U.S. DEPARTMENT OF ENERGY

Response to Findings and Recommendations of the Hydrogen and Fuel Cell Technical Advisory Committee during Fiscal Years 2016 and 2017

Sixth Biennial Report to Congress
September 2018

United States Department of Energy
Washington, DC 20585

Message from the Secretary

This is the Department of Energy's sixth biennial report to Congress, provided in response to the Energy Policy Act of 2005 ("EPACT 2005").[1] EPACT 2005 established the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) to advise the Department of Energy on programs and activities under EPACT 2005 Title VIII, *Hydrogen*.

EPACT 2005 states that HTAC is to review and make recommendations to the Secretary on:

1. The implementation of programs and activities under Title VIII of EPACT 2005;
2. The safety, economical, and environmental consequences of technologies for the production, distribution, delivery, storage or use of hydrogen energy and fuel cells; and,
3. The plan called for by section 804 of EPACT 2005, known as the *DOE Hydrogen and Fuel Cells Program Plan* (formerly the *Hydrogen Posture Plan*).

Section 807 also requires the Department of Energy to transmit a biennial report to Congress that responds to recommendations made by HTAC since the previous report. This document, *Response to Findings and Recommendations of the Hydrogen and Fuel Cell Technical Advisory Committee: Sixth Biennial Report to Congress*, is the Department of Energy's official response to recommendations made by HTAC during fiscal years 2016 and 2017.

This report is being provided to the following Members of Congress:

- **The Honorable Greg Walden**
  Chairman, House Committee on Energy and Commerce
- **The Honorable Frank Pallone, Jr.**
  Ranking Member, House Committee on Energy and Commerce
- **The Honorable Lisa Murkowski**
  Chairman, Senate Committee on Energy and Natural Resources
- **The Honorable Maria Cantwell**
  Ranking Member, Senate Committee on Energy and Natural Resources

[1] Specifically, section 807(d)(2) of the Energy Policy Act of 2005, P.L. 109-58, August 8, 2005.

If you have any questions or need additional information, please contact me or Mr. Dwayne Bolton, Deputy Assistant Secretary for House Affairs, or Mr. Shawn Affolter, Deputy Assistant Secretary for Senate Affairs, Office of Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Rick Perry

Rick Perry

Executive Summary

The Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) was established under the Energy Policy Act of 2005 ("EPACT 2005"), P.L. 109-58, August 8, 2005, to advise the Secretary on programs and activities under EPACT 2005 Title VIII, Hydrogen. Section 807 requires HTAC to review and make recommendations to the Secretary on:

1. The implementation of programs and activities under Title VIII of EPACT 2005;

2. The safety, economic, and environmental consequences of technologies for the production, distribution, delivery, storage, or use of hydrogen energy and fuel cells; and,

3. The plan called for by section 804 of EPACT, also known as the *DOE Hydrogen and Fuel Cells Program Plan* (*Program Plan*, formerly the *Hydrogen Posture Plan*).

In this report, DOE is responding to section 807(d)(2) of EPACT 2005, which requires that:

> *The Secretary shall transmit a biennial report to Congress describing any recommendations made by the Technical Advisory Committee since the previous report. The report shall include a description of how the Secretary has implemented or plans to implement the recommendations, or an explanation of the reasons that a recommendation will not be implemented.*

The body of this report consists of 10 recommendations made by HTAC since the previous biennial report. These recommendations were delivered through two subcommittee reports, "Advanced Manufacturing Status and Opportunities to Accelerate Growth in Fuel Cell and Hydrogen Products" (January 2015) and "Hydrogen Safety and Event Response" (May 2017), and two annual state-of-the-industry reports in August 2016 and June 2017 and their accompanying letters to the Secretary of Energy. These documents are provided in the appendices to this report.

The recommendations in HTAC's 2015 and 2016 Annual Reports and cover letters focused on addressing the major challenges remaining to achieve the goals of Title VIII of the Energy Policy Act of 2005,[2] particularly those challenges related to establishing fuel cell electric vehicles and fueling infrastructure as a viable and affordable option for the mass consumer market by 2020. The recommendations called on DOE to define an explicit plan for achieving the 2020 Title VIII goals and highlighted the importance of public-private partnerships, lowering technology costs through manufacturing scale economies, and providing stable policy support and funding levels.

[2] Specifically, section 805(f) (1) and (2) of the Energy Policy Act of 2005, P.L. 109-58, August 8, 2005.

The "Hydrogen Safety and Event Response" subcommittee report assessed the current status of hydrogen safety and event response resources and practices and provided recommendations to address gaps and ensure a comprehensive, consistent, and coordinated response to hydrogen safety-related events. Recommendations included maximizing the role of the Hydrogen Safety Panel, leveraging the capabilities of public-private partnerships, timely reopening of hydrogen stations, and identifying and supporting other Federal and state agencies as they incorporate hydrogen into their programs.

This report to Congress presents these recommendations based on the source material (see Appendices), followed by DOE's responses.

RESPONSE TO FINDINGS AND RECOMMENDATIONS OF THE HYDROGEN AND FUEL CELL TECHNICAL ADVISORY COMMITTEE DURING FISCAL YEARS 2016 AND 2017

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I. Legislative Language

The Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) was established under the Energy Policy Act of 2005 ("EPACT 2005"), P.L. 109-58, August 8, 2005, to advise the Secretary on programs and activities under EPACT 2005 Title VIII, Hydrogen. Section 807 requires HTAC to review and make recommendations to the Secretary on:

1. The implementation of programs and activities under Title VIII of EPACT 2005;

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II. Recommendations from HTAC's 2015 and 2016 Annual Report and Cover Letter

Recommendation

> *"**DOE support is critical to ensuring positive retail hydrogen fueling experience.** To successfully achieve Title VIII goals, customers must experience positive retail hydrogen fueling experiences, in California and other early markets. This challenge requires DOE support through public-private collaborations like H2USA and complementary DOE projects like H2FIRST. These initiatives fulfill critical roles in helping to validate station performance, assuring station reliability, verifying hydrogen purity, and establishing accurate metering."*

Response

The Department agrees that the deployment of hydrogen refueling infrastructure continues to be a challenge. As a result, the Department established an infrastructure strategy that focuses on three key research and development (R&D) areas:

1. Hydrogen fueling station cost reduction
2. Improved fueling station reliability
3. Hydrogen safety to facilitate fueling station rollout

Within these three areas, the Department conducts a number of activities such as component and systems R&D, contaminant detection and hydrogen sensor development, and hydrogen release R&D. Examples of significant achievements through the Department's efforts include:

- Lowering the cost of hydrogen delivery and dispensing by about 50 percent since 2005.
- Decreasing the hydrogen storage setback distances at fueling locations by 50 percent, which reduces the cost for land at fueling stations and increases the number of gasoline stations where a hydrogen fueling station can be located.
- Awarding the $1 million H2Refuel Prize for the development of a small-scale/home refueling appliance, which can provide a 1-kilogram fill to vehicles in 15 minutes or less at 700 bar pressure.

