Hydrogen Safety and Event Response

Subcommittee Report

Hydrogen and Fuel Cells Technical Advisory Committee

Table of Contents

Executive Summary

As fuel cell electric vehicles (FCEVs) enter the commercial market, a growing number of customers will purchase hydrogen fuel at retail stations. While vehicles and fuel tanks are built and certified to meet all Federal Motor Vehicle Safety Standards (FMVSS) and stations are built and operated to stringent safety codes and standards, the growing volume of fueling events increases the potential for a release of hydrogen or other safety concern. In Fall 2015, the U.S. Department of Energy (DOE) Hydrogen and Fuel Cells Technical Advisory Committee (HTAC) recognized the need to assess the current status of resources and practices that support a comprehensive, consistent, and coordinated response to hydrogen safety-related events. The goal is to enable the community of hydrogen stakeholders to understand event causes, address issues, share learnings, communicate status effectively with multiple stakeholders, including media, and maintain focus on advancing commercialization of hydrogen fuel. This activity is within HTAC's scope as outlined in its charter to "…review and make recommendations to the Secretary on…the safety, economical, and environmental consequences of technologies for the production, distribution, delivery, storage, or use of hydrogen energy and fuel cells."[1]

A subcommittee of HTAC members worked together beginning in January 2016 to review and assess current resources such as safety plans; event response plans; current federal, state, and local requirements; and case studies to identify gaps and recommend actions to address current and projected needs. This report summarizes the findings of the subcommittee and makes recommendations to address the gaps revealed through this process.

Overview

Nationwide, there are 35 public hydrogen stations as of April 2017, of which 26 are retail stations where customers can purchase fuel with a credit card similar to retail gasoline stations. Hydrogen stations dispense fuel into vehicles according to industry standard fueling protocols and incorporate multiple safety features that take into account the specific properties of hydrogen fuel. Stations are required to comply with the same types of safety approval and permitting processes as gasoline stations, such as conducting a formal analysis to identify risks, evaluating failure modes and incorporating mitigation measures, adopting a fire safety plan, and training employees and operators on the proper emergency response and communication procedures. As with all fuels, in the event of an incident involving a spill or release, communicating clear and accurate information with authorities, stakeholders, and the public is the foundation of effective decision making and response. This is especially important for hydrogen as it is a new retail fuel for which there is not yet broad awareness, understanding, and acceptance of its safety.

Elements of Event Response

The goal of an immediate event response is to expeditiously activate the response team; conduct an initial diagnosis; and contain the event to minimize injury to people, operational interruptions, and property damage. First responders who will respond to any hydrogen production, storage, or dispensing site must be specifically trained regarding the properties of and risks related to hydrogen and the proper techniques for handling an incident involving hydrogen. Responding parties should have ready access to information regarding hydrogen properties, risks, and response techniques to accompany clear and concise statements

[1] https://www.hydrogen.energy.gov/pdfs/htac_charter.pdf

of what is currently known about the specific incident. Media may get involved during this phase and should have access to basic facts regarding hydrogen as well as information regarding the specific incident, as available.

Key goals of the diagnosis, resolution, and closing phases of an event are to (1) perform a root cause analysis; (2) take permanent corrective action for the specific site, vehicle, or issue; (3) document lessons learned; and (4) communicate and apply these to other sites as appropriate. A coordinated effort is needed to ensure that all stakeholders understand and are comfortable with the cause and corrective action for any incident. Having a documented root cause analysis process and template for communicating findings developed in advance is critical to efficient investigation and communication. This is especially important at fueling sites so the site can reopen and resume operation as soon as possible.

The Hydrogen Safety Panel

The Hydrogen Safety Panel (HSP) was formed in 2003 to address concerns about hydrogen as a safe and sustainable energy carrier. The HSP's principal goal is to promote the safe operation, handling, and use of hydrogen and hydrogen systems across all installations and applications. The core objectives of the HSP are to:

- Provide expertise and recommendations and assist with identifying safety-related technical gaps, best practices, and lessons learned, and
- Help ensure that safety planning and safety practices are incorporated into hydrogen projects.

The 14-member Panel has over 400 years of combined experience and is comprised of a cross section of expertise from the commercial, industrial, government, and academic sectors. Panel members participate in a variety of standards development organizations including the National Fire Protection Association (NFPA), American Society for Mechanical Engineers (ASME), SAE International, and the International Organization for Standardization (ISO). The HSP also contributes to peer-reviewed literature and trade magazines on hydrogen safety and presents at national and international forums. The HSP has reviewed more than 285 projects covering vehicle fueling stations, auxiliary power, backup power, combined heat and power, industrial truck fueling, portable power, mobile applications, and research and development (R&D) activities.

The Panel is a unique resource and can be a valuable asset for supporting the safe commercial rollout of fuel cell vehicles, stationary applications, and the supporting equipment and infrastructure. The HSP contributes to its objective by:

- Participating in safety reviews,
- Reviewing project designs and safety plans,
- Participating in incident investigations, and
- Sharing safety knowledge and best practices.

Recommendations

Recommendation #1: Maximize the Role of the Hydrogen Safety Panel

DOE should develop a strategic plan that positions the HSP as a trusted resource on hydrogen safety, invests in marketing to make the HSP more visible, and provides resources to enable the HSP to develop relationships with safety officials at the local, state, and national levels. While state and privately funded projects should also budget for HSP involvement, DOE should enable federal funding to support non-DOE funded projects with the goal of broadly advancing hydrogen FCEVs.

Recommendation #2: Leverage the Capabilities of Public–Private Partnerships, Including Clean Cities Coalitions and Other Regional Partnerships

The broader stakeholder community can play an important role in supporting those who are new to the industry and communicating information to the media regarding hydrogen properties and safety. Regional partnerships such as the California Fuel Cell partnership (CaFCP), Connecticut Center for Advanced Technology (CCAT), and Ohio Fuel Cell Coalition (OFCC), as well as local coalitions such as Clean Cities, can act as a central point of contact for those not immediately involved in hydrogen fueling activity to stay up to date on the latest developments and be prepared to get involved where appropriate. The goal is to provide factual and accurate information to counteract potential sensationalist coverage by media.

DOE could take the following specific actions to further leverage partnerships to support hydrogen projects.

1. Engage Clean Cities Coalitions to incorporate hydrogen information into their programs.
2. Identify specific responsibilities that regional partnerships and local coalitions such as Clean Cities could carry out, such as providing basic information about hydrogen, running periodic "table top" exercises, activating media response resources as needed, and communicating learnings.
3. Expand Clean Cities tiger teams to include hydrogen.
4. Prepare others to take action by providing training, resources, and case studies.

Recommendation #3: Take Steps to Support Reopening Hydrogen Stations in a Timely Fashion after a Safety-Related Incident

The hydrogen bus fueling station featured in the incident case study described on Page 13 re-opened nine months after the hydrogen release incident. This is significantly longer than the time it would take to reopen a gasoline station that experienced an unintentional release or fire. Hydrogen stations should be able to recover and reopen from safety-related incidents on a timeline similar to gasoline stations. Meeting this goal will require that local officials and station operators understand the process that responsible parties will undertake to ensure the incident was properly investigated, the root cause was identified and fixed, and equipment and procedures were redesigned as needed to enable full recovery and safe reopening to the public.

Recommendation #4: Identify and Support Other Federal and State Agencies that Need to Incorporate Hydrogen into Their Programs

Hydrogen fuel will eventually be as familiar as gasoline fuel as we move toward low-carbon, zero-emission fuels. DOE and state agencies (such as California Air Resources Board [CARB] and California Energy Commission [CEC] in California) that have expertise in hydrogen can be a resource to encourage and support other federal and state agencies that will need to incorporate hydrogen into their regular programs.

Introduction and Current Landscape

Hydrogen station technology has evolved significantly over the past 15 years. For example, when the CaFCP was launched in 1999, and as stations were built under DOE's Technology Validation program beginning in 2004, hydrogen stations were "behind the fence" and operators wore personal protective equipment such as Nomex coats and safety goggles. With the advent of NFPA 2 that defined requirements for dispenser safety, these personal protective equipment requirements were eliminated, but most stations still required special access procedures and training. Early fueling protocols standardized the fill process, giving automakers confidence stations would fill their vehicles without exceeding temperature and pressure specifications of fuel tanks. Fueling protocols matured over the years, culminating in the first publication of SAE J2601 as an industry technical information report in March 2010. Stakeholders developed hydrogen quality requirements to protect fuel cell performance and first published these as SAE J2719 in November 2005. California defined hydrogen as a transportation fuel subject to fuel quality requirements, as well as other labeling and metering requirements. Both SAE J2601 and J2719 have been revised, and the current versions are referenced by the State of California as requirements for retail fueling stations. These and other industry and government actions were essential in maturing toward the retail hydrogen station of today.

The initial network of technology demonstration stations has been largely replaced by retail stations, located on conventional fuel station forecourts, where customers can swipe a credit card and fill their fuel cell cars with hydrogen in minutes, much as gasoline vehicles are filled today. As shown in Figure 1, California leads the nation with 27 open retail hydrogen fueling stations as of April 10, 2017, 22 stations in various stages of development, and 16 more recently awarded. California has plans for at least 100 stations within five years. Air Liquide plans an initial network of 12 hydrogen stations to support FCEV deployment in the northeastern United States and has announced locations for six sites in Connecticut, Massachusetts, and New York. Japan, Germany, Korea, the United Kingdom, and Scandinavian countries are also building out networks of hydrogen stations for consumer use within the next 3–5 years.

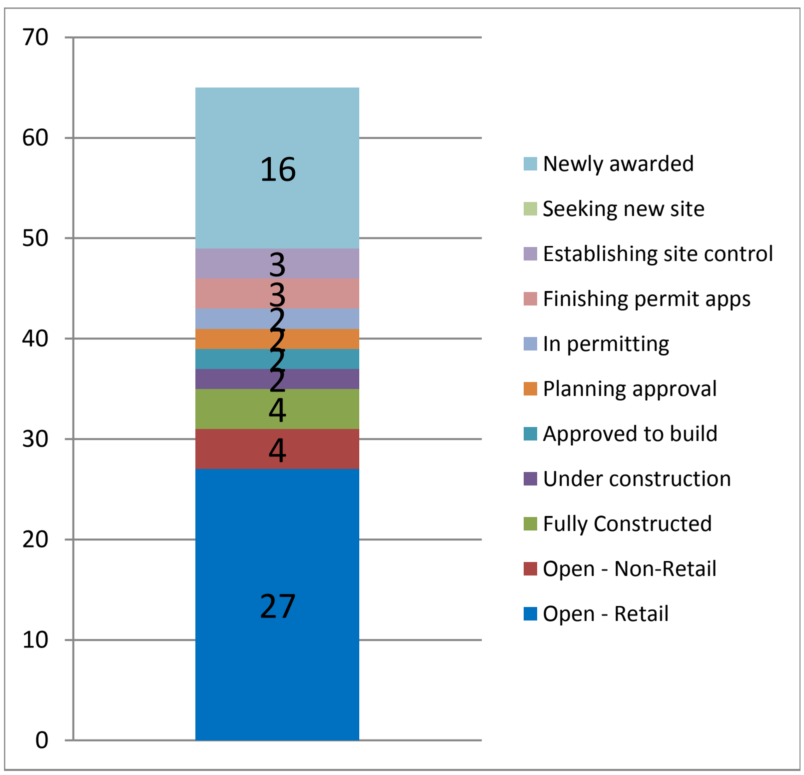


Figure 1. Status of California hydrogen stations, April 2017

Hydrogen stations undergo normal development review and approval processes at the local level, requiring planning, building and fire approvals during the design and construction process. For the most part, communities have embraced these advanced technology, zero-emission fueling stations. While business models vary, in California most stations have been integrated into existing gasoline stations, with developers leasing property from the land or business owner or business operator. Station technology will continue to evolve. Based on annual surveys of automaker plans, CARB projects 13,500 fuel cell electric vehicles by 2019 and 43,600 by 2022. While FCEVs are still in the early commercialization phase, the hydrogen station network will need to expand rapidly to meet growing demand (see Figure 2).

(a) (b)

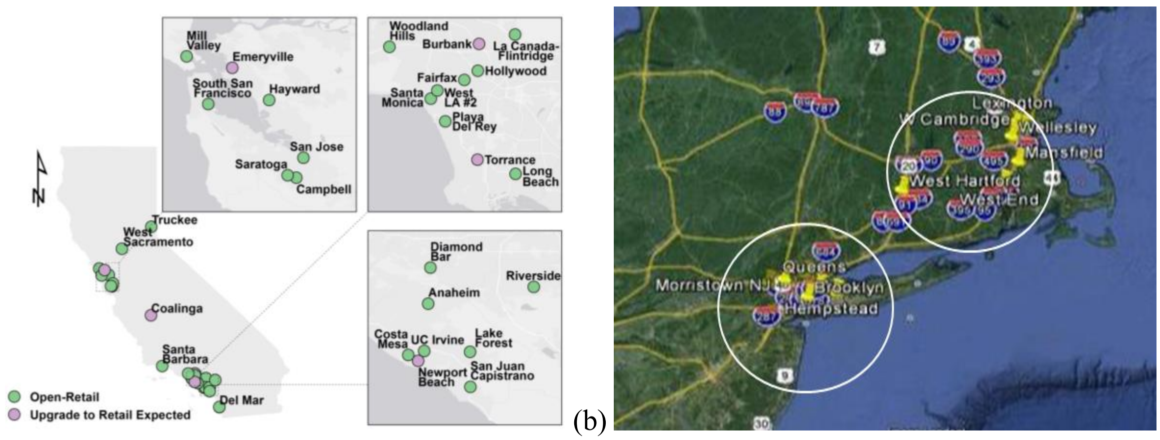


Figure 2. (a) Current status of open stations in California's Hydrogen Fueling Network. (b) Focus areas for the Northeast Network.

Overview of Hydrogen Station Technology

Currently, all hydrogen stations dispense gaseous hydrogen, typically at both 35 MPa and 70 MPa (5,000 psi and 10,000 psi). What varies is how that hydrogen gets to the station, whether delivered or made on site. Delivered hydrogen is shipped either as compressed gas in a tube trailer or as cryogenic liquid in a tanker truck from a centralized production plant. Hydrogen produced onsite is by electrolysis (electric power separating hydrogen from water) or steam methane reforming of natural gas or biogas. There is also a limited hydrogen pipeline network in southern California and in the Gulf Coast area, which is a third method for hydrogen delivery where it exists.

Most of the retail hydrogen stations operating today in California have hydrogen delivered to the station as a liquid or gas, as depicted in Figure 3. Placards and other markings are required on bulk shipments of either gas or liquid to help first responders recognize the material and respond appropriately in the event of an emergency. If hydrogen is delivered in the form of liquid, it is stored in cold cryogenic liquid storage vessels, vaporized to gas at the station, then compressed and stored for dispensing to vehicles.

LH2–Liquid hydrogen

Figure 3. Delivered hydrogen station (liquid delivery example)

The station shown in Figure 4 produces hydrogen from natural gas via steam methane reforming using equipment housed in the enclosure pictured below. Hydrogen sensors and leak detectors are located throughout the station as a safety feature.

Figure 4. Onsite hydrogen generation by reforming natural gas

A unique station at the AC Transit facility in Emeryville, California, shown in Figure 5, includes hydrogen dispensing for passenger vehicles and buses using separate dispensers located on opposite sides of a wall that separates the bus yard from the city street. Passenger vehicles receive hydrogen produced by an electrolyzer that separates hydrogen from water using renewable energy (the solar panel pictured with the bus), while the buses receive hydrogen delivered and stored as a liquid.

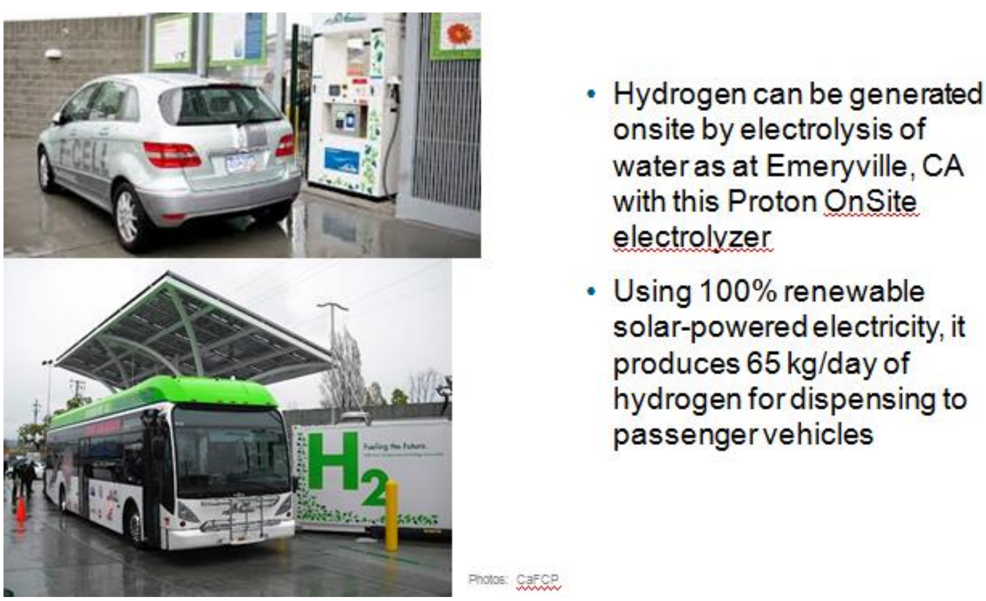


Figure 5. Onsite hydrogen generation by electrolysis at Emeryville, California, station

Regardless of whether it is delivered or produced onsite, all stations will store a bulk supply of hydrogen. If that supply is liquid hydrogen, it will be vaporized to a gas before compression and storage at high pressure for dispensing to the vehicle. Because of variables related to station location, and compliance with varying local fire and building codes, not every station utilizes the same equipment. Station layout is challenging if liquid hydrogen is the bulk storage medium, as the current separation distance requirements are prohibitive for stations with small footprints. Presently, the technical codes and standards committees and the research community are collaborating to generate data which may allow for the modification of separation distance requirements in the code, in an effort to allow for more stations to utilize bulk liquid hydrogen storage (i.e., larger capacity stations that can serve more vehicles) and to enable the development of smaller sites as hydrogen fueling stations.

Figure 6, from ISO 19880-1 (2015), "Gaseous hydrogen-fueling stations," illustrates the key components of the fueling station dispenser, including the FCEV compressed hydrogen storage system (CHSS), which includes sensors for temperature and pressure as well as for hydrogen leaks, and the thermally activated pressure relief devices, which protect the storage tanks against overpressure due to an external fire.

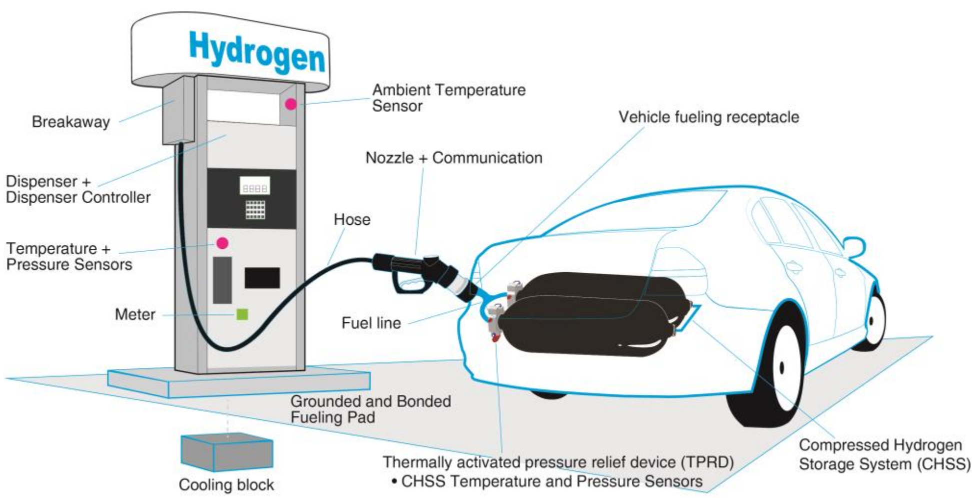


Figure 6. Hydrogen fueling diagram (courtesy of ISO) illustrating key components of a hydrogen fuel dispenser

Hydrogen fuel dispensing is currently offered at two pressures: 35 MPa or 70 MPa, which equals approximately 5,000 psi or 10,000 psi. The newest models of light-duty passenger vehicles have 70 MPa fuel storage systems. A 70 MPa-capable vehicle may be fueled from a 35 MPa dispenser if desired, but a 35 MPa vehicle may not be fueled from a 70 MPa dispenser. Buses, other medium- and heavy-duty applications, and industrial trucks typically use 35 MPa. Industrial truck fueling and bus fueling are done at private, non-publically accessible fueling locations such as a warehouse or bus fleet yard. Hydrogen fuel cell powered forklifts are now commercial, as shown in Figure 7, using 35 MPa storage pressures.

Hydrogen stations dispense fuel into vehicles according to industry standard fueling protocols such as SAE J2601 for light-duty vehicles and SAE J2601/2 for transit buses. Fueling protocols are confirmed using test procedures published in CSA Group hydrogen gaseous vehicle (CSA HGV) 4.3 utilizing a test device such as the Hydrogen Station Equipment Performance (HyStEP) device, which was developed by DOE and Sandia National Laboratories with multiple industry and government partners. Data from HyStEP is used to confirm that a dispenser delivers hydrogen within the pressure and temperature requirements of SAE J2601.

Figure 7. Hydrogen fueling for material handling equipment

Safety Plans and Accident Prevention for Hydrogen Stations

Similar to gasoline stations, hydrogen stations are designed and built with multiple safety features that take into account the specific properties of hydrogen fuel. These typically include gas detection systems, rupture disks to prevent overpressure, pressure relief devices, redundant and repetitive valve isolation throughout the system, emergency stops, a breakaway valve at the fueling hose, leak detection during fueling, flame detection, grounded concrete fueling pads, fueling logic, and fault testing during performance evaluation. As with all fueling stations, before plans are approved through the permitting process, station designs undergo a formal risk analysis to identify risks and evaluate failure modes and incorporate mitigation measures. Guidance for safety planning is available from the DOE H2Tools web portal.[2]

As with all fueling stations, hydrogen stations are required to adopt a fire safety plan and train their employees and operators on the proper emergency response and communication procedures. Per the International Fire Code (IFC)/California Fire Code (CFC), Section 2309.4, all fueling stations (gasoline, diesel, hydrogen, natural gas, etc.) must comply with Section 2311 and "the owner of a self-service hydrogen motor fuel-dispensing facility shall provide for the safe operation of the system through the institution of a fire safety plan submitted in accordance with Section 404, the training of employees and

---

[2] https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-March_2016.pdf

operators who use and maintain the system in accordance with Section 406, and provisions for hazard communication in accordance with Section 407."

Safety plans and training documents are generally provided to local officials as a part of the planning package. These must be regularly updated and offered for review upon request by an inspector. Should there be an incident involving injury or death, the Occupational Safety and Health Administration (OSHA) at the federal or state level will review procedures and determine if there were shortcomings such as poor preparedness, inadequate practice drills, or other issues.

Vehicle manufacturers, both on their own and through organizations like the CaFCP, have developed and contributed information to first responder training curriculum developed for hydrogen and fuel cell vehicles. The National Hydrogen and Fuel Cells Emergency Response Training Resource is the most recent example and is part of a larger safety resource located on the H2Tools portal.[3] Vehicle manufacturers develop emergency response guides for the specific vehicles, also available at H2Tools. NFPA has incorporated this information into its Alternative Fuel Vehicles Emergency Field Guide and Alternative Fuel Vehicle Safety Training Program.

SAE recently published J2990-1 Gaseous Hydrogen and Fuel Cell Vehicle First and Second Responder Recommended Practice. This document received input from the vehicle manufacturers and the first and second responder communities. A related area of effort among the vehicle manufacturers is to assure that fire and building codes accommodate repair facilities for hydrogen fuel cell vehicles. Vehicle manufacturers also provide their customers with tools and resources that enable them to get safety information, such as apps, toll free contact phone numbers, and specially trained personnel.

Incidents such as fires and fuel spills have become somewhat accepted and normal at gasoline stations (roughly 7,000 incidents per year in the United States). First responders are experienced in the tools, techniques, and procedures for responding to those incidents. As well, members of the community and the media generally accept that incidents occasionally occur. As a hydrogen station is a new type of installation and hydrogen is a fuel which, while its properties are well known, has not previously been offered at retail locations, first responders will have less experience to draw on in responding to any incident that might arise. Entities such as the CaFCP and DOE conduct regular training for first responders in communities with hydrogen stations and vehicles; yet, until these stations and vehicles become widespread, they will remain somewhat unfamiliar. The purpose of this document is to encourage information sharing as experience is gained in order to improve techniques and procedures as rapidly as possible and inform media with factual information regarding hydrogen. One example of the importance of sharing information is an incident that occurred at a hydrogen bus fueling facility on May 4, 2012.

[3] http://h2tools.org

Fuel Cell Transit Bus Fueling Station Case Study

A regional transit agency district has operated a hydrogen fuel cell bus program since 2000 and is currently operating 13 second-generation buses in regular fare service.[4] In 2011, the district built a state-of-the-art combined bus and light vehicle hydrogen fueling station to support the program, having already built and operated three previous hydrogen stations.

Incident Report

At approximately 7:45 am on May 4, 2012, an incident occurred at the station. A manufacturing defect in one of 18 pressure release valves (PRVs) installed with the storage system for the buses caused the device to fail under normal conditions with no over-pressure in the system. The hydrogen began rushing out under high pressure and mixed with air in the open atmosphere upon exiting the vent tube, leading to ignition of the gas plume with an audible "boom" sound, and subsequently a flame extending horizontally from the end of an orifice at the top of the stack. Emergency responders were immediately notified and the system was shut down by staff from the hydrogen supply company.

Responders from the fire department arrived approximately 10 minutes after the start of the incident, but due to unclear communication procedures, it took over an hour for the safety officials to receive better information about the condition of the station. Partly due to this delay, a one-block radius of the site was evacuated almost two hours after the initial incident, and then about an hour later (three hours total elapsed time), the incident was ended when hydrogen supply vendor personnel were allowed to enter the site to close an isolation valve on the leaking vent stack. Approximately 300 kg of hydrogen was ultimately released and flared. It is important to note that despite some confusion in the response to the incident, all involved safety systems performed as expected and the incident was routine in that sense.

Subsequent analysis by Sandia National Laboratories revealed that metal embrittlement (an issue with use of pure hydrogen) and the use of an improper grade of stainless steel alloy (440C) in the key inner subassembly of the PRV was the root cause of the incident, along with an apparent error with the device assembly.

Corrective Actions

In response to the incident, the following corrective actions were taken to improve emergency response procedures.

- A complete analysis was conducted of all site safety systems and procedures.
- All similar PRVs to the one that failed were replaced, and the vent stacks for some PRVs in the station were elevated further above canopy areas.
- Evacuation blow horns were added for an audible alarm system.
- Additional remote emergency shut downs were installed in the maintenance superintendent's offices in the nearby maintenance building and in the 24/7 Operations Control Center at the other end of the yard.
- The 18 pressure banks were isolated with additional valving to be divided into three banks of six vessels each rather than being entirely interconnected.
- Improvements were made to incident communications procedures (see below).

Key Lessons Learned

Advance training on the unique conditions of hydrogen storage systems for local first responders is of critical importance, especially for incident commanders and higher-level responder staff. In the above incident there was some confusion among responders about the difference between a liquid hydrogen storage system and liquefied natural gas, which have rather different properties.

Verification of specified equipment with full hazard and operability (HAZOP) and control management process assessment is needed to ensure that the correct materials and equipment are provided by all vendors and subcontractors.

Recurring (rather than one time) training drills are also of key importance to refresh knowledge and to capture staff turnover. Annual training drills around major fuel depot facilities would be appropriate, particularly for hydrogen until it becomes better known and understood in fuel dispensing applications.

Clear step-by-step guidelines for incident response and communications are needed. In the case of this incident, a full set of communication channels was not completely and clearly established, leading to some confusion during the event.

[4] Alameda-Contra Costa Transit, "The HyRoad," http://www.actransit.org/environment/the-hyroad/

Elements of Event Response

Event response involves six distinct phases as described in Figure 8. The goal of the immediate event response is to expeditiously activate the response team, conduct an initial diagnosis, and contain the event to minimize injury to people, operational interruptions, and property damage. Successfully executing these steps is first priority and an essential precursor to the subsequent diagnosis, resolution, and closing steps.

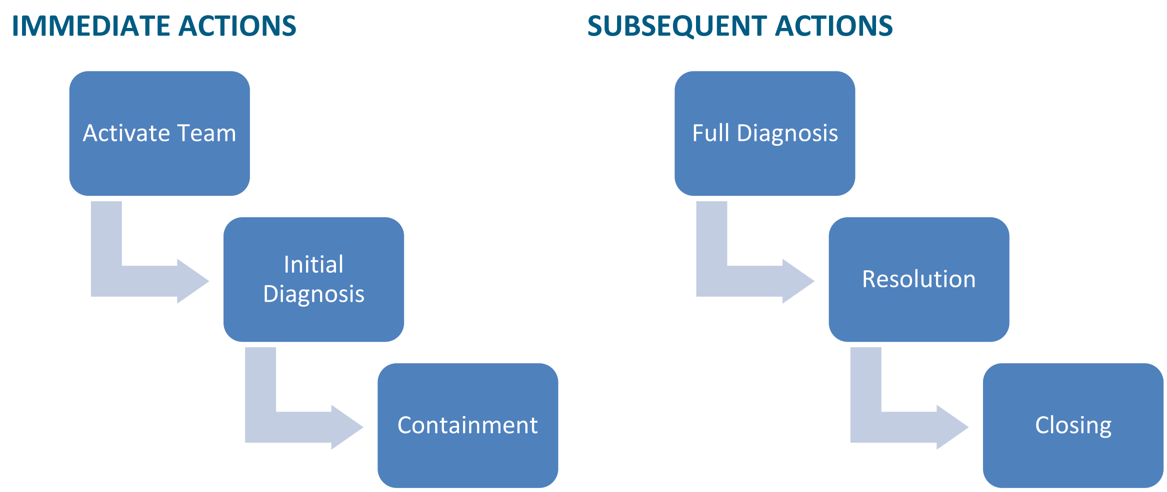


Figure 8. Phases of event response

The emergency response plan for each individual site, reviewed and approved as part of the permitting process, will govern the initial response and containment activities. The plan should clearly identify the members of the Incident Core Team, including the site operator, the station developer (if different than the operator), and the hydrogen supplier (if delivered), and designate the lead and alternate team leads who are responsible for activating the team. In the event of an incident involving hydrogen transport, the Incident Core Team must include any carrier or producer whose service or product is involved. For a transport operation, the responsibility for establishing an emergency response plan will lie with the transporter; and for a vehicle situation, first responders will need immediate access to information published by the vehicle original equipment manufacturer (OEM) regarding approaching and securing a damaged vehicle. Vehicle OEMs will also need to identify a contact point which will provide support for the full diagnosis and resolution phases of the response as needed. Table-top exercises to practice response to various scenarios are recommended and should include all of the stakeholders noted for each type of situation.

Especially during the initial phases of event response, clear and accurate information will support effective decision making and communication with authorities, stakeholders, and the public. During an event, emotions may run high and it is important to communicate "just the facts" of the situation to avoid misunderstandings. A key element of incident response plans is to ensure that first responders to any hydrogen production, storage, or dispensing site are specifically trained regarding the properties of and risks related to hydrogen and the proper techniques for handling an incident involving hydrogen. Responding parties should have ready access to information regarding hydrogen properties, risks, and response techniques to accompany clear and concise statements of what is currently known about the specific incident. Media may get involved during this phase, and they should have access to basic facts regarding hydrogen and information regarding the specific incident, as available. Background information regarding the project and properties of hydrogen as a fuel should be included with incident response plans so it is available when needed.

Key goals of the diagnosis, resolution, and closing phases of an event are to ensure that a root cause analysis is performed; a permanent corrective action is taken for the specific site, vehicle, or issue; and lessons learned are documented, communicated, and applied to other sites if needed. A coordinated effort is needed to ensure that all stakeholders understand and are comfortable with the cause and corrective action for any incident. The Incident Core Team should identify the appropriate stakeholders and communication paths. Having a documented root cause analysis process and template for communicating findings developed in advance is critical to efficient investigation and communication. This is especially important at fueling sites so the site can reopen and resume operation as soon as possible.

Who is the Hydrogen Safety Panel?

The Hydrogen Safety Panel was formed in 2003 to address concerns about hydrogen as a safe and sustainable energy carrier. The HSP's principal goal is to promote the safe operation, handling, and use of hydrogen and hydrogen systems across all installations and applications. The core objectives of the HSP are to:

- Provide expertise and recommendations and assist with identifying safety-related technical gaps, best practices, and lessons learned, and
- Help ensure that safety planning and safety practices are incorporated into hydrogen projects.

The 14-member Panel has over 400 years of combined experience and is comprised of a cross section of expertise from the commercial, industrial, government, and academic sectors. Panel members participate in a variety of standards development organizations including NFPA, ASME, SAE and ISO. The members also contribute to peer-reviewed literature and trade magazines on hydrogen safety and present at national and international forums. The HSP has reviewed more than 285 projects covering vehicle fueling stations, auxiliary power, backup power, combined heat and power, industrial truck fueling, portable power, mobile applications, and R&D activities.

The Panel is a unique resource and can be a valuable asset for supporting the safe commercial rollout of fuel cell vehicles, stationary applications, and the supporting equipment and infrastructure. The HSP contributes to its objective by

- Participating in safety reviews,
- Reviewing project designs and safety plans,
- Participating in incident investigations, and
- Sharing safety knowledge and best practices.

The Panel's broad industry experience and interaction with a large portfolio of hydrogen and fuel cell projects puts it in a unique position to be an asset in responding to incidents. As part of a post-incident fact finding or investigation, the HSP's expertise on hydrogen hazards, hydrogen behavior, and equipment utilized for storage, dispensing, and use can help with analyzing data and postulating the event cause. The HSP can also be a resource for identifying potential equipment and process modifications to address safety and prevent event reoccurrence.

Potential Gaps and Recommended Actions

The subcommittee reviewed current practices and resources as described above and in Appendix A with a view toward how these practices will work in a retail hydrogen fuel environment, identifying potential gaps that, if filled, could support a more effective response and resolution of issues. Through a series of in depth discussions, the subcommittee identified four general recommendations along with specific actions that DOE and others could take to promote more effective response to hydrogen events in the retail fuel environment.

Recommendation #1: Maximize the Role of the Hydrogen Safety Panel

DOE should develop a strategic plan that positions the HSP as a trusted resource on hydrogen safety, invests in marketing to make the HSP more visible, and provides resources to enable the HSP to develop relationships with safety officials at the local, state, and national levels. While state and privately funded projects should budget for HSP involvement, federal funding should also be available to support projects with the goal of broadly advancing hydrogen FCEVs.

- The HSP can play several potential roles as illustrated in Figure 9.
- During project development, through launch, and during ongoing operations, the HSP can provide expert advice and safety resources to developers, operators, and local approving authorities on hydrogen safety, codes and standards, and best safety practices.
- After a safety related incident, the HSP can help facility operators, local and state agencies, and insurance companies understand and interpret event information and conduct an investigation.
- Once an investigation is complete, the HSP can advise on proposed facility and operations modifications.
- The HSP could conduct a post-event site visit to confirm the modifications have been implemented to achieve the desired effect.

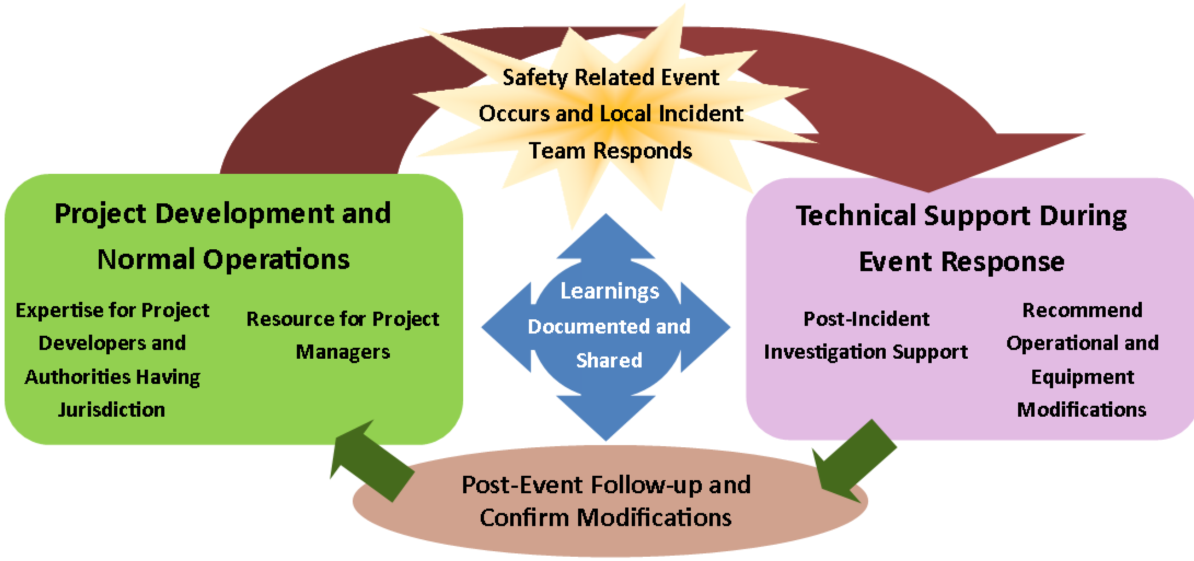


Figure 9. Potential support roles for Hydrogen Safety Panel within the cycle of normal operations and event response

See Appendix B for a more detailed incident response flow diagram that highlights the potential role of the DOE HSP.

Why is it valuable for the HSP to be involved in post-event investigations? There are a number of formal methods for performing investigations of a safety-related hydrogen event (NFPA 921, Center for Chemical Process [CCPS] guidelines, DOE accident investigation). However, facility owners may not use formal methods or may implement their own methodology. During the investigation, site owners and state hazardous materials organizations may be permitted onsite, but others may be restricted. Confidentiality and legal issues might also prevent involvement or delay a response. State fire marshal (SFM) offices are often involved in high visibility incidents, but they may not have specialized capabilities for investigating

Example of Interaction

Several HSP members participated in the investigation of a refueling station fire. After an inquiry by the station operator, arrangements were worked out with two individuals on the Panel who were not employees of the companies involved. The arrangements included separate confidentiality agreements with the station operator and refueling system equipment provider, and an understanding that labor and travel charges would be covered through normal Panel invoicing. The incident involved both a high pressure hydrogen release and ignition (both the hydrogen gas and flame were detected and alarmed), and a subsequent lubricating oil pool fire. There were no injuries. The hydrogen release, which was attributed to a failure of an electronic switch sensing high pressure hydrogen, occurred shortly after a vehicle had finished refueling and exited the station. The investigation was extremely thorough and included root cause determinations and recommendations to prevent future similar incidents and equipment component failures.

hydrogen. When an event occurs, the SFM offices could involve DOE's HSP members for their expertise as needed (e.g., to help understand the phenomenon and equipment involved). DOE's resources could also help a jurisdiction in reviewing a root cause analysis to see if it is appropriate and complete. These groups may not have specialized knowledge of hydrogen safety and materials compatibility, and DOE's resources could provide vital technical assistance, advice, and support.

DOE should include at least the following items into its strategic plan for the HSP.

1. Raising awareness of DOE resources: project developers, station owners, and state and local officials may not be aware of DOE resources such as H2Tools and the HSP. DOE's strategic plan should identify steps to communicate and market these resources to companies and communities. For example, DOE might gain visibility and develop SFM interest through outreach with the National Association of State Fire Marshals.
2. Establishing working relationships: to be effective, the HSP should establish and maintain strong relationships at the state and local levels. DOE's strategic plan should identify specific methods the HSP could use, such as entering into agreements (e.g., memoranda of understanding) with SFM offices that could include regular outreach, training, and safety information. Working with state officials may be the most successful path to involvement in hydrogen incidents as businesses may block participation for liability reasons. DOE could also explore the possibility of non-disclosure agreements to enable closer involvement in the early phases of discovery.
3. Paying for services: The HSP performs a public service to advance America's sustainable energy future and should be funded from the baseline operations budget. DOE's strategic plan should examine how the HSP can access state, local, and private funding to augment the baseline operations. For example, DOE could identify ways to encourage hydrogen projects, whether government or private funded, to include budget for engaging the Panel to review project plans and engage with the project during and after any safety-related event. DOE should recommend an appropriate level of project funding, e.g., percentage or flat amount.
4. Types of projects and events: the Hydrogen Safety Panel will add value to any retail or commercial hydrogen project and research projects that support developing commercial technologies. DOE's strategic plan should determine specific criteria for projects in which the HSP should be engaged with a focus on avoiding duplication of effort. For example, the HSP may not need to be involved in industrial projects or bulk hydrogen transportation. However, the HSP will add value to projects such as mobile fuelers, portable equipment, or any equipment with large volume fuel tanks.

The strategic plan should consider both near- and longer-term priorities and actions as the landscape in the hydrogen arena will change rapidly over the next 5–10 years.

Recommendation #2: Leverage the Capabilities of Public/Private Partnerships, Including Clean Cities Coalitions and Other Regional Partnerships

Because hydrogen is a new fuel for retail settings, some project developers and operators may have limited experience in developing safety plans, communicating with authorities having jurisdiction, practicing for event response, and responding to media inquiries regarding hydrogen. The broader stakeholder community can play an important role in supporting those who are new to the industry and communicating information to the media regarding hydrogen properties and safety.

In California, the CaFCP plays an important coordinating role for information exchange among the hydrogen stakeholder community. CaFCP is clearly the “go to” resource for information about all things related to hydrogen fuel and FCEVs, and CaFCP staff monitor media and blogs for emerging issues. CaFCP has trained media experts who can respond as appropriate to inquiries, directing media to those immediately involved and providing general information. They can act as a central point of contact for those not immediately involved to stay up to date on the latest developments and be prepared to get involved where appropriate. Other regional partnerships with similar capability include the CCAT and OFCC.

Local coalitions, including Clean Cities and regional partnerships, can get involved immediately or soon after an incident and gain knowledge of the situation through direct communication with entities involved. The local group with the benefit of local expert knowledge can then act as a third-party conduit to share hard facts to community officials, public, and media. The goal would be to provide factual and accurate information to counteract potential sensationalist coverage by media. Communications days or weeks after the incident may offer more detail (pressure, quantity of release, number of affected people, status of the station at the time of incident) and therefore may be of most value to the stakeholder community. Potential challenges include getting station owner and operator permission to access and release information and in what form, and questions about how the Freedom of Information Act may affect potential learning and liability.

DOE could take the following specific actions to further leverage partnerships to support hydrogen projects.

1. Engage Clean Cities Coalitions: DOE should encourage, and to the extent possible require, Clean Cities Coalitions to incorporate hydrogen information into their programs. Clean Cities Coalitions can be the eyes and ears of hydrogen within the communities where stations and vehicles operate, and can provide a central point of communication regarding hydrogen to local officials and project developers, as well as communicate facts about safety-related incidents should these occur. This would be especially important outside of California where there currently are no regional entities similar to the CaFCP.
2. Identify specific responsibilities: listed below are the types of responsibilities that Clean Cities or another partnership entity such as CaFCP could carry out.
    - Provide basic information about hydrogen as a vehicle fuel to local officials, the public, and media
    - Run periodic table-top exercises to practice communications in the event of a safety-related incident
    - In the event of a safety-related incident, activate the greater hydrogen community
    - Ensure a media response plan is activated successfully
    - Respond to general media inquiries as needed
    - Support responsible parties as needed

- Encourage filing event information into H2incidents.org
- Communicate learnings

3. Expand tiger teams to include hydrogen: for safety-related incidents involving other fuels, Clean Cities coordinators make a request to DOE to establish a tiger team. These teams are highly respected and trusted within the alternative fuel community and have been active in a number of incidents. At present, there is no routine process for identifying and establishing a tiger team for hydrogen. For example, a subgroup of HSP could function as a tiger team if it were formalized within the Clean Cities process.
4. Prepare others to take action: as part of the ongoing outreach to local coalitions, DOE can emphasize through training, resources, and examples the need for station emergency or incident response plans to include a core crisis team with names and phone numbers to activate the hydrogen community through a communication tree. A facility operator should be able to make one call to activate the greater community. Having this system in place up front, and exercised regularly through table-top drills, will make responding to an incident much more normal when it occurs.

What Can We Learn from Clean Cities and the Natural Gas Vehicle Community?

In the event of a safety incident involving a natural gas vehicle, Clean Cities Coordinators will hear about it through the natural gas technical team (NGVAmerica). Clean Cities coordinators will notify the National Renewable Energy Laboratory (NREL) of incidents or issues that may occur in their area. In these cases NREL will provide information to and support the coordinators so they can understand the incident more clearly and provide more constructive feedback to their coalition members. One recent example is an incident in New Jersey where attorneys initially blocked NREL's direct involvement. U.S. Department of Transportation National Highway Traffic Safety Administration (NHTSA) intervened and was able to make an allowance for NREL experts to see the truck along with NGVAmerica and the cylinder manufacturer. By having NREL's involvement, it assured that a report was developed and that valuable details were documented, including the vehicle involved.

Recommendation #3: Take Steps to Support Reopening Hydrogen Stations in a Timely Fashion after a Safety-Related Incident

The hydrogen bus fueling station featured in the incident case study above reopened on February 3, 2013, a full nine months after the hydrogen release on May 4, 2012. The investigation of root cause was completed in October 2012 and station modifications to address root cause were completed in early 2013. Internal processes within the agency added a number of months to the station reopening. This is significantly longer than the time it would take to reopen a gasoline station that experienced an unintentional release or fire.

Hydrogen stations should be able to recover and reopen from safety-related incidents on a timeline similar to gasoline stations. Meeting this goal will require that local officials and station operators understand the process that responsible parties will undertake to ensure the incident was properly investigated, the root cause was identified and fixed, and equipment and procedures were redesigned as needed to enable full recovery and safe reopening to the public.

DOE could take the following specific actions to support faster station recovery and reopening.

1. Develop a guidebook on incident recovery that the HSP can use during outreach and initial engagement with project developers and state and local officials. Such a guidebook should be user-friendly and intended to familiarize new audiences with hydrogen technology and safety, and to provide clear guidelines on recommended steps and actions for reopening a hydrogen station after a safety-related event. Clear guidelines would help assure those who are responsible for making a decision to reopen that root cause investigation, equipment and process redesign, and confirmation of safe operations are completed by qualified individuals. The guidebook should avoid a check-the-box approach but also should avoid putting forth too much detail on disaster response that may lead readers to overestimate risks.
2. Develop virtual training courses that demonstrate what first responders can expect during a hydrogen leak or fire at a fueling station. As these will be rare incidents, most first responders will never experience such events in person. If they do respond to an incident in their community, it may be so unfamiliar that they apply worst-case responses such as wide scale evacuations and media alerts that would unduly escalate the situation and reduce the opportunity for timely reopening of a station. Training could also be developed and provided by another agency, such as the International Association of Fire Fighters, with DOE guidance.

Recommendation #4: Identify and Support Other Federal and State Agencies that Need to Incorporate Hydrogen into Their Programs

Hydrogen fuel will eventually be as usual as gasoline fuel as states and the nation move toward low-carbon, zero-emission fuels. While DOE's program supports the research, development, demonstration, and early deployment of hydrogen technologies, other agencies will take on responsibilities as hydrogen technologies move into the commercial market. DOE and state agencies (such as CARB and CEC in California) that have expertise in hydrogen can be a resource to encourage and support other federal and state agencies that will need to incorporate hydrogen into their regular programs. For example, the Occupational Safety and Health Administration within the U.S. Department of Labor is responsible for assuring safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education, and assistance.

DOE could convene a government agency stakeholder group to identify government functions that will need to address hydrogen in their programs, and determine what support they may need to be successful. Some government agencies may already have a hydrogen program but may also have mainstream programs that will need to adapt to accommodate and recognize hydrogen vehicles and fuel. One example is the California Department of Food and Agriculture, Division of Measurement Standards, which has responsibility for enforcing fuel quality and certifying fuel meters. In preparation for FCEV commercial launch in California, they developed fuel quality and metrology programs specific to hydrogen with support from other state agencies such as CARB and CEC. Many more state and federal agencies will need to address hydrogen to enable broad commercialization of FCEVs nationwide. This process can help increase awareness and acceptance of hydrogen as a safe and normal vehicle fuel.

Conclusions

Although the use of hydrogen in industrial processes and facilities is routine with well-established safety and event response protocols, hydrogen as a retail fuel for light-duty vehicles is new and unfamiliar to station operators, vehicle drivers, and first responders. As the number of fueling stations and vehicles increases, more safety-related events and accidents may occur. Although we expect hydrogen station and vehicle incidents to be less frequent than gasoline-related incidents due to safety systems designed into hydrogen stations and vehicles, those who respond to an incident must have access to training, information, and support in addressing any hydrogen safety-related event that may occur.

As with other fuels, accurate and objective information on the risks and proper procedures for responding to an incident involving hydrogen fuel is critical to minimizing potential injury, damage, and disruption. Ready access to information and resources will facilitate effective and efficient investigation and resolution of hydrogen incidents, identification and implementation of corrective action, and reopening the station in a timely manner.

In support of these objectives, this report recommends the use of consistent experienced technical resources in developing incident response plans and a simple six-step incident response process implemented by a pre-identified response team. The report further offers four specific recommendations to encourage identification, training, and support for teams developing the necessary plans and for those responding to any hydrogen fuel related incident.

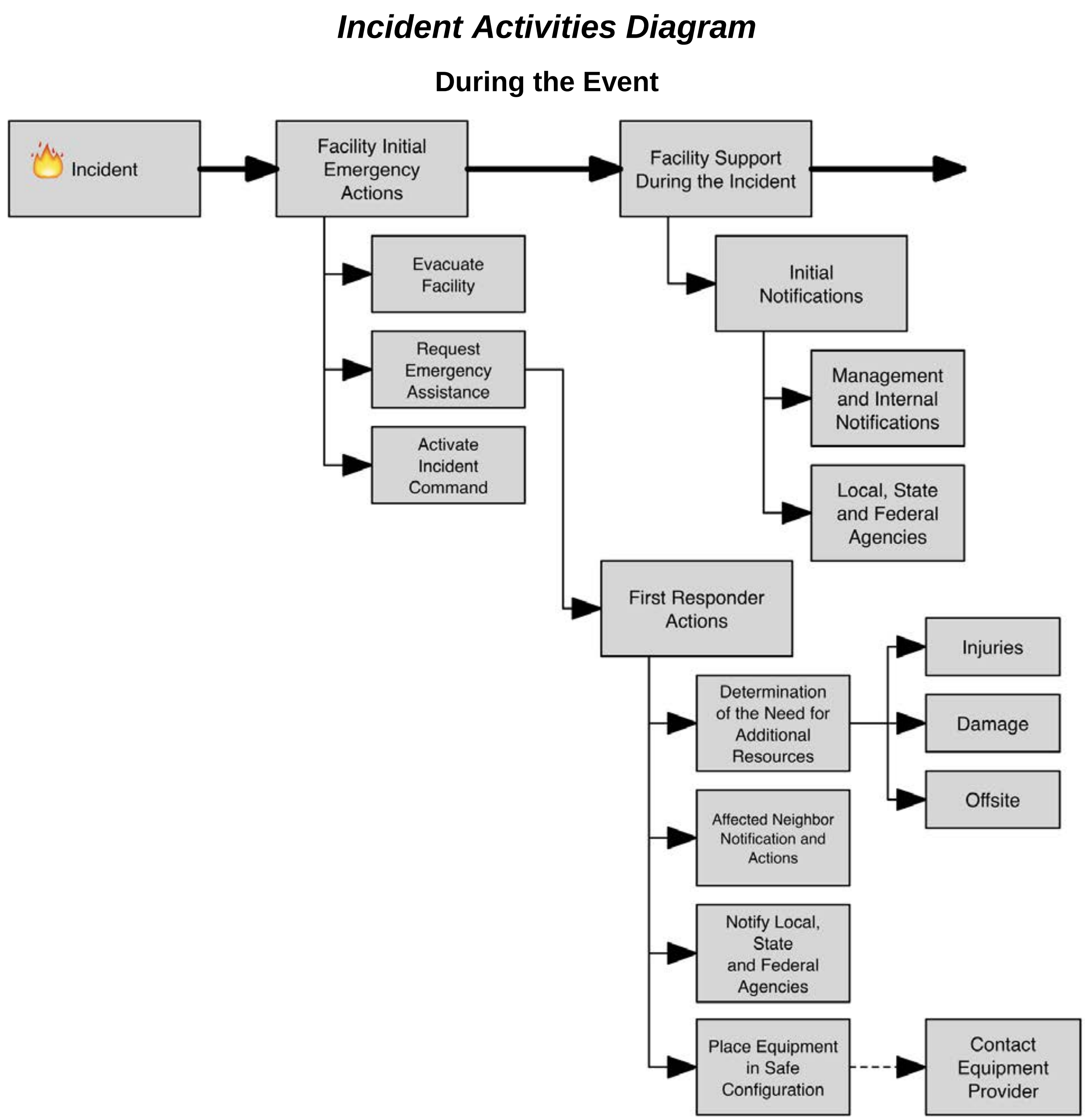
Appendix A. Existing Hydrogen and Fuel Cell Safety Electronic Resources

Notes: Resources such as NFPA 2/853, Air Products Safetygrams, and material safety data sheets are shown as examples, recognizing that other codes and standards organizations (e.g., Compressed Gas Association, International Code Council, SAE, CSA Group, ASME) and industrial gas suppliers also develop and provide similar resources.

DATABASES/WEBSITES (INCLUDING REGULATIONS, CODES AND STANDARDS)	
Hydrogen Tools Portal	http://h2tools.org
Hydrogen Incident Reporting and Lessons Learned Database	https://h2tools.org/lessons
Hydrogen Safety Bibliographic Database	https://h2tools.org/bibliography
Hydrogen/Fuel Cell Codes and Standards	https://h2tools.org/content/hydrogenfuel-cell-codes-standards
Hydrogen and Fuel Cell Safety	http://www.hydrogenandfuelcellsafety.info/
29 CFR 1910.103 Occupational Safety and Health Standards (Hydrogen)	https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9749
Storage and Handling of Gaseous and Liquefied Hydrogen	http://www.michigan.gov/lara/0,4601,7-154-35299_42271_4115_4237-193832--,00.html
International Fire Code & International Building Code	http://www.iccsafe.org/Pages/default.aspx
NFPA 1: Fire Code	http://www.nfpa.org/1
NFPA 2: Hydrogen Technologies Code	http://www.nfpa.org/2
NFPA 853: Standard for the Installation of Stationary Fuel Cell Power Systems	http://www.nfpa.org/853
MANUALS	
Hydrogen Safety Best Practices	https://h2tools.org/bestpractices
Technical Reference for Hydrogen Compatibility of Materials	https://h2tools.org/tech-ref/technical-reference-for-hydrogen-compatibility-of-materials
ANSI/AIAA G-095 - Guide to Safety of Hydrogen and Hydrogen Systems	http://www.aiaa.org/StandardsDetail.aspx?id=3864
ISO/TR 15916 - Basic Considerations for the Safety of Hydrogen Systems	http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=56546
FM Global Property Loss Prevention Data Sheets	http://www.fmglobal.com/research-and-resources/fm-global-data-sheets
FLIERS, POSTERS, NEWSLETTERS, REPORTS, APPS, OTHER LITERATURE	
H2 Safety Snapshot	http://energy.gov/eere/fuelcells/h2-safety-snapshot-newsletter
Hydrogen Safety Tips for First Responders	http://www.dhses.ny.gov/ofpc/publications/documents/HydrogenPoster_v15.pdf

FLIERS, POSTERS, NEWSLETTERS, REPORTS, APPS, OTHER LITERATURE cont.	
Fact Sheet on Hydrogen Safety (FCHEA)	http://fchea.org/core/import/PDFs/factsheets/Hydrogen%20Safety_NEW.pdf
Hydrogen Safety Fact Sheet (NHA)	http://www.arhab.org/pdfs/h2_safety_fsheet.pdf
National Template: Hydrogen Vehicle and Infrastructure Codes and Standards	http://www.afdc.energy.gov/pdfs/48609.pdf
National Permit Guide for Hydrogen Fueling Stations	https://h2tools.org/file/motor-fueling-station-permit-guide-final-march2016_1pdf
Hydrogen Vehicle and Infrastructure Codes and Standards Citations	http://www.afdc.energy.gov/pdfs/48608.pdf
Regulations, Codes, and Standards Template for California Hydrogen Dispensing Stations	http://www.nrel.gov/docs/fy13osti/56223.pdf
Reaching the U.S. Fire Service with Hydrogen Safety Information: A Roadmap	http://www.nfpa.org/~/media/Files/Research/Research%20Foundation/Research%20Foundation%20reports/For%20emergency%20responders/report%20final%20h2fs.pdf
Safetygrams	http://www.airproducts.com/company/Sustainability/environment-health-and-safety/product-safety-safetygrams.aspx
Materials Safety Data Sheet for Gaseous Hydrogen	http://www.praxair.com/-/media/documents/sds/hydrogen/hydrogen-gas-h2-safety-data-sheet-sds-p4604.pdf?la=en
Materials Safety Data Sheets for Liquefied Hydrogen	http://www.praxair.com/-/media/documents/sds/hydrogen/liquid-hydrogen-gas-h2-safety-data-sheet-sds-p4603.pdf?la=en
TRAINING	
Introduction to Hydrogen Safety for First Responders	https://h2tools.org/content/training-materials
Introduction to Hydrogen for Code Officials	https://h2tools.org/content/training-materials
Hydrogen Safety Training for Researchers	https://h2tools.org/content/training-materials
IAFF HazMat/WMD Training	http://www.iaff.org/et/HW/index.htm
PROPERTIES, CALCULATORS	
Basic Hydrogen Properties	https://h2tools.org/tools
Hydrogen Conversions Calculator	https://h2tools.org/tools

Appendix B. Detailed Incident Response Flow Diagram



Suggested DOE Incident Communications Diagram

Post Event