VIII.6 Hydrogen Safety Panel, Safety Knowledge Tools and First Responder Training Resources

Nick Barilo

Pacific Northwest National Laboratory (PNNL)
P.O. Box 999
Richland, WA 99352
Phone: (509) 371-7894
Email: nick.barilo@pnnl.gov

DOE Manager: Will James
Phone: (202) 287-6223
Email: Charles.James@ee.doe.gov

Subcontractors:

- David J. Farese, Air Products and Chemicals, Inc., Allentown, PA
- William C. Fort, Shell Global Solutions (ret), Fairfax, VA
- Larry Fluer, Fluer, Inc., Paso Robles, CA
- Don Frikken, Becht Engineering, St. Louis, MO
- Livio Gambone, CSA Group, Langley, B.C., Canada
- Jennifer Hamilton, BKi, West Sacramento, CA
- Aaron Harris, Air Liquide, Houston, TX
- Richard A. Kallman, City of Santa Fe Springs, CA
- Larry Moulthrop, Proton OnSite, Wallingford, CT
- Glenn W. Scheffler, GWS Solutions of Tolland, LLC, Tolland, CT
- Steven C. Weiner, Excelsior Design, Inc., Richland, WA
- Tom Witte, Witte Engineered Gases, Seminole, FL
- Robert G. Zalosh, Firexplo, Wellesley, MA

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

Overall Objectives

- Provide expertise and recommendations to DOE and help identify safety-related technical data gaps, best practices, and lessons learned.
- Help DOE integrate safety planning into funded projects to ensure that all projects address and incorporate hydrogen and related 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) 2016 Objectives

- Provide updated content for first responder web-based and operations-level courses and the national training template.
- Participate in outreach events on hydrogen safety aimed at a variety of stakeholder groups to emphasize available tools and resources.
- Complete a third-party hydrogen certification guide to facilitate timely project permitting and approval by code officials.
- Incorporate additional enhancements for the Hydrogen Tools Portal, including workspace customization, mobile device display improvements, search engine optimization, and site performance.

Technical Barriers

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

Hydrogen Safety, Codes and Standards

(A) Safety Data and Information: Limited Access and Availability

(B) Availability and Affordability of Insurance

(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 FCT Office Multi-Year Research, Development, and Demonstration Plan.

Hydrogen 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 2016 Accomplishments

The 22nd Hydrogen Safety Panel (HSP) meeting was held in Torrance, California, December 8–10, 2015, enabling consideration of timely and relevant safety issues and the engagement of key hydrogen infrastructure stakeholders.

- The HSP conducted 23 reviews (including safety plans and project designs) since July 1, 2015, for projects within the FCT Office.
- Revised the National Hydrogen and Fuel Cells Emergency Response Training resource in December 2015 to include up-to-date pictures, text, and speaker notes.
- Released a draft Hydrogen Equipment Certification Guide for stakeholder review in December 2015, and feedback is currently being incorporated.
- Provided support to the DOE H2 Refuel competition by developing safety criteria, evaluating safety plans, and providing guidance and recommendations.
- PNNL led a team of team of four first responders from the United States to participate in the European Hydrogen Emergency Response Training Program for First Responders (HyResponse), held at L'École Nationale Supérieure des Officiers de Sapeurs-Pompiers (The French Academy for Fire, Rescue, and Civil Protection Officers) in Aix en Provence, France, May 9–13, 2016.
- Added additional resource tools for codes and standards permitting, the Hydrogen Fueling Infrastructure Research and Station Technology project, and the Hydrogen Station Equipment Performance (HyStEP) device to the Hydrogen Tools Portal (http://h2tools.org).
- Provided outreach and educational sessions for a variety of audiences, including the International Code Council (ICC), International Association of Fire Chiefs, Sacramento fire prevention officers, and stakeholders and code officials in New York and Massachusetts.

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 FCT Office. 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 FCT 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 as a whole. 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 projects and their safety plans, and explores ways to develop and disseminate best practices and lessons learned, all broadly benefiting the FCT program. The panel currently has 16 members with a total of over 400 years of industry and related experience (see Table 1 for FY 2016 panel membership).

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 hydrogen safety-related knowledge 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, educating, and informing stakeholders whose contributions will help enable the deployment of new hydrogen and fuel cell technologies.

A suitably trained emergency response force is essential to a viable infrastructure. The FCT Office has placed a high 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

TABLE 1. Current Hydrogen Safety Panel Membership

Nick Barilo, Program Manager	PNNL
Richard Kallman, Chair	City of Santa Fe Springs, CA
David Farese	Air Products and Chemicals
Larry Fluer	Fluer, Inc.
Bill Fort	Shell Global Solutions (ret)
Don Frikken	Becht Engineering
Livio Gambone*	CSA Group
Aaron Harris	Sandia National Laboratories
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
Steven Weiner	Excelsior Design, Inc.
Tom Witte*	Witte Engineered Gases
Robert Zalosh	Firexplo

* New panel members

in their communities and can be a positive force in the introduction of hydrogen and fuel cells into local markets. This report covers hazardous materials emergency response training 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. Project safety plans and design documents are reviewed 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 audits or regulatory exercises. Through this approach, the HSP is trying to achieve safe operation, handling and use of hydrogen and hydrogen systems for all projects.

The approach for disseminating safety knowledge in FY 2016 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's 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 "live" training when appropriate. The online awareness-level course provides the student with 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 and Hawaii 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

The 22nd HSP meeting was held in Torrance, California, December 8-10, 2015. The meeting provided opportunities to consider timely and relevant safety issues and provide direct input to the FCT Office. The topics discussed and outcomes achieved at the meeting are detailed in the meeting minutes [2]. Two panel task groups were formed at the meeting to (1) evaluate recent HSP reviews for new and unique applications (e.g., mobile auxiliary power units, mobile fuelers, refrigeration units, etc.) to determine if safety or code gaps exist and (2) capture unique learnings from projects and make the information available to future projects through a document or online resource.

During the past year, the HSP has provided safety reviews and support to projects identified in Table 2. Since 2004, the panel has participated in 441 project reviews (including safety plans, site visit reviews, follow-up phone interviews, and design review work). In addition to reviewing safety plans, the HSP provided crucial support to the DOE H2 Refuel competition by developing safety criteria, leading a safety webinar, and providing recommendations to both the judges and applicants. FY 2016 also marked the start of the HSP providing support for non-DOE projects. This included a review for the California Air Resources Board and support for the California general funding opportunity for

TABLE 2. HSP Project Safety Work since July 1, 2015

Work	Project Title	Contractor
Safety Plan Review	Biohydrogen production and bench-scale hydrogen-producing reactors	Oregon State University
Site Visit	Brentwood Hydrogen Fueling Station	National Renewable Energy Laboratory (NREL)
Design Review	NREL H_2 Station Reconfiguration	NREL
Document Review	HyStEP Procedures Review (two reviews)	California Air Resources Board
Safety Plan Review	Conformable Hydrogen Storage Coil Reservoir	Center for Transportation and the Environment
Safety Plan Review	Tandem Particle-slurry Batch Reactors for Solar Water Splitting (two reviews)	University of California, Irvine
Safety Plan Review	High Performance Platinum Group Metal Free Membrane Electrode Assemblies Through Control of Interfacial Processes	Proton OnSite
Safety Plan Review	Hydrogen Adsorbents with High Volumetric Density: New Materials and System Projections	University of Michigan
Safety Plan Review	H-Prize - Ion Submittal	Ion Power, Inc.
Safety Plan Review	H-Prize - Katsu Submittal	Katsu Technologies, Inc.
Safety Plan Review	H-Prize - Millennium Submittal (two reviews)	Millennnium Reign Energy
Safety Plan Review	H-Prize - Reactwell Submittal	ReactWell, LLC
Safety Plan Review	H-Prize - Simple.Fuel. Submittal	Simple.Fuel.
Safety Plan Review	H-Prize - WSU Submittal	Washington State University
Safety Plan Review	Design and Synthesis of Materials with High Capacities for Hydrogen Physisorption (two reviews)	Caltech
Safety Plan Review	Advanced Catalysts and Membrane Electrode Assemblies (MEAs) for Reversible Alkaline Membrane Fuel Cells (two reviews)	Giner, Inc.
Design Review	Mobile Fuel Cell Generator	California Air Resources Board
Document Review	Fire Protection Engineering Design Brief Template: Hydrogen Refueling Station	Sandia National Laboratories

fueling stations through a safety-planning webinar and safety consultation for applicants.

A significant HSP accomplishment during FY 2016 was the public release of the draft Hydrogen Equipment Certification Guide. The purpose of the guide is to enable designers, users, and code officials to better apply the requirements in cases where the use of listed, labeled, certified, or approved equipment or methods is required and to increase awareness and understanding of what the equipment is expected to do. The challenge with equipment certification is that the listing process for rapidly changing products, consistent with developing technologies, tends to be cost-prohibitive for equipment providers (each change to the equipment requires recertification). The circumstance of new technologies under development and low demand for early market applications results in few components and systems being currently listed. The scarcity of listed equipment places an extraordinary burden on code officials to ensure (and approve) that products include the appropriate inherent or automatic safety measures. The guide identified listing requirements in the ICC codes and National Fire Protection Association 2 (Hydrogen Technologies Code) for hydrogen equipment, and suggests criteria for approval when listed equipment is not available. Stakeholder comments were received and the guide is being revised for a fall 2016 release.

Panel members also helped the Hydrogen Technical Advisory Committee draft a safety communications plan. The plan assesses the status of resources and practices that support a comprehensive, consistent, and coordinated response to hydrogen safety-related events. The goal is to enable the hydrogen stakeholder community to understand event causes, address issues, share lessons learned, communicate status effectively with multiple stakeholders (including media), and maintain focus on advancing commercialization of hydrogen fuel.

International collaboration is important to PNNL's hydrogen safety work. PNNL led a team of four first responders to participate in the European Hydrogen Emergency Response Training Program for First Responders (HyResponse), held at L'École Nationale Supérieure des Officiers de Sapeurs-Pompiers in Aix en Provence, France, May 9–13, 2016 (additional discussion provided below). PNNL also offered highlights of accomplishments of the HSP and other international collaborations through two presentations at the 2015 International Conference on Hydrogen Safety in Yokohama, Japan [3,4]:

- "Overview of the DOE Hydrogen Safety, Codes and Standards Program Part 2: Hydrogen and Fuel Cells - Emphasizing Safety to Enable Commercialization"

- "First Responder Training: Supporting Commercialization of Hydrogen and Fuel Cell Technologies."

The Hydrogen Tools Portal was made publicly available in June 2015. The portal saw mostly steady growth in its use as a resource during FY 2016 (see Figure 1). Additional resources added to the portal included information from NREL on codes and standards permitting; the Hydrogen Fueling Infrastructure Research and Station Technology project; and information from Sandia National Laboratories on the HyStEP device, including specifications and design documents to enable others to replicate the equipment.

Disseminating safety information continues to be an important aspect of this project. A significant outreach effort during this reporting period focused on membership associated with the ICC Annual Business Meeting and conference. ICC membership includes building, fire, plumbing, mechanical, and energy officials representing state, county, municipal, and federal government agencies. Ensuring that this group is informed on hydrogen safety-related issues and resources can help facilitate a safe and timely transition to fuel cell technologies. The outreach event for the ICC's annual business meeting was a collaboration between PNNL, H2USA, and the California Fuel Cell Partnership. The event included a ride-and-drive event, a Toyota Mirai booth display, an educational session, and tours of a fueling station and fuel cell vehicle repair garage. Other hydrogen safety outreach activities during this reporting period are listed below:

- Boston area fire chiefs and code officials (August 2015)
- Sacramento Fire Prevention Officers (August 2015)
- International Association of Fire Chiefs (September 2015)
- The ICC Colorado Code Official Institute (March 2016)
- A joint Toyota, Air Liquide, NREL and PNNL outreach to code officials and stakeholders in New York and Massachusetts (April 2016)
- The Washington State Alternative Vehicles Working Group (July 2016)

To facilitate a more strategic approach for outreach activities, PNNL will lead a collaboration with NREL and Sandia National Laboratories to develop a DOE Safety, Codes and Standards long-term outreach plan. The goal of the plan is to reach all stakeholders that can impact the development, deployment and/or continued safe use of technologies that use hydrogen as a fuel. The plan is expected to be completed in early FY 2017.

FY 2016 activities directed toward the first responder training task included updating content for the National Hydrogen and Fuel Cell Emergency Response Training Resource (https://h2tools.org/fr/nt); development work for updating the Introduction to Hydrogen Safety for First Responders (http://hydrogen.pnl.gov/FirstResponders/) online course; organizing a team of four U.S. first responders to participate in HyResponse training; and planning classroom training activities for the Northeast in FY 2017.

PNNL organized a team of four U.S. first responders from Los Angeles County Fire Department, San Jose Fire Department, Littleton Massachusetts Fire Department and New York City Fire Department, for participation in the European Hydrogen Emergency Response Training Program for First Responders (HyResponse), held at L'École Nationale Supérieure des Officiers de Sapeurs-Pompiers in Aix en Provence, France, May 9-13, 2016. The HyResponse training included lectures focused on the fundamentals of hydrogen safety and tactics for responding to a variety of events, hands-on training exercises with well-developed props, and virtual reality interactive sessions. The four U.S. first responders participated directly in all activities, and staff from PNNL observed. Participation in this training afforded a number of positive benefits:

- Provided first responders with the needed experience and knowledge to train others in their region and support additional United States-based training outreach.
- Gained valuable first responder feedback on the training strategies implemented by the HyResponse project in

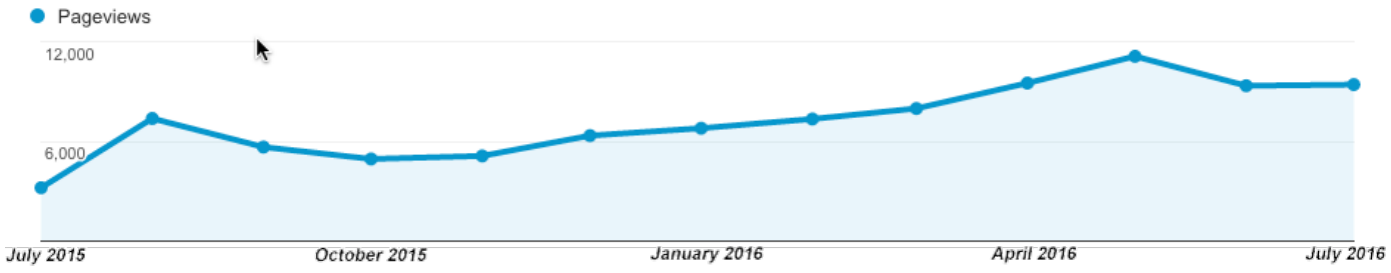

FIGURE 1. Hydrogen Tools Portal pageviews (source: Google Analytics)

order to consider improvements to PNNL/DOE first responder training activities.

- Discussed opportunities for future collaborations with HyResponse organizations (including participating in a proposed Spring 2017 Northeast United States training event).

CONCLUSIONS AND FUTURE DIRECTIONS

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 FCT Office. 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.

HSP initiatives over the next year will include the following:

- Support the rollout of California's hydrogen fueling stations by reviewing safety plans for applicants to the Energy Commission's general funding opportunity.
- Engage non-DOE entities to identify opportunities to use the panel to review hydrogen and fuel cell initiatives and promote safety.
- Release the Hydrogen Equipment Certification Guide to the public in the fall of 2016.
- 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 new opportunities for sharing safety information and reaching broader audiences. In FY 2017, opportunities to collaborate with other national laboratories, state organizations, and industry partners will continue to be explored to identify and integrate new resources into this valuable website. It is also anticipated that PNNL will participate in a number of strategic outreach efforts similar to FY 2016.

The project's First Responder Training Resources address a key H2USA barrier, ensure a safe transition to fuel cell vehicles and a hydrogen infrastructure, and pave the way for broader public acceptance. Potential activities for FY 2017 will include deployment of the updated online training, and onsite training activities in New York, Massachusetts, Connecticut, and Rhode Island. It is anticipated that this training will take place in November 2016 and the spring of 2017. The latter date will likely include classroom training and prop demonstrations, and could also include virtual reality training exercises through collaboration with participants in the HyResponse project.

REFERENCES

1. U.S. Department of Energy, "Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration 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., "Minutes from the 22nd Hydrogen Safety Panel Meeting," February 8, 2016.

3. Barilo, N.F., and S.C. Weiner, "Overview of the DOE Hydrogen Safety, Codes and Standards Program Part 2: Hydrogen and Fuel Cells - Emphasizing Safety to Enable Commercialization," International Conference on Hydrogen Safety, Yokohama, Japan, October 20, 2015.

4. Barilo, N.F., J.J. Hamilton, and S.C. Weiner, "First Responder Training: Supporting Commercialization of Hydrogen and Fuel Cell Technologies," 2015 International Conference on Hydrogen Safety, Yokohama, Japan, October 19, 2015.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. Barilo, N.F., "Hydrogen Equipment Certification Guide Listing, Labeling and Approval Considerations," PNNL-25053, Richland, WA, December 2015.

2. Barilo, N.F., "Safety Planning for Hydrogen and Fuel Cell Projects," PNNL-25279, Richland, WA, March 2016.

3. Barilo, N.F., Weiner, S.C., and James, C.W., "Overview of the DOE Hydrogen Safety, Codes and Standards Program Part 2: Hydrogen and Fuel Cells: Emphasizing Safety to Enable Commercialization," International Journal of Hydrogen Energy, June 2016.

4. Barilo, N.F., Hamilton, J.J., and Weiner, S.C., "First Responder Training: Supporting Commercialization of Hydrogen and Fuel Cell Technologies," International Journal of Hydrogen Energy, July 2016.

5. Barilo, N.F., "Safety Considerations for Hydrogen and Fuel Cell Applications," presented at the ICC Annual Business Meeting, Long Beach, CA, September 29, 2015.

6. Barilo, N.F., and Frikken, D., "Safety Planning for the H-Prize Competition," presented at the "Safety First" webinar for the H2 Refuel competition online webinar on August 6, 2015.

7. Barilo, N.F., "Hydrogen and Fuel Cells Are Coming...Are You Ready?" presented at the United States Fire Administration and International Association of Fire Chiefs online webinar on September 15, 2015.

8. Barilo, N.F., Hamilton, J.J., and Weiner, S.C., "First Responder Training: Supporting Commercialization of Hydrogen and Fuel Cell Technologies," presented at the International Conference on Hydrogen Safety, Yokohama, Japan on October 19, 2015.

9. Barilo, N.F., and Weiner, S.C., "Overview of the DOE Hydrogen Safety, Codes and Standards Program Part 2: Hydrogen and

Fuel Cells - Emphasizing Safety to Enable Commercialization," presented at the International Conference on Hydrogen Safety, Yokohama, Japan on October 20, 2015.

10. Barilo, N.F., "Hydrogen and Fuel Cell Applications," presented at the Colorado Chapter Educational Institute (ICC), Denver, CO on March 3, 2016.

11. Barilo, N.F., "Hydrogen Safety Panel, Safety Knowledge Tools and First Responder Training Resources," presented at the 2016 DOE Hydrogen Program Annual Merit Review and Peer Evaluation Meeting, Washington, DC, on June 7, 2016.

12. Barilo, N.F., "Hydrogen Fueling Stations," presented at outreach events in New York and Massachusetts in April 2016.

13. Barilo, N.F., "Hydrogen Safety Information Resources," presented at outreach events in New York and Massachusetts in April 2016.

14. Barilo, N.F., "Safety Planning for Hydrogen and Fuel Cell Projects," presented at outreach events in New York and Massachusetts in April 2016.

15. Barilo, N.F., Markwort, J.M., and Jo, I.D., "Hydrogen Tools Information Video," PNNL-SA-113244, Richland, WA, September 2015.