In addition, the Department has collaborated across Federal agencies and with external partnerships to leverage the knowledge and capabilities of those entities. These collaborations have resulted in improved hydrogen metering codes and the testing and characterization of hydrogen interaction with materials such as composites, metals, and polymers. For example, DOE collaborated with the National Institute for Standards and Technology (NIST) to modify the standard for hydrogen metering accuracy. The previous standard was unachievable with current technology; however, as a result of collaboration between the National Renewable Energy Laboratory (NREL) and NIST and through support by the State of California, a modified hydrogen metrology standard of 5% was accepted in FY 2017, which enables hydrogen to be commercially sold as a retail fuel. In addition, the Department's Hydrogen and Fuel Cells Program (the Program) has an ongoing project to improve the accuracy of state of the art mass flow meters.

DOE's $10 million investment in the H2FIRST (Hydrogen Fueling Infrastructure Research and Station Technology) R&D project has helped to jump-start the development of technologies and collaborative activities to address challenges with hydrogen infrastructure. Current tasks within the H2FIRST project include quantitative risk analysis and evaluation of station performance and reliability with different component configurations and fueling methods to help guide potential future early stage R&D.

In 2017, the Department's Hydrogen and Fuel Cells Program further enhanced collaborations with public and private stakeholders on hydrogen infrastructure research through selections from NREL's call for Cooperative Research and Development Agreement (CRADA) projects. Thirteen projects were selected in the areas of hydrogen fueling components.

It is important to note that the Department does not fund hydrogen retail stations but leverages state and private sector funding to gather and analyze data to identify critical R&D focus areas. This R&D focuses on high impact and high risk projects, as well as early stage R&D that industry typically does not pursue on its own without government cost share.

Recommendation

> ***"Securing industry commitments to high volume manufacturing requires clear and stable policy.***
> *The vehicle and refueling infrastructure investments are capital intensive and require a predictable environment, with a pathway to positive long-term economic returns. Commitments in line with those for battery electric vehicles (BEVs) would send a clear signal of that promise."*

Response

The Department continues to support a broad portfolio of energy research and development which includes hydrogen and fuel cell technologies. All technologies, whether BEVs or fuel cell electric vehicles (FCEVs) must ultimately be cost competitive with incumbent/current technologies without subsidies for them to achieve widespread and sustained market acceptance. The Department intends to issue a Request for Information to identify potential regulatory barriers or policies that may hinder increased deployment of FCEVs and infrastructure. In line with the President's 2018 budget request, the Hydrogen and Fuel Cells Program is focusing resources on early-stage research and will continue to focus R&D resources on high-impact hydrogen and fuel cell technologies, and will coordinate and collaborate with industry, state government, and other Federal agencies and offices to address technical and market challenges.

Recommendation

> ***"Extending the federal FCEV tax credit is an essential enabler for promoting fuel cell commercialization and achieving Title VIII goals.***
> *Exacerbating the challenges above is the fact that the FCEV tax credit is scheduled to expire in 2016. Any interruption of the tax credit will negatively impact FCEV deployments."*

Response

While the Department does not set Federal tax incentives, we will continue to provide information related to these or other policies, as requested by our colleagues in the legislative branch. The Program will continue to fund high-impact R&D in support of its mission to enable technologies to be competitive in the long term without subsidies.

Recommendation

> ***"Additional funding is required to achieve 2020 Title VIII goals.***
> *Although budgets have stabilized, and the DOE Program has been extremely effective given budget constraints, it is clear that more funding is required to achieve 2020 Title VIII goals. A well vetted comprehensive plan would serve as a foundation to support incremental funding requests that will help achieve those goals."*
> *"The U.S. has led the world in developing fuel and hydrogen technologies, but our leadership position is now potentially at risk. Most commercial advances in areas of FCEVs, stationary power, and hydrogen technologies are now from outside the U.S. creating a growing gap in leadership and competitiveness. The importance of federal support in these areas cannot be understated."*

Response

The Hydrogen and Fuel Cells Program continues to focus budget requests on critical early-stage R&D, especially for hydrogen fuel production and durable, low-cost fuel cells. The Fuel Cell R&D subprogram focuses on early-stage fuel cell component R&D with potential for transportation and cross-cutting applications, while the Hydrogen Fuel R&D subprogram's efforts emphasizes materials research and early-stage component and process development to enable industry to develop and deploy novel hydrogen production, delivery, and storage technologies capable of utilizing diverse domestic energy resources. As the most effective and appropriate role for government, funding focuses on transformative science and technology solutions that industry either does not have the technical capacity to undertake or is too far from market realization to merit sufficient industry focus and critical mass. The Department will continue to work with the private sector to leverage research and transition early stage research to commercial application.

The highlights in FY 2018 will be National Laboratory-led efforts, offering state-of-the-art multi-lab core capabilities that leverage university and industry partners to dramatically accelerate materials breakthroughs and innovations. These efforts are aligned with the DOE's Energy Materials Network (EMN) which serves as an effective model for organizing national lab capabilities around specific technology challenges with potential to increase industry engagement. The three hydrogen and fuel cells consortia are ElectroCat for PGM-free catalysts, HydroGEN for advanced water-splitting, and HyMARC for hydrogen storage materials research. By using both computational and high-throughput combinatorial techniques to identify promising technologies, we will accelerate materials discovery and development to tackle some of the toughest hydrogen and fuel cell technology and materials challenges head on.

In addition, the program's focus will include early-stage R&D activities to support the H2@Scale concept, which lays a framework for the potential wide-scale production and utilization of hydrogen to address key issues such as grid resiliency and energy security. The Department will invest in fundamental and transformational materials R&D to enable industry to develop and deploy viable and safe technologies, including advanced liquefaction and delivery technologies.

The Department continues to revise and update key planning documents including the Hydrogen and Fuel Cells Program Plan, which will include input from across DOE offices since hydrogen is an energy carrier that can unite all domestic energy research – natural gas, coal, nuclear, and renewables. The next revision will be conducted in 2018. In addition, detailed multi-year R&D plans from relevant offices (e.g., FCTO's Multi-Year RD&D Plan, FE's Hydrogen from Coal RD&D Plan, and SC's Basic Research Needs for the Hydrogen Economy) will also be updated as needed.

Basic and early-stage applied research are critical components of the American research enterprise and the basis of new technological development and commercialization. However, in the development of high-payoff technology, early-stage research often involves greater uncertainty and may not provide the economic incentive needed to attract private sector investment. Therefore, DOE gives priority to funding basic and early-stage applied research that, supplemented by private sector financing of later-stage R&D, can result in the development of transformative commercial products and services. Strong partnerships with the private sector will be critical to maximizing the efficacy of Federal funding.

Recommendation

> ***"Clean Cities program emphasis must actively promote and educate consumers on FCEV technology.***
> *Since 1993, The U.S. Department of Energy's Vehicle Technologies Office has funded local Clean Cities coalitions, with the goal of eliminate 2.5 billion gallons of petroleum consumption, by 2020. To date, hydrogen FCEV's comprise less than 0.01% of all alternative fuel or advance technology vehicles, according to the 2014 Clean Cities Annual Metrics Report. As FCEVs are commercialized in higher numbers, the Clean Cities emphasis must actively promote and educate consumers on the technology. Furthermore, the Clean Cities program must be updated, to extract available synergies with EPACT Title VIII, while minimizing NOx and VOC vehicle emission."*

Response

The Department's Alternative Fuels Data Center (AFDC) contains extensive information about hydrogen fuel and FCEVs as part of a consumer resource supporting the use of alternative fuels for transportation. The AFDC website provides data and tools for use by consumers, fleet operators, and other transportation decision makers. Given the focus on early stage R&D, the Department is not requesting additional funds for the Clean Cities Program. However, FCEVs are being actively promoted through mechanisms such as Clean Cities Coalitions, state agencies, the California Fuel Cell Partnership, H2USA, and other partnerships without DOE funding.

Recommendation

> ***"The Committee reasserts that the U.S. is still not on track to meet the 2020 EPACT Title VIII goals for FCEVs.***
> *Evidence shows that even the 2015 Title VIII have still only partially been met, and only in California where state zero emission vehicle mandates (with favorable "travel provisions" that are well aligned with the Title VIII goals) exist. DOE support is critical to continue efforts in material and process integration and technology acceleration in order to meet the 2020 goals. Rapid learning cycles and manufacturing scale economies are essential prerequisites to overcome challenges in reducing costs to competitive levels. "The Department should provide an explicit plan in 2017-2018, including measurable milestones, stating how the 2015 and 2020 Title VIII goals will be achieved and how the plan will be funded."*

Response

While progress has been substantial and DOE's efforts are currently on track to meet key technology-readiness targets, DOE's developmental timeline for hydrogen and fuel cell technologies was not intended to meet the specific deployment goals specified in EPACT. While DOE has already achieved cost reductions necessary to enable hydrogen to be produced from natural gas on a cost-competitive basis and is on track to enable widespread availability of hydrogen from renewable resources, the ultimate decision rests with industry whether to deploy these technologies and produce sufficient hydrogen for the commercial rollout of FCEVs. The Department continues to focus on early stage R&D, particularly through its lab-led consortia, to address technical challenges, including the three hydrogen and fuel cell related consortia that are part of DOE's Energy Materials Network (HydroGEN, ElectroCAT, and HyMARC).

DOE has put into place a number of activities and resources that address hydrogen and fuel cell competitiveness and demand. For example, H2@Scale is exploring opportunities that could increase U.S. demand for hydrogen across multiple sectors, including the potential for bundling demand to supply regionally based industry, transportation, and power generation needs. The recent call for CRADA projects has resulted in the selection of 25 Industry-national laboratory partnership projects focused on H2@Scale. Rather than directly funding demonstrations of stations and vehicles, the Program is conducting a rigorous assessment of the challenges and needs involved in developing a hydrogen infrastructure—both from an R&D and business-case perspective. This includes resources such as H2FAST, a financial analysis tool that can model individual hydrogen stations or groups of stations. The program has also built on its success in catalyzing early market applications, with new projects focused on fuel cell range extenders for battery-powered parcel delivery vans, airport ground support equipment, and marine applications.

Other activities have focused on building and strengthening the U.S. supply chain and manufacturing competitiveness, including:

- A Request for Information published in 2016 to identify components for manufacturing standardization;
- Working with the Ohio Fuel Cell Coalition to establish regional technical exchange centers and organize national standardization efforts;
- Partnering with the Virginia Clean Cities Coalition to develop the HFC Nexus website, which includes a database on more than 350 companies that offer hydrogen and fuel cell components and products; and
- Funding and publishing an analysis of the global fuel cell and hydrogen supply chain to determine opportunities for U.S. competition and expansion, as well as a report identifying manufacturing cost reduction opportunities for five key fuel cell components (bipolar plates, membranes, gas diffusion layers, catalysts, and hydrogen storage vessels).

DOE is also funding targeted R&D on key hydrogen and fuel cell manufacturing challenges, through funding opportunity announcements issued by the Department's Fuel Cell Technologies Office within the Office of Energy Efficiency and Renewable Energy. Specific activities include rolled goods quality control, low-cost methods for manufacturing fiber-reinforced composite pipeline, and modeling of the effect of defects on fuel cell material performance. The program is also coordinating with DOE's Advanced Manufacturing Office to identify opportunities for advanced manufacturing in the production of hydrogen and fuel cell components in areas such as wide bandgap semiconductor materials, additive manufacturing, roll-to-roll manufacturing, and advanced composite materials and manufacturing.

As stated in an earlier response within this report, the Department continues to revise and update key planning documents including the Hydrogen and Fuel Cells Program Plan. The plan currently under revision will include measurable milestones, stating areas required to achieve Title VIII goals, per the HTAC recommendation.

III. Recommendations from the Hydrogen Safety and Event Response Subcommittee Report

HTAC formed the Hydrogen Safety and Event Response subcommittee to assess the current status of hydrogen safety and event response resources and practices and provide recommendations to address gaps and ensure a comprehensive, consistent, and coordinated response to hydrogen safety-related events. The subcommittee's report was approved by HTAC and delivered to DOE in June 2017, and included the following four recommendations.

Recommendation

> ***Maximize the role of the Hydrogen Safety Panel (HSP)***
> *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, federal funding should also be available to support projects with the goal of broadly advancing hydrogen FCEVs.*

Response

The Department appreciates the importance of hydrogen safety and is taking steps to ensure continuity of critical hydrogen safety research by integrating key activities into the technology R&D programs. We plan to work with the private sector and other external stakeholder groups to determine how the work of the Hydrogen Safety Panel (HSP) may best be continued. Specifically, DOE and the HSP have initiated development of a strategic plan as recommended. Collaboration with external groups (such as the American Institute of Chemical Engineers) is being investigated and is anticipated to provide opportunities for safety information dissemination as well as support in the development of the long-term strategic plan. Additionally, the Program is pursuing collaboration with the National Fire Protection Association on the development of a standard permitting template. The Program has also integrated hydrogen safety into its funding opportunity process by including requirements for project safety evaluations in new awards.

Recommendation

> ***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.

- *Engage Clean Cities Coalitions to incorporate hydrogen information into their programs.*
- *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.*
- *Expand Clean Cities tiger teams to include hydrogen.*
- *Prepare others to take action by providing training, resources, and case studies.*

Response

The HSP is working to strengthen its relationships and engagement with non-DOE entities, including state and regional organizations. For example, the HSP is currently being leveraged as a safety resource by the California Energy Commission (CEC). Through the recent H2@Scale CRADA funding opportunity, the HSP will continue its support of CEC's infrastructure deployment efforts by providing thorough safety plan review of applications to their funding opportunities. The HSP has also engaged with the CCAT, and will be working with them on a CRADA project to provide pre-project safety planning consultation, review of safety plans and design reviews, site visits, as well as support of authorities having jurisdiction (AHJs) in the review process.

Recommendation

Take steps to support reopening hydrogen stations in a timely fashion after a safety-related incident

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.

Response

The HSP continues to disseminate Best Safety Practices, Lessons Learned, and other key safety knowledge resources. H2Tools.org has had over 200,000 site visits to date. The most frequently accessed resource on the site continues to be the Best Safety Practices site. A key resource supporting deployment of hydrogen infrastructure is the National Hydrogen and Fuel Cell Emergency Response Training Resource, which enables training of first responders in key jurisdictions by local trainers.

Recommendation

> ***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.*

Response

The program already coordinates on safety with relevant agencies such as the U.S. Department of Transportation (DOT) and the National Fire Protection Association. In addition, in support of other Federal and State agencies, the HSP, along with NREL, is collaborating with external entities, including the Federal Energy Management Program (FEMP), to enable the safe incorporation of hydrogen into Federal fleets. For example, HSP representatives provided a course on hydrogen safety at FEMP's Energy Exchange in August of 2017. That presentation was recorded and is being developed into a stand-alone training module that will be available to all FEMP training users in Spring 2018. As previously mentioned, NREL collaboration with NIST has enabled improvements to the standard for hydrogen metering accuracy. The Program also coordinates with DOT in support of the United Nations Global Technical Regulation 13, which has entered Phase II. State agencies and the private sector are also supporting such activities and therefore DOE funds will focus on early stage R&D, rather than outreach.

Appendices: HTAC Letters and Reports

A. HTAC 2015 Annual Report and Cover Letter and Department of Energy Response
    i. https://www.hydrogen.energy.gov/pdfs/2015_htac_annual_report.pdf
    ii. https://www.hydrogen.energy.gov/pdfs/2016_doe_response_htac_secretary_letter.pdf

B. HTAC 2016 Annual Report and Cover Letter and Department of Energy Response
    i. https://www.hydrogen.energy.gov/pdfs/2016_htac_annual_report.pdf
    ii. https://www.hydrogen.energy.gov/pdfs/2017_doe_response_htac_secretary_letter.pdf

C. HTAC Hydrogen Safety and Event Response Subcommittee Report
    i. https://www.hydrogen.energy.gov/pdfs/htac_hser_report_6-17.pdf

APPENDIX A

HTAC 2015 Annual Report and Cover Letter and Department of Energy Response

The Hydrogen and Fuel Cell Technical Advisory Committee
Washington, D.C.

August 3, 2016

The Honorable Ernest Moniz
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave. SW
Washington, D.C. 20585

Dear Mr. Secretary:

Enclosed is the Hydrogen and Fuel Cell Technical Advisory Committee's (HTAC's) 2015 Annual Report on Hydrogen and Fuel Cell Commercialization and Technical Development. The Committee is once again pleased to report that our working relationship with the Department of Energy's Fuel Cell Technologies Office (FCTO) continues to be proactive, productive, and cooperative. The Office effectively orchestrates the Department's ongoing efforts on fuel cell durability, costs, advanced research and manufacturing, codes and standards and infrastructure. It also provides important leadership for other programs, including H2USA, the public-private partnership focusing on fueling infrastructure for fuel cell electric vehicles. The HTAC received sustained support and strong engagement from key members of your leadership team, including: Under Secretary for Science and Energy Franklin Orr, Assistant Secretary for EERE David Danielson, Principal Deputy Assistant Secretary David Friedman, Deputy Assistant Secretary EERE Reuben Sarkar, and FCTO Director, Sunita Satyapal. We very much appreciate the advice they provide on how our committee can best advise both you and the Department to help it complete its mission to support commercial hydrogen and fuel cell deployment within the United States.

HTAC finds the updated Hydrogen and Fuel Cells Program Plan to be comprehensive.
In your September, 2015 letter to John Hofmeister (previous HTAC Chairman), you asked the Committee to conduct a detailed review of the Department's updated Hydrogen and Fuel Cells Program Plan. I am happy to tell you that we completed that review, and the HTAC provided feedback directly to Dr. Satyapal. We found the updated Plan to be comprehensive, with specific areas of focus that are consistent with Title VIII, of the U.S. Energy Policy Act of 2005 (EPACT). Overall, our comments offer enhancements, rather than substantive content changes.

Annual Report recognizes significant progress in advancing hydrogen/fuel cell system utilization.
Of note is the growth of the global hydrogen and fuel cell technology market, which, according to an *E4Tech* report, expanded over 80%, in total megawatt (MW) terms, from 180 MW in 2014

to 340 MW in 2015. In addition, early stage commercial fuel cell electric vehicle (FCEV) and hydrogen fueling infrastructure deployments are now actually happening in California. The Committee is particularly excited about the Department's *Hydrogen at Scale* "Big Idea" project. This work illustrates the unique potential for hydrogen and fuel cells to significantly contribute to achieving the Nation's goal to reduce GHG emissions 83 percent by 2050, in that they can simultaneously enable dramatic greenhouse gas source reductions across multiple sectors/industries. Moreover, the work specifically addresses areas that you highlighted in your September letter, including hydrogen energy storage for both grid resiliency and fuel applications.

Annual Report also cautions that major challenges remain to achieving Title VIII goals. As you know, 2015 marks a major EPACT 2005 milestone, where the goals are:

1) *"To enable a commitment by automakers no later than year 2015 to offer safe, affordable, and technically viable hydrogen fuel cell vehicles in the mass consumer market and to enable production, delivery, and acceptance by consumers of model year 2020 hydrogen fuel cell and other hydrogen-powered vehicles that will have, when compared to light duty vehicles in model year 2005:*
    a. *Fuel economy that is substantially higher,*
    b. *Substantially lower emissions of air pollutants,*
    c. *Equivalent or improved vehicle fuel system crash integrity and occupant protection.*
2) *"To enable a commitment not later than 2015 that will lead to infrastructure by 2020 that will provide:*
    a. *Safe and convenient refueling,*
    b. *Improved overall efficiency,*
    c. *Widespread availability of hydrogen from domestic energy sources,*
    d. *Hydrogen for fuel cells, internal combustion engines, and other energy conversion devices for portable, stationary, micro, critical needs facilities, and transportation applications."*

The Committee acknowledges and applauds the important progress made toward these goals since 2005. However, the evidence shows that the 2015 Title VIII goals have only partially been met, and only in California where State ZEV mandates (with favorable "travel provisions" that are well aligned with the Title VIII goals) exist. The successes in California, to date, have certainly enabled a beginning; however, much more is needed to create necessary momentum and to achieve essential scale that can deliver sustainable solutions for the future. The industry is still in its infancy, and the number of vehicles deployed in the marketplace today measures only in the hundreds. Given these facts, the accomplishment of Title VIII goals for 2020 is dependent upon a currently fragile vehicle and infrastructure business model that could easily be impeded by changing government policy and an unstable regulatory environment. The HTAC, therefore, recommends that the DOE, in the 2016-2017 timeframe, define an explicit plan, including measurable progress milestones, for achieving the 2020 Title VIII goals. The plan should be accompanied by sufficient funding and supportive policies to ensure successful execution. We realize that it is unrealistic to expect FCEVs and hydrogen fueling infrastructure to become simultaneously available across the country, so a more regional approach will likely be appropriate.

HTAC Observations and Recommendations

Be assured that as we share our current observations and recommendations with you, the Committee stands ready to support you and the Department in addressing the challenges during this critical period. We respectfully request that you consider the following points, as you balance the many priorities facing you.

- ***DOE support is critical to ensuring positive retail hydrogen fueling experience.***
  To successfully achieve Title VIII goals, customers must experience positive retail hydrogen fueling experiences, in California and other early markets. This challenge requires DOE support through public-private collaborations like H2USA and complementary DOE projects like H2FIRST. These initiatives fulfill critical roles in helping to validate station performance, assuring station reliability, verifying hydrogen purity, and establishing accurate metering.

- ***Rapid learning cycles and manufacturing scale economies are essential prerequisites to overcome unfavorable cost structures.***
  Retail vehicle prices are currently subsidized and do not reflect true production cost structures. As long as these production costs are high and the customer value proposition remains challenged, there will be a natural tendency for vehicle makers to moderate commercial field deployments. Refueling infrastructure networks are similarly challenged, requiring innovation and high capacity utilization that can only be achieved by growing fuel cell vehicle fleets Addressing these obstacles will in turn address concerns with both the vehicle and infrastructure business models.

- ***Securing industry commitments to high volume manufacturing requires clear and stable policy.***
  The vehicle and refueling infrastructure investments are capital intensive and require a predictable environment, with a pathway to positive long-term economic returns. Commitments in line with those for Battery Electric Vehicles (BEVs) would send a clear signal of that promise.

- ***Extending the federal FCEV tax credit is an essential enabler for promoting fuel cell commercialization and achieving Title VIII goals.***
  Exacerbating the challenges above is the fact that the FCEV tax credit is scheduled to expire in 2016. Any interruption of the tax credit will negatively impact FCEV deployments.

- ***Additional funding is required to achieve 2020 Title VIII goals.***
  Although budgets have stabilized, and the DOE Program has been extremely effective given budget constraints, it is clear that more funding is required to achieve 2020 Title VIII goals. A well vetted comprehensive plan, as described above, would serve as a foundation to support incremental funding requests that will help achieve those goals.

- ***Clean Cities program emphasis must actively promote and educate consumers on FCEV technology.***
  Since 1993, The U.S. Department of Energy's Vehicle Technologies Office, has funded local Clean Cities coalitions, with the goal of eliminate 2.5 billion gallons of petroleum consumption, by 2020. To date, hydrogen FCEV's comprise less than 0.01% of all alternative fuel or advance technology vehicles, according to the 2014 Clean Cities Annual Metrics Report. As FCEVs are commercialized in higher numbers, the Clean Cities emphasis must actively promote and educate consumers on the technology. Furthermore, the Clean Cities program must be updated, to extract available synergies with EPACT Title VIII, while minimizing NO_x and VOC vehicle emissions.

The Committee appreciates and again commends your personal leadership. Your Department clearly demonstrates its commitment to hydrogen and fuel cell technologies, while emphasizing the importance of a portfolio approach to our nation's energy security. We look forward to continuing our service to you, your Department of Energy team, the Fuel Cell Technologies Office Program Office, and the nation in advancing this important subset of the 21st Century U.S. energy and environmental systems. We welcome your feedback and any ideas about how we can best support you.

Sincerely yours,

Frank J. Novachek

Chairman, HTAC
On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee

2015 ANNUAL REPORT of

The Hydrogen and Fuel Cell Technical Advisory Committee

Hydrogen and Fuel Cells

2015 HTAC ANNUAL REPORT SUMMARY

This Annual Report of the United States (U.S.) Department of Energy (DOE) Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) highlights worldwide advances and challenges with regard to hydrogen and fuel cell commercialization, policy, regulations, standardization, financial climate, and research and development (R&D) during 2015.

Hydrogen and fuel cell technologies continued to advance steadily during 2015. Significant commercial progress and new technical milestones for fuel cell systems and hydrogen production, delivery, and storage were achieved. This growth has come despite the precipitous drop in oil prices that may have slowed interest in alternate fuels. Moreover, the DOE *Hydrogen at Scale* "Big Idea" project this year illustrates even greater potential for hydrogen and fuel cell technologies. These technologies are uniquely valuable in that they can enable dramatic greenhouse gas (GHG) source reductions across many sectors/industries simultaneously. This makes them relevant to achieving the Nation's goal to significantly reduce GHG emissions.

Key highlights from 2015 include:

- Toyota released the Mirai fuel cell electric vehicle (FCEV) to initial customers in the U.S., following up on a late 2014 release in Japan, pledging to make FCEVs a key component of its future vehicle development strategy.
- FuelCell Energy and Beacon Falls Energy Park LLC announced what would be the world's largest stationary fuel cell power plant development in Connecticut, with 63.3 megawatts of ultimate capacity, and construction scheduled for start in 2016.
- Hyundai continued to sell commercial FCEVs in Asia, Europe, and the U.S., with a new FCEV taxi service launched in Paris, France, and announced an autonomous FCEV driving trial in the U.S.
- Honda announced that the 2016 Clarity FCEV is to go on sale in Japan in March 2016, with U.S. (California) and European introductions later in 2016.
- California continues to lead the U.S. in hydrogen fueling infrastructure development, with 12 open stations, 19 additional stations constructed or under construction, and 21 additional stations in planning or permitting at the end of 2015. This compares to the largest deployment of hydrogen fueling stations, in Japan, which has about 45 retail stations as of the end of 2015. Germany, meanwhile, had 20 open retail stations at the end of 2015 and a goal of 400 stations by the end of 2023.[1]
- Hydrogenics announced a broad supply agreement deal with a Chinese consortium that includes Yutang, the largest bus original equipment manufacturer (OEM) in China. The deal covers more than 2,000 vehicles of different types over the next 3–5 years, and includes heavy-duty fuel cells and fueling stations.
- Japan's ENE-FARM project achieved a total of over 140,000 units of stationary fuel cell systems in residential applications.

Despite these encouraging steps, key challenges for the hydrogen and fuel cell industry remain. Individual sectors have their specific challenges, including:

- Evidence suggests that the U.S. is not on track to meet the 2020 goals for hydrogen FCEVs and refueling infrastructure set by the U.S. Energy Policy Act of 2005 (EPACT) Title VIII. It is, therefore, important that an explicit plan, *including measurable progress milestones,* be provided in 2016–2017 that outlines how this will be successfully achieved.
- Developing a sufficient and robust hydrogen refueling structure for FCEVs is an ongoing challenge, given unfavorable economics, until the vehicle market further develops.
- Stationary fuel cell costs remain somewhat high compared to other forms of distributed power generation, at about $4,000–$7,000 per kilowatt, but offer higher operational efficiency and lower onsite emissions than combustion-based generators.

Overall, 2015 was an important and encouraging year for hydrogen and fuel cell system developments. Much progress is being made, but greater momentum is needed for these technologies to provide the larger benefits of which they are capable in 2020 and beyond. More specifically, with continued investment in critical infrastructure and R&D, hydrogen and fuel cells can create additional energy diversity leading to greater energy security and economic resilience.

Overall, hydrogen and fuel cell industries continued to progress at a steady rate in 2015, with growing installations and research and development (R&D) progress around the world. The year was marked by the achievement of key market development milestones in the transportation, stationary, backup, and materials handling sectors. Noteworthy events in 2015 in the United States included a Fuel Cell and Hydrogen Energy Policy Forum on Capitol Hill on May 5, and the celebration of National Hydrogen and Fuel Cell Day on October 8. At the Policy Forum, Congressman Charlie Dent (R-PA), Co-Chair of the House Hydrogen and Fuel Cell Caucus, remarked that:

> "Hydrogen fuel cell technology is developing rapidly and holds the promise of benefiting both consumers and the environment. Continued research and development will lead to greater efficiencies in production and practical applications. We owe it to future generations to invest now in this safe, reliable, and virtually unlimited source of clean energy."[2]

Caucus Co-Chair Congressman John Larson (D-CT) added:

> "Hydrogen and fuel cell energy technology is providing businesses and consumers with clean, reliable, domestic power that can be used in a variety of applications. Fuel cells represent the best of American ingenuity and manufacturing. Along with the continued collaboration with the Department of Energy, this industry will continue to grow and support American jobs."[3]

2015 is also a year that is called out in the U.S. Energy Policy Act of 2005 (EPACT), Title VIII, as a milestone that includes the following goals:

1) "To enable a commitment by automakers no later than year 2015 to offer safe, affordable, and technically viable hydrogen fuel cell vehicles in the mass consumer market and to enable production, delivery, and acceptance by consumers of model year 2020 hydrogen fuel cell and other hydrogen-powered vehicles that will have, when compared to light duty vehicles in model year 2005: 1) fuel economy that is substantially higher; 2) substantially lower emissions of air pollutants; and 3) equivalent or improved vehicle fuel system crash integrity and occupant protection;" and
2) "To enable a commitment not later than 2015 that will lead to infrastructure by 2020 that will provide: 1) safe and convenient refueling; 2) improved overall efficiency; 3) widespread availability of hydrogen from domestic energy sources; and 4) hydrogen for fuel cells, internal combustion engines, and other energy conversion devices for portable, stationary, micro, critical needs facilities, and transportation applications."

Considerable progress has been made toward these goals since 2005, and the 2015 commitments have been partially met. Efforts such as H2USA have brought industry and government together in important ways toward achieving these goals. FCEVs by two manufacturers have now been fully safety certified and commercialized, with a third expected in 2016 and more in the 2018–2020 timeframe. However, this progress has been mostly driven by state-level zero-emission vehicle (ZEV) programs. Federal support does not appear to be adequate to spur the developments that are necessary for the 2020 goals of EPACT 2005.

It is unrealistic to expect FCEVs and hydrogen fueling infrastructure to become available at the same time all across the country; analysis concludes that a more regional approach is appropriate. However, it also appears that greater momentum is needed to reach the 2020 goals, particularly since achieving greater manufacturing scale is required for necessary cost reductions. It is thus important that an explicit plan, *including measurable progress milestones,* be provided in 2016–2017 for how to successfully achieve the 2020 EPACT Title VIII goals, with commensurate funding commitments.

With regard to key metrics of commercial progress, a 2015 industry assessment report, *E4Tech,* reports that the size of the global hydrogen and fuel cell technology market (in total megawatt [MW] terms) expanded by over 80% from the prior year. This represents the greatest expansion in fuel cell markets in any calendar year. The report estimates 340 MW of total shipments across sectors in 2015 compared with 180 MW in 2014. A substantial increase in the average size of units is driving much of this increase. Asia stands out as deploying about two-thirds of total units and about half the total global capacity. Meanwhile, North American deployments are relatively steady in numbers of shipments, but with an almost doubling of total capacity in MW in 2015, and deployments in Europe were almost tripled from 2014 levels in MW terms.[4]

Significant Challenges Remain

Despite this progress, fuel cell and hydrogen R&D programs are still developing technologies to address ongoing technical, commercial, and logistical challenges. Major technical improvements have been realized in recent years in reducing costs and improving system durability, but cost targets are not yet achieved in key markets. Achieving cost competitiveness will require a combination of increased production volume and additional efforts to reduce costs of both fuel cell stacks and "balance of plant" components. However, achieving complete cost parity may not be necessary because some types of fuel cell systems can serve multiple applications (for example, primary power and also backup power with onsite fuel storage).

Challenges for Fuel Cell Power Systems

Hydrogen fuel cell systems are of two fairly distinct classes, and each has different performance and long-term durability issues. The first class of fuel cells—relatively low-temperature (i.e., 80–200 °C) proton exchange membrane and phosphoric acid systems—are dependent on noble-metal catalysts including platinum, and are sensitive to impurities in fuel quality (especially sulfur compounds and carbon monoxide). The second class of fuel cells—high-temperature molten carbonate and solid oxide systems (500–1,000 °C)—require less expensive catalyst materials but more expensive bipolar plate and inter-cell sealing materials to withstand the higher temperatures. Fuel impurities are somewhat less of a concern, but sulfur compounds are still a key issue. In addition to hydrogen, the high-temperature systems can run directly on hydrocarbon fuels such as pipeline natural gas that then break down into hydrogen/carbon monoxide "syngas" within the system.

Key challenges for low-temperature fuel cells include further reducing the amount (or changing the type) of precious metal catalyst required for good performance while maintaining durability requirements, and continuing to improve system integration and driving down balance-of-plant system costs. For high-temperature systems, concerns include overall system durability, such as maintaining the integrity of inter-cell seals over time, tolerance for thermal cycling (e.g., due to shutdown for maintenance events), and further refinement of system design to optimize for "electricity only" versus "combined heat and power" applications. Hybridization of high-temperature fuel cell systems with a gas-turbine generator for increased overall efficiency is an active area of development with additional system integration challenges.

Remaining challenges include:

- Improved system integration and balance-of-plant cost reductions
- Further validation of system durability, especially for stationary markets with long runtime requirements
- Improved integration of fuel cell systems and fuel supply options, such as for longer run-time of fuel cell backup power systems through onsite reforming of liquid fuels
- Better strategies for the limited ability of stationary high-temperature fuel cells to dynamically change output to match changing electric loads

Challenges for Hydrogen Production, Storage, and Distribution

For hydrogen production and storage, key challenges relate to electrolytic production of hydrogen with good system durability over time, and the potential for increased efficiency of hydrogen production from renewable energy sources using various thermo-chemical and photo-electrochemical means. Hydrogen storage remains an ongoing challenge, with high-pressure composite storage vessels being the dominant means of vehicle-based storage (but relatively heavy and expensive), and with other options possible in the future such as organic and metal hydride and ammonia-based storage, and cryogenic gas/liquid combined systems. Hydrogen distribution for vehicle fueling applications has experienced significant progress but challenges remain, including the relatively high costs of hydrogen fueling station equipment, siting and permitting of fueling stations, and fueling station reliability.

Key remaining challenges for hydrogen production, storage, and distribution include:

- Improved membrane electrode assembly integration for hydrogen crossover reduction/mitigation and combination of membrane and catalyst advances for electrolyzers
- Development and validation of value propositions and systems solutions for renewable energy to hydrogen for power, fuel, and grid-stabilization
- Improved hydrogen storage solutions that are lightweight, compact, safe, energy efficient, and fully reversible
- Cost of hydrogen fuel infrastructure and difficulties with station siting/permitting and reliability

More generally, hydrogen and fuel cell technologies are now competing in a world of low-cost fossil fuels, due to major expansion of production in the U.S. and weakening of OPEC power to reduce output to boost prices of crude oil. As of late 2015, oil prices were below $35 per barrel, their lowest price in real terms since 2009 when prices quickly rebounded after a precipitous fall from over $130 per barrel in 2008. However, there also has been strong growth recently in renewable energy supplies, and increased adoption of carbon emissions regulations, zero emissions standards, and renewable portfolio standards worldwide. These developments have significantly helped to support the growth of hydrogen and fuel cell systems by increasing interest levels due to their relatively efficient, clean, and quiet operation.

HTAC Activities In 2015

Key HTAC activities in 2015 include that the Committee:

- Published the 2014 HTAC Annual Report and HTAC's associated letter to the Secretary of Energy, Dr. Ernest Moniz in July 2015. The Secretary, in a September 2015 response letter to the HTAC Chair, highlighted the ongoing challenges with hydrogen and fuel cell system commercialization, but also noted significant market and DOE successes. His letter noted that DOE was responsible for "more than 515 U.S. patents, 40 commercial technologies in the market related to hydrogen and fuel cells, and another 65 technologies we anticipate to be commercial in the next three-to-five years." The Secretary also noted the potential of hydrogen for cross-cutting applications for grid energy storage as well as fuel for vehicles and stationary applications.
- Released a Manufacturing Sub-Committee report highlighting progress in fuel cell manufacturing systems and key remaining challenges and bottlenecks. In particular, the report points out specific potential public-private initiatives that could help fuel cell development and commercialization, including the use of advanced

manufacturing techniques. Some recommendations have already been acted upon, such as highlighting the use of backup power fuel cell technology and collaboration in China as part of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) conference in Wuhan, China on May 29, 2015. The report also cited the need for greater standardization and concentration of the stationary supply chain in order to achieve the next level of cost competitiveness and market growth, especially for U.S. fuel cell exports.

- Distributed a financial analysis of H_2 infrastructure that highlighted the key station capital cost, operation and maintenance costs, and profit margins needed to make hydrogen refueling infrastructure investments attractive to private investors. The report suggests that station costs somewhat lower than today's costs are needed, along with high levels of station utilization and relatively low and predictable station maintenance costs.[5]

Commercialization Initiatives

Fuel cells continue to make significant inroads into an array of commercial sectors, further highlighting the broad potential impact of these technologies. Key sectors include stationary power markets (i.e., primary and backup power), transportation markets (e.g., cars, buses, trucks, and forklifts), electricity grid-support applications, military applications, underwater vehicles, and small electronics. Hydrogen as an industrial chemical also has broad impact for ammonia production, metal and semiconductor processing, and refining of petrochemicals.

Fuel Cells for Stationary Applications

Fuel cells continue to make steady inroads into stationary power markets. Approximately 200 MW of stationary fuel cell systems were shipped in 2015, compared with about 150 MW in 2014.[6] Details include:

- Doosan announced an agreement to supply 70 fuel cell power plants for Korea Hydro and the city of Busan for a total of 30.8 MW, with installation expected by 2017.[7]
- Installations of Japan's ENE-FARM residential fuel cell systems increased to approximately 140,000 units.[8]
- SOLIDpower began selling its "mCHP EnGen™-2500" 2.5 kilowatt (kW) solid-oxide fuel cell (SOFC) system in Europe along with its 1.5 kW BlueGen units.[9]
- In a noteworthy international development, Implats Platinum mine announced plans to install a 1.8 MW Fuji Electric fuel cell power plant at its mine in South Africa. The ultimate plan calls for up to 22 MW of fuel cell power to make the mine independent of the local power grid.[10]

Fuel Cells for Passenger Cars

2015 was a milestone year for fuel cells for passenger cars, with key commitments for vehicle commercialization and hydrogen infrastructure development. Key developments include:

- In May 2015, Toyota announced that eight California dealers would sell or lease the 2016 Mirai FCEV for initial U.S. introduction. Order requests were opened in summer 2015, with the first deliveries beginning in fall 2015. U.S. sales volume is expected to be approximately 3,000 units through 2017.[11]
- Toyota plans to continue the commercial rollout of Mirai vehicles on Oahu in Hawaii, for late 2016 or early 2017, in conjunction with the first commercial hydrogen fueling station in Hawaii.
- Hyundai continued to lease its Tucson FCEVs in Asia and Southern California, and has partnered with an electric taxi service in Paris called STEP (Société du Taxi Electrique Parisien) to employ five Tucson FCEVs in commercial taxi service.
- Hyundai also announced that it had been granted permission by the State of Nevada to test fully autonomous FCEVs in the U.S., the first automaker to receive this clearance.[12]
- Honda announced the production version of the 2016 Clarity Fuel Cell that will go on-sale in Japan in March 2016 for a retail price of 7.66 million yen (about $67,000), with U.S. and European introductions later in 2016.[13]
- A consortium of Ford, Nissan, and Daimler aims to start releasing commercial FCEVs using common componentry in 2017, General Motors is pursuing fuel cell technology independently and in connection with Honda, and BMW is pursuing FCEV development with a 2020 target date.[14]
- Three Daimler F-Cell vehicle customers drove over 1,000 miles each in a three-day road rally between Southern and Northern California, taking advantage of a new hydrogen fueling station in Coalinga along the I-5 highway corridor. The event was supported by Mercedes Benz Research and Development North America and intended to highlight the growing level of fueling infrastructure in California.[15]

Source: Toyota.com

Source: HyundaiUSA.com

Source: Honda.com

Figure 1: Toyota 2016 Mirai, Hyundai 2016 Tucson, and Honda 2016 Clarity Fuel Cell Electric Vehicles

Fuel Cells for Buses

Fuel cell buses continued to make excellent progress in performance. Separate bus trial programs in the U.S. and England both established over 20,000 hours of fuel cell system durability for buses in regular fare service. In addition:

- Ballard Power Systems announced a partnership to develop fuel cell buses in China. The deal is for 33 buses for a value of about $10 million. The project will employ Ballard's FCvelocity®-HD7 modules and partnerships with Chinese electric vehicle companies to deploy the buses in the cities of Rugao (Nantong) and Yunfu (Guangdong) starting in 2016.[16]
- Ballard Power Systems also announced a Strategic Collaboration Agreement with Xiamen King Long United Automotive Industry Co., Ltd. ("King Long") to design and deploy fuel cell buses.[17]
- Ballard Power Systems reported that the highest-mileage fuel cell bus in the Transport for London (TfL) fleet reached 20,000 hours of operation since being placed in service in 2010. The overall fleet of eight fuel cell buses has achieved over 690,000 kilometers (428,000 miles) of operation. TfL recently agreed with Ballard to operate the buses for an additional five years, through 2020.[18]
- In late 2015, Hydrogenics announced a broad supply agreement deal with a Chinese consortium, including Yutang, the largest bus OEM in China. The deal covers more than 2,000 vehicles of different types over the next 3–5 years, and includes heavy-duty fuel cells, fueling stations, and assessments for converting surplus wind and other renewable electricity sources to hydrogen using Hydrogenics' Power-to-Gas energy storage technology.[19]

Source: Transport for London

Source: Leslie Eudy/NREL

Figure 2: Fuel Cell Buses in California and London have Achieved 20,000+ Hours of Accumulated Operation in 2015

Fuel Cells for Other Vehicles

- US Hybrid announced a project in conjunction with the Port of Houston to develop and test three fuel cell powered drayage trucks with a 200-mile driving range and 60 mile per hour top speed. The $7.6 million program will involve converting Class 8 Navistar International ProStar cab tractors; additional partners include the U.S. DOE, Gas Technology Institute, Environmental Defense Fund, and University of Texas.[20]
- Intelligent Energy announced a fuel cell range extender for drones, expected to be unveiled at the 2016 Consumer Electronics Show in Las Vegas, NV.

Hydrogen Production and Distribution

Key milestones in hydrogen production and distribution include progress in building hydrogen refueling infrastructure in California, and the announcement by Proton Onsite that the company has achieved over 1 billion cell hours of PEM electrolysis operation in the field. Furthermore:

- California's aggressive hydrogen infrastructure development effort continued, with 12 fueling stations open, an additional 19 currently constructed or under construction, and 21 more in various stages of planning and permitting. This progress represents steady movement toward a planned initial network of 100 stations by 2024.[21]
- Toyota and Air Liquide announced plans to develop a hydrogen fueling network in the Northeastern U.S.[22]
- Japan currently has the largest deployment of hydrogen fueling stations, with about 45 operating retail stations as of the end of 2015. This includes 4–5 mobile refuelers along with the other permanent stations.
- Germany continued hydrogen station development efforts, with 20 stations operational at the end of 2015. By 2023, a network of 400 stations is envisioned, with a station sited every 90 kilometers along the autobahn network, and with a total investment of approximately $455 million. The effort is led by a consortium of six companies that include Air Liquide, Daimler, Linde, OMV, Shell, and Total.[23]
- Air Liquide announced on December 1, 2015, that it had installed the first commercial hydrogen station in Paris, France. The opening coincided with the COP21 international climate chance conference.
- The Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) announced €16 million in funding for large scale electrolysis: a 6 MW PEM electrolysis demonstration (€12 million) and a 3 MW alkaline electrolysis demonstration (€4 million).

- Air Products and Chemicals Inc. announced hydrogen deliveries using higher-pressure hydrogen gen trailers, capable of delivering hydrogen fuel at pressures of up to 500 bar (7000 psi).[24]

Figure 3: Hydrogen Delivery System
Source: Air Products and Chemicals, Inc.

Fuel Cells for Material Handling

- Plug Power Inc. launched the model 3340 GenDrive fuel-cell unit for its production forklifts. Plug Power has produced more than 9,000 GenDrive units with over 107 million hours of runtime.[25]
- NACCO (Hyster-Yale) acquired Nuvera's technology for its own forklift vehicles, creating additional competition in this sector.

Fuel Cells for Backup Power Applications

- Ballard Power Systems announced shipment of its 3,000th ElectraGen™ backup system. The company reports over 50 million operating hours and over 1 million hours of backup to critical telecom sites.[26]
- Ballard Power Systems also reported the sale of 100 fuel cell backup power units in India in April 2015, in conjunction with Reliance Jio Infocomm Limited (RJIL) for 100 ElectraGen™-ME fuel cell backup power systems.[27]
- Altergy Systems reported that it has surpassed over 32 million hours of operation from its fleet of PEM Freedom Power™ fuel cell backup units, with more than 8.3 MW of installations around the world.[28]
- Intelligent Energy announced a deal with GTL Limited for £1.2 billion ($1.8 billion) over ten years to supply hydrogen fuel cell backup power units to 27,400 telecom towers in India.[29]

Hydrogen for Grid Support Applications

- Germany announced continued efforts to explore "power-to-gas" concepts using hydrogen technologies, with several ongoing investigations by consortia groups using both power-to-hydrogen and power-to-methane systems. In one recent development, in what is being called the "the world's most modern power-to-gas plant," a new 800 kW power-to-hydrogen project in the Hamburg/Reitbrook district was inaugurated in October 2015. The €13 million project (half supported by the German government) converts wind power to hydrogen that is then fed into the Hamburg gas grid. The project is led by German regional energy provider E.on Hanse, with partners Hydrogenics GmbH, SolviCore GmbH, Deutsches Zentrum fuer Luft- und Raumfahrt, and the Fraunhof Institute for solar energy systems.[30]

Figure 4: Fuel Cell Powered Forklifts by Plug Power Inc.
Source: Plug Power Inc.

- Proton Onsite will provide its 7 kW and 60 kW electrolyzers for the first power-to-gas project in the U.S. The project will be performed in collaboration with SoCal Gas, and take place at the University of California campus in Irvine, California.[31]

Policy, Regulations, Codes and Standards

Policy and Regulations

Noteworthy policy developments include:

- The 30% U.S. Investment Tax Credit (ITC) for stationary fuel cell systems is now set to sunset at the end of 2016, based on the December 2015 omnibus budget bill. If allowed to expire, this is expected to slow the pace of installation of fuel cell systems that otherwise would benefit from this program.
- The Fuel Cell Motor Vehicle Tax Credit of up to $8,000 on light-duty FCEVs is also set to expire at the end of 2016, after only a two-year prior extension from 2014.[32] Expiration of the credit just as major automakers are moving to bring FCVs to market would be unfortunate, and the industry is hopeful for an extension of this program.
- On December 4, 2015, President Obama signed the Fixing America's Surface Transportation (FAST) Act, the first long-term transportation bill in a decade, which provides authorizations for FY 2016 through FY 2020. This bill includes a Section 1413, "National electric vehicle charging and hydrogen, propane, and natural gas fueling corridors." The language instructs the Secretary of Transportation to designate alternative fueling corridors for electric, natural gas, and hydrogen vehicles, and identify

the near- and long-term need for, and location of, these fueling spots at strategic locations along national highways.

- Stationary fuel cell systems continue to qualify for capital cost support under the California Self-Generation Incentive Program (SGIP). The initial incentive of $1,650 per installed kW (which began in 2009) has declined to a current level of $1,490 per installed kW, with an additional incentive of $1,310 per kW if biogas is used as the fuel source.[33]
- FCEVs receive a $5,000 purchase incentive under the California Clean Vehicle Rebate Project.[34]

Codes and Standards

Codes and standards for hydrogen and fuel cell systems continue to evolve to fill in gaps due to technology evolution and to keep up with the latest industry practices. Key codes and standards developments include:

- *NFPA 2: Hydrogen Technologies, Edition 2016* was released as a vital document for the fuel cell and hydrogen industry, providing fundamental safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas (GH_2) form or cryogenic liquid (LH_2) form.
- SAE J2601, with the latest revision finalized in 2014, is now being promoted as a worldwide standard for hydrogen refueling, including fuel flow rate, temperature, end pressure, and other aspects. The SAE J2719 standard, which specifies hydrogen fuel quality standards for vehicle applications, was updated in late 2015.
- The "H2TOOLS" portal was unveiled at H2TOOLS.ORG as a central location for information on hydrogen safety, best practices, lessons learned, and supportive resources. The site, sponsored by DOE, includes a collection of resources for education and training and forums for exchanging information among key groups such as project developers, safety officials, and incident first responders.

Financial Climate

The financial climate for hydrogen and fