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

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## Subcontractors:

- WHA International, Inc., Las Cruces, NM
- UL, LLC, Northbrook, IL
- Campbell Training Solutions, Kennewick, WA
- American Institute of Chemical Engineers, New York, NY
- Air Products and Chemicals, Inc., Allentown, PA
- Becht Engineering, St. Louis, MO
- Nikola Motors, Phoenix, AZ
- California Fuel Cell Partnership, West Sacramento, CA
- City of Santa Fe Springs, CA
- Calgary Fire Department, Calgary, Canada
- Larry Moulthrop Proton OnSite (retired), Wallingford, CT
- Proton OnSite, Wallingford, CT
- Somerday Consulting, LLC, King of Prussia, PA
- Stottler Development, LLC, Honeoye Falls, NY
- Tedeschi Consulting Solutions, LLC, Kennewick, WA
- Witte Engineered Gases, Seminole, FL
- Firexplo, 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 the 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) 2019 Objectives

- Produce high-impact hydrogen safety videos clips for the first responder training 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 in Maryland, Massachusetts, New Jersey, and New York.
- Partner with the American Institute of Chemical Engineers (AIChE) to stand up an international Center for Hydrogen Safety (CHS).

## Technical Barriers

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

### Safety, Codes and Standards

- Task 1: Address Safety of DOE 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).

## INTRODUCTION

Safety is essential to support the transition to hydrogen as an energy carrier, including the 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 HSP’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 HSP 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 HSP currently has 17 members with more than 500 cumulative years of industry and related experience (see Table 1 for HSP membership).

## FY 2019 Accomplishments

- Partnered with AIChE to establish the CHS, thus enabling long-term sustainability and broader impact of the Hydrogen Safety Panel (HSP), first responder training, and safety knowledge resources.
- Initiated efforts to produce high-impact hydrogen safety training videos for first responders.
- Held the 25th HSP meeting in New Orleans, Louisiana, April 2–4, 2019, which included participation in the launch of the CHS as well as the discussion of timely and relevant safety issues.
- Conducted 16 reviews (including safety plans and project designs) from October 1, 2018, to September 30, 2019, to support the safe implementation of DOE FCTO project activities.
- Provided stakeholder and educational sessions in Massachusetts, Maryland, New Jersey, and New York. The sessions were attended by code officials, energy policy makers, project proponents, and others interested in the deployment of the technology. Approximately 150 persons attended the sessions.

**Table 1. HSP Membership (as of September 30, 2019)**

Nick Barilo, Program Manager	PNNL
Richard Kallman, Chair	City of Santa Fe Springs, CA (retired)
Harold Beeson	WHA International, Inc.
Ken Boyce	UL, LLC
David Farese	Air Products and Chemicals
Don Frikken	Becht Engineering
Livio Gambone	Nikola Motors
Aaron Harris	Air Liquide
Brian Ladds	Calgary Fire Department
Chris LaFleur	Sandia National Laboratories
Miguel Maes	NASA White Sands Test Facility
Larry Moulthrop	Proton OnSite (retired)
Spencer Quong	Quong and Associates, Inc. (consultant for Toyota Motors)
Brian Somerday	Somerday Consulting, LLC
Gary Stottler	Stottler Development, 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. The 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 HSP reviews project safety plans and design documents to encourage thorough and continuous attention to safety aspects of the specific work being conducted. HSP safety reviews focus on engagement, learning, knowledge sharing, and active discussion of safety practices and lessons learned because HSP recognizes its nature as an expert body and not a regulatory/oversight entity. Through this approach, the HSP is promoting safe operation, handling, and use of hydrogen and hydrogen systems for all projects.

The project's approach for disseminating safety knowledge in FY 2019 focused on continuous improvements to the Hydrogen Tools Portal and participation 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 course has optional hands-on/prop-based training and 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 HSP 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 project activity in FY 2019 was partnering with AIChE to establish the CHS to enable long-term sustainability of the HSP and associated safety resources. Through the CHS, organizations can now access the HSP for reviews and support through more streamlined contracting efforts. Additionally, the time needed to initiate an HSP review has been reduced from 3–6 months to 1–2 weeks.

Benefits to CHS members will include:

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

The 25th HSP meeting was held in New Orleans, Louisiana, April 2–4, 2019. 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 2019 [3]. The document was also reconfigured so that it could be used for both DOE and non-DOE projects.

During the past fiscal year, the HSP has provided safety reviews and support to 16 projects (Table 2). Since 2004, the HSP has participated in 511 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 the National Renewable Energy Laboratory to evaluate the lab’s Thermal and Catalytic Process Development Unit. The visit included meetings with representatives from the project team and supporting organizations and a tour of the facility. Comments and recommendations will be provided to the project team in early in FY 2020. The HSP also participated in a site visit and document reviews for the U.S. Department of Defense Advanced Power and Energy Demonstration project. Two distinct activities were performed: a site visit to Keyport, Washington, in November 2018 and a design review meeting in San Diego, California, in August 2019. The HSP also continues to support light-duty hydrogen fueling infrastructure in California by reviewing safety plans for two renewable production plants and four liquid hydrogen fueling stations.

Table 2. HSP Project Reviews for FY 2019

Work	Project Title	Contractor
Safety Plan	High-Efficiency Reversible Alkaline Membrane Fuel Cells	Giner
Safety Plan	Cryo-Catalysis Hydrogen Experiment Facility (CHEF)	Washington State University
Safety Plan	Stationary Direct Methanol Fuel Cells Using Pure Methanol	University of Kansas
Safety Plan	Composite PEMs from Electrospun Crosslinkable Poly(Phenylene Sulfonic Acid)s	Vanderbilt University
Safety Plan	Electrolyzer Integrated Modular Nano-Array Monolithic Catalytic Reactors	Skyre
Safety Plan	CEC-Hydrogenics-Stratosfuel	Hydrogenics
Safety Plan	CEC-H2B2	H2B2
Safety Plan	Anode-Boosted Electrolyzer	Giner EXL, LLC
Safety Plan	Laser 3D Printing of Highly Compacted Protonic Ceramic Electrolyzer Stack	Clemson University
Safety Plan	CEC-2019-Iwatani	Iwatani
Safety Plan	CEC-2016-09-Revised	FirstElement
Safety Plan	High Performance PEFC Electrode Structures	United Technologies Research Center
Safety Plan	CEC-2019-ITM	ITM Power
Site Visit	Large Displacement Unmanned Underwater Vehicle, Advanced Power & Energy Demonstration Project	U.S. Department of Defense (Navy)
Safety Plan	Demonstration of a Fuel Cell Powered Ground Support Equipment (GSE) Revised Safety Plan	Plug Power, Inc.
Safety Plan	H Thin-Film, Metal-Supported High-Performance and Durable Proton-Solid Hybrid Electrochemical Hydrogen/Metal Hydride Compressor	United Technologies Research Center

In FY 2019, PNNL entered into a cooperative research and development agreement with the California Energy Commission (CEC) to support deployment of the light-duty hydrogen vehicle infrastructure. The activity includes reviewing hydrogen fueling stations and renewable production plant designs and safety plans, performing outreach to stakeholders and code officials, and participating in site evaluations and incident fact-finding. Additionally, at the request of the CEC, the HSP 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 made available on the Hydrogen Tools Portal in early FY 2020.

PNNL performed outreach activities and stakeholder meetings in Massachusetts, Maryland, New Jersey, and New York during FY 2019. The primary purpose of these meetings was to:

- Raise awareness of the PNNL HSP among state/local officials and project developers.
- Establish working relationships with key state and local organizations to enable seamless incident response and development of safety lessons learned.
- Identify types of projects that would benefit from PNNL involvement.
- Develop market strategies for additional safety reviews.

The meetings were well attended and included significant participant interaction.

PNNL's leadership in hydrogen safety is reinforced through its international collaborations. PNNL presented on hydrogen safety and its partnership with CHS at the International Partnership for Hydrogen and Fuel Cells in the Economy meeting in Vienna, Austria, in April 2019; the World Hydrogen Technologies Convention in June 2019; and the International Conference on Hydrogen Safety in Adelaide, Australia, in September 2019. A PNNL employee also led hydrogen safety workshops in Adelaide, Australia, in November 2018.

During FY 2019, PNNL contracted and collaborated with the AIChE CHS to transfer and improve the further dissemination and implementation of the hydrogen safety first responder training resources. This activity included AIChE modifying the existing knowledge management website section of the AIChE Academy (<https://www.aiche.org/academy>) to accommodate content of the hydrogen safety training materials that presently exist on the PNNL-hosted Hydrogen Tools Portal website, (<https://h2tools.org/training-materials>), and includes issuing official accredited continuing education credits to students.



PNNL also worked with U.S. domestic first responders, automotive industry leaders in hydrogen fuel cell vehicles (FCVs), international industrial gases and chemical suppliers, and domestic bus transit companies to produce five short (4–10 minutes each) hydrogen safety training videos. The video topic areas were chosen to fill in the technical gaps of concern for first responders. The following video topics completed pre-production (storyboarding, outline, and scripting), production (filming in five locations in Southern California), and post-production editing (splicing and adding animations and narrations):

- Occupant Extrication from an Automobile FCV
- Safety Features of an FCV
- Compressed Gas Tube Cylinder Transport Truck Safety
- Hydrogen Filling Station Safety
- FCV Bus Safety.

Minor updates were also made to the National Hydrogen and Fuel Cell Emergency Response Training Resource in March 2019.

## 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 HSP's successful activities in California. PNNL is also seeing increased interest in using the HSP for review of both fuel cell and non-fuel cell hydrogen applications, both in the United States and internationally. As a result of the new partnership with CHS and increased activities at the FCTO, it is anticipated that the demand for HSP review and support could reach record levels in FY 2020.

Hydrogen safety knowledge tools help remove barriers to the deployment and commercialization of hydrogen and fuel cell technologies. The Hydrogen Tools Portal provides opportunities to share new information and

reach broader audiences. Recent personnel changes at PNNL have prompted the need to use a third party for the maintenance of the Hydrogen Tools Portal. PNNL will issue a contract in early FY 2020, and the new arrangement should facilitate a timelier resolution of issues and a robust website. It is also likely that a new resource focusing on the status of world-wide codes and standards will be implemented in cooperation with the Fuel Cell & Hydrogen Energy Association.

PNNL will complete the transition of the project's first responder training resources to CHS in FY 2020. This includes transferring the national training resource, online awareness training, and the training props.

## FY 2019 PUBLICATIONS/PRESENTATIONS

1. N.F. Barilo, "Safety Planning for Hydrogen and Fuel Cell Projects," Pacific Northwest National Laboratory, Richland, WA, 2019, PNNL-25279-2.
2. N.F. Barilo, A.C. Dalton, R. Kallman, T. Witte, R.G. Zalosh, and R.G. Zalosh, "An Investigation of Mobile Hydrogen and Fuel Cell Technology Applications," Presented at the International Conference on Hydrogen Safety, Adelaide, South Australia, September 25, 2019, PNNL-SA-142286.
3. N.F. Barilo, "Center for Hydrogen Safety... Connecting a Global Community," Presented at World Hydrogen Technologies Convention, Tokyo, Japan, June 4, 2019, PNNL-SA-143848.
4. N.F. Barilo, A.C. Dalton, R. Kallman, T. Witte, R.G. Zalosh, and R.G. Zalosh, "An Investigation of Mobile Hydrogen and Fuel Cell Technology Applications," In International Conference on Hydrogen Safety, 2019, PNNL-SA-142286.
5. N.F. Barilo, "Hydrogen Safety Outreach to Expedite Hydrogen Fueling and Energy Project Deployment and Promote Public Acceptance for Zero Emission Vehicles and Reliable Distributed Power Generation," Crystal City, Virginia, 2019, PNNL-SA-141331.
6. N.F. Barilo, "Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources," Crystal City, Virginia, 2019, PNNL-SA-141360.
7. N.F. Barilo, "Hydrogen Safety Panel Evaluation of Hydrogen Facilities," Crystal City, Virginia, 2019, PNNL-SA-141332.
8. "National Hydrogen and Fuel Cells Emergency Response Training," Richland, WA, February 26, 2019, <https://h2tools.org/fr/nt>.
9. N.F. Barilo, "Increasing the Value Proposition: Hydrogen Safety," Online Webinar, United States, 2018, PNNL-SA-139982.
10. N.F. Barilo, "Update on Hydrogen Safety Panel Sustainability and the AIChE Center for Hydrogen Safety," Hydrogen and Fuel Cell Technical Advisory Committee Meeting, Washington, DC. December 13, 2018, PNNL-SA-139915.
11. N.F. Barilo, "FY2018 PNNL Hydrogen Safety Program Annual Report," PNNL-SA-140012 (Richland, WA: Pacific Northwest National Laboratory, 2018).
12. N.F. Barilo, "Hydrogen and Fuel Cell Technologies – U.S. Standards/Regulations and Government Role in Technology Rollout," Presented in Adelaide, Australia, November 13, 2018, PNNL-SA-139917.

## REFERENCES

1. U.S. Department of Energy, "Fuel Cell Technologies Office Multi-Year Research, Development and Demonstration Plan," <https://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22>.
2. N.F. Barilo to D. Farese, et al., "25th Hydrogen Safety Panel Meeting Minutes," June 14, 2019.
3. "Safety Planning for Hydrogen and Fuel Cell Projects," PNNL-25279-2, September 2019, [https://h2tools.org/sites/default/files/Safety\\_Planning\\_for\\_Hydrogen\\_and\\_Fuel\\_Cell\\_Projects.pdf](https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects.pdf).