, but also because firefighters and other emergency responders are influential in their communities and can be a positive force in the introduction of hydrogen and fuel cells into local markets. This report covers emergency response training for hazardous materials to provide a tiered hydrogen safety education program for emergency responders. The effort started with development and distribution of the awareness-level online course in FY 2006–2007. An operations-level classroom curriculum was developed

in FY 2008–2009, including design, construction, and operation of a fuel cell vehicle prop for hands-on training. PNNL and the California Fuel Cell Partnership collaborated to develop a national hydrogen safety training resource for emergency responders, which was made publicly available in September 2014.

APPROACH

The HSP strives to raise safety consciousness most directly at the project level through organizational policies and procedures, safety culture, and priorities. The panel reviews project safety plans and design documents to encourage thorough and continuous attention to safety aspects of the specific work being conducted. Panel safety reviews focus on engagement, learning, knowledge sharing, and active discussion of safety practices and lessons learned, rather than being audits or regulatory exercises. Through this approach, the HSP is promoting safe operation, handling, and use of hydrogen and hydrogen systems for all projects.

The panel's approach for disseminating safety knowledge in FY 2018 focused on adding resources to the existing Hydrogen Tools Portal and participating in impactful outreach activities. The portal brings together and enhances the utility of a variety of tools and web-based content on the safety aspects of hydrogen and fuel cell technologies. It is intended to help inform those tasked with designing, approving, or using systems and facilities, as well as those responding to incidents. Additional discussion is provided in the Results section of this report.

PNNL collaborates with subject matter experts in hydrogen safety and first responder training to develop, review, and revise training materials as needed. The PNNL project team works with DOE to inform stakeholder groups of training opportunities and to provide in person training when appropriate. The online awareness-level course provides a basic understanding of hydrogen properties, uses, and appropriate emergency response actions. The operations-level classroom/hands-on prop-based course has been presented at the Volpentest Hazardous Material Management and Materials Response Federal Training Center in Richland, Washington, and at several fire-training centers in California, Hawaii, and the Northeastern United States. This has enabled the panel to reach larger audiences in areas where hydrogen and fuel cell technologies are being deployed. The National Hydrogen and Fuel Cell Emergency Response Training Resource provides a consistent source of accurate information and current knowledge to ensure that training organizations have the information needed to develop or supplement their own courses. As part of this resource, a training template has been developed to guide the delivery of a variety of training regimens to various audiences.

RESULTS

A significant activity in FY 2018 was identifying long-term sustainability of the HSP and project safety resources. The goal is to make the HSP more readily available to industry and agencies, and to improve contracting efforts by making them less cumbersome and time consuming. PNNL evaluated three organizations and entered into significant talks with AIChE. The discussions resulted in a partnership between PNNL and AIChE to establish the Center for Hydrogen Safety (CHS). CHS will be a not-for-profit, non-biased membership organization within AIChE that promotes the safe operation, handling, and use of hydrogen and hydrogen systems across all installations and applications. The CHS will identify and addresses concerns regarding the safe use of hydrogen:

- As a sustainable energy carrier
- In commercial and industrial applications
- In hydrogen and fuel cell technologies.

Benefits to CHS members will include:

- Access to the U.S. Hydrogen Safety Panel for reviews and support
- Accredited education, training, and outreach materials
- Conferences and networking opportunities.

Membership in CHS will also demonstrate to stakeholders and the public that safety is a priority for the member organizations. This will be important messaging as infrastructure is more broadly deployed in locations where stakeholders are less familiar with hydrogen and fuel cell technologies.

The 24th HSP meeting was held in Cambridge, Massachusetts, September 26–28, 2017. The meeting provided opportunities to consider timely and relevant safety issues. The topics discussed and outcomes achieved at the meeting are detailed in the meeting minutes [2]. Significant activities during the meeting included interaction with a certification organization and discussion on sustainability of the HSP. The HSP guidance document, “Safety Planning for Hydrogen and Fuel Cell Projects,” was discussed along with proposed changes. These changes were incorporated, and the revised document was released in November 2017 [3]. The document was also reconfigured so that it could be used for both DOE and non-DOE projects.

During the past year, the HSP has provided safety reviews and support to 20 projects (Table 2). Since 2004, the panel has participated in 494 project reviews (including safety plans, site visit reviews, follow-up phone interviews, and design review work). In addition to reviewing safety plans for DOE, the HSP performed a site visit at Argonne National Laboratory to evaluate proposed changes to their gas blending system for turbines and engines using 100% hydrogen as a fuel. The visit included meetings with representatives from the project team and supporting organizations and a tour of the facility. Comments and recommendations were provided to the project team in September 2018. In March 2018, the HSP participated in an outreach event in Berkeley, California, to help the public become acquainted with specifics on the proposed Berkeley hydrogen fueling station. The PNNL project manager presented on the HSP’s role in deployment of the California hydrogen fueling station infrastructure.

In FY 2018, PNNL entered into a cooperative research and development agreement (CRADA) with the Connecticut Center for Advanced Technologies to raise the awareness of the HSP and identify projects that would benefit from safety reviews, outreach, and engagement with stakeholders. Stakeholder meetings were conducted in Connecticut, Rhode Island, and New Jersey in September 2018. In conjunction with these meetings, PNNL led hydrogen safety training focusing on fundamental safety knowledge and available safety resources.

At the request of the California Energy Commission (CEC), the HSP initiated a task group on mobile applications. The task group is evaluating the safety of mobile hydrogen and fuel cell applications (mobile auxiliary power units, mobile fuelers, multi-cylinder trailer transport, refrigeration units, etc.). The effort includes examination of the applications, requirements, and performance of mobile hydrogen to understand how safety considerations are applied. A report summarizing HSP activities, conclusions, and recommendations will be provided to the CEC and likely will be made available on the Hydrogen Tools Portal.

The HSP issued two white papers in FY 2018. The first, “Safety issues associated with the use of alternative fuel tanks: What can the hydrogen community learn from the CNG experience?” was published in June 2018 [4]. This paper (1) considered historical data from compressed natural gas (CNG) tank failures, including tank design and failure modes; (2) further evaluated vehicle fires and localized effects on tanks; and (3) identified research and testing gaps that the hydrogen industry should consider. The panel published a second white paper, “Qualified Individual for Liquefied Hydrogen,” on the Hydrogen Tools Portal in April 2018 [5]. This white paper is intended to help develop and implement practices and procedures that would ensure safety in the operation, handling, and use of hydrogen and hydrogen systems.

The Hydrogen Tools Portal was made publicly available in June 2015 and continues to grow in popularity. Based on current Google Analytics, the portal is becoming an international resource, as more than half of user sessions are from outside of the United States. Activities during 2018 focused on updating the portal from Drupal 7 to Drupal 8, improving the user interface, and revising the HSP site.

Table 2. HSP Project Safety Work July 1, 2017, to September 30, 2018

| Work | Project Title | Contractor |
|---------------|---|--------------------------------------|
| Site Visit | Gas Blending System Hydrogen Modifications | Argonne National Laboratory |
| Safety Plan | PGM-Free Engineered Framework Nano-Structure Catalyst | Greenway Energy, LLC |
| Safety Plan | Super Metallated Frameworks as Hydrogen Sponges | University of California Berkeley |
| Safety Plan | Thin-Film, Metal-Supported High-Performance and Durable Proton-Solid | UTRC |
| Safety Plan | Characterization and Accelerated Life Testing of a New Solid Oxide Electrolysis Cell | Northwestern University |
| Safety Plan | Proton-Conducting Solid Oxide Electrolysis Cells for Large-Scale Hydrogen Production at Intermediate Temperatures | University of Connecticut |
| Safety Plan | Advanced PGM-Free Cathode Engineering for High Power Density and Durability | Carnegie Mellon University |
| Safety Plan | Best-in-Class Platinum Group Metal-Free (PGM-Free) Catalyst Integrated Tandem Junction Photoelectrochemical (PEC) Water Splitting Devices | Rutgers |
| Safety Plan | Vapor Deposition Process for Engineering of Dispersed PEMFC ORR Pt/NbO _x /C Catalysts | Ford |
| Design Review | Overview of the Medium Pressure Reactor System Design | University of Hawaii |
| Safety Plan | Hydrogen Fuel Cell Range Extender for Battery Electric Vehicle | FedEx |
| Design Review | Carbon Free Data Center | National Renewable Energy Laboratory |
| Safety Plan | Innovative Non-PGM Catalysts for CHP Relevant Proton Conducting Membrane Fuel Cells | Northeastern University |
| Safety Plan | CEC-2016-09-Revised | FirstElement |
| Safety Plan | High Performance PEFC Electrode Structures | UTRC |
| Safety Plan | Modular SOEC System for Efficient Hydrogen Production at High Current Density | FuelCell Energy |
| Safety Plan | High Temperature Alkaline Water Electrolysis | Giner, Inc. |
| Safety Plan | Solid Oxide Based Electrolysis and Stack Technology with Ultra-High Electrolysis Current Density (>3 A/cm ²) and Efficiency | FuelCell Energy |
| Safety Plan | Hybrid Electrochemical Hydrogen/Metal Hydride Compressor | Greenway Energy, LLC |

Disseminating safety information continues to be an important aspect of this project. In addition to the CRADA activities described above, PNNL participated in outreach to personnel that construct, operate, and maintain energy-efficient and cost-effective federal facilities and fleets in the United States. Working with the Federal Energy Management Program (FEMP), PNNL participated in an outreach at the 2017 Energy Exchange Training and Trade Show in Tampa, Florida, in August 2017. The 90-minute presentation on fuel cell technologies was professionally recorded and made into a training course that has been deployed on FEMP's website. PNNL also collaborated with Clean Cities to co-present "Hydrogen Fuel Cells and Fuel Cell Electric Vehicles: Emerging Applications and Safety Management" at the Green Transportation Summit and Expo on April 17, 2018, in Tacoma, Washington. The event was well attended and included a good interactive discussion with participants.

PNNL's leadership in hydrogen safety is reinforced through its international collaborations. PNNL worked with Hydrogen South Africa, the International Association for Hydrogen Safety (HySafe), and the United Kingdom's Health and Safety Laboratory to provide an online hydrogen safety awareness webinar/panel discussion for code officials and stakeholders in South Africa in May 2018. PNNL also presented on the HSP and project learnings at the 2017 International Conference on Hydrogen Safety in Hamburg, Germany, in September 2017, and participated in the HySafe Research Priorities workshop in Buxton, United Kingdom, in September 2018.

First responder outreach activities for FY 2018 were limited to updating the National Hydrogen and Fuel Cell Emergency Response Training Resource (<https://h2tools.org/fr/nt>) in February 2018 and providing limited support to Frontier Energy's first responder training activities in the Northeast during the spring of 2018.

CONCLUSIONS AND UPCOMING ACTIVITIES

The HSP will continue to focus on how safety knowledge, best practices, and lessons learned can promote the safe conduct of project work and the deployment of hydrogen technologies and systems in applications of interest and priority in the DOE FCTO. The HSP can also be used more broadly as an asset for safe commercialization by reaching out to new stakeholders and users involved in early deployment, as shown by the panel's successful activities in California.

HSP initiatives over the next year will include the following:

- PNNL will work with AIChE to make the HSP available through AIChE.
- Continue to support the CEC's rollout of California's hydrogen fueling station infrastructure.
- Engage non-DOE entities to identify opportunities to use the panel to review hydrogen and fuel cell initiatives and promote safety.
- Continue to evaluate the panel membership to maintain its leadership role in hydrogen safety through an appropriate mix of safety expertise and perspective to perform safety reviews and address relevant issues.

Hydrogen safety knowledge tools help remove barriers to the deployment and commercialization of hydrogen and fuel cell technologies. The introduction of the Hydrogen Tools Portal opens opportunities to share new information and reach broader audiences. The primary focus in FY 2019 will be to maintain the portal in an operating state with minimal change.

The project's First Responder Training Resources can help ensure a safe transition to fuel cell vehicles and a hydrogen infrastructure and pave the way for broader public acceptance. This resource and associated props will be transitioned to the CHS in FY 2019, consistent with the President's direction toward a focus on early-stage R&D for DOE laboratories. To ensure a successful transition and long-term impact, the resource will be updated prior to the transfer.

FY 2018 PUBLICATIONS/PRESENTATIONS

1. Barilo, N.F. 2017. "Hydrogen Fuel Cells and Fuel Cell Electric Vehicles: Emerging Applications and Safety Management." Richland, WA: Pacific Northwest National Laboratory. Video, PNNL-SA-130157.
2. Barilo, N.F. 2018. "Safety issues associated with the use of alternative fuel tanks: What can the hydrogen community learn from the CNG experience?" PNNL-SA-132793. Richland, WA: Pacific Northwest National Laboratory.
3. Barilo, N.F. November 1, 2017. "Assuring Safety for Deployment of Hydrogen and Fuel Cell Technologies." Paris, France. PNNL-SA-129784.
4. Barilo, N.F. November 8, 2017. "Safety Learnings from Hydrogen Light Duty Vehicle Fueling Station Projects." Presented at Fuel Cell Seminar, Long Beach, California. PNNL-SA-130058.

5. Barilo, N.F. February 22, 2018. “Safety Planning for Hydrogen and Fuel Cell Projects.” Presented at California GFO-17-602 Webinar, “Online Conference,” United States. PNNL-SA-132444.
6. Barilo, N.F. May 25, 2018. “Hydrogen Safety Resources.” Presented at Hydrogen South Africa Hydrogen Safety Awareness. PNNL-SA-135026.
7. Barilo, N.F. 2017. “Hydrogen Safety Panel, Safety Knowledge Tools and First Responder Training Resources.” PNNL-SA-127936. Richland, WA: Pacific Northwest National Laboratory.
8. Barilo, N.F. March 30, 2018. “Hydrogen Safety Panel Activities in California Hydrogen Infrastructure Rollout.” Berkeley, CA. PNNL-SA-133425.
9. Barilo, N.F. August 15, 2017. “Hydrogen Fuel Cells and Fuel Cell Electric Vehicles, Emerging Applications and Safety Management.” Tampa, FL. PNNL-SA-127986.
10. Barilo, N.F. 2017. “Safety Planning for Hydrogen and Fuel Cell Projects.” PNNL-25279-1. Richland, WA: Pacific Northwest National Laboratory.
11. Barilo, N.F. June 15, 2018. “Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources.” Presented at DOE Annual Merit Review, Washington, DC. PNNL-SA-133744.
12. Barilo, N.F. September 12, 2018. “Introducing the Hydrogen Safety Panel and Safety Resources.” Presented at DOE CCAT Stakeholder Meetings, New York, NY. PNNL-SA-137746.
13. Barilo, N.F. September 19, 2018. “Hydrogen Safety Panel Learnings and Gaps.” Presented at HySafe Research Priorities Workshop, Buxton, United Kingdom. PNNL-SA-137902.
14. Barilo, N.F. September 12, 2018. “Introduction to Hydrogen and Fuel Cell Technologies and Safety Considerations.” Presented at stakeholder meetings in the Northeast U.S., New York, NY. PNNL-SA-137745.
15. Barilo, N.F. September 12, 2017. “U.S. Hydrogen Safety Panel Experience.” Presented at International Conference on Hydrogen Safety, Hamburg, Germany. PNNL-SA-128907.
16. Barilo, N.F. September 14, 2017. “Addressing the Hydrogen Infrastructure Safety Challenge.” Presented at Air Liquide, Paris, France. PNNL-SA-128908.

REFERENCES

1. U.S. Department of Energy, “Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration (MYRD&D) Plan,” <http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22>.
2. Barilo, N.F. to Farese, D. et al., “24th Hydrogen Safety Panel Meeting Minutes,” November 10, 2017.
3. “Safety Planning for Hydrogen and Fuel Cell Projects,” PNNL-25279-1, November 2017, https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-November2017_0.pdf.
4. “Safety issues associated with the use of alternative fuel tanks: What can the hydrogen community learn from the CNG experience?,” November 2017, https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-November2017_0.pdf.
5. “Qualified Individual for Liquefied Hydrogen,” April 2018, https://h2tools.org/sites/default/files/HSP_White_Paper-LH2_Qualified_Individuals.pdf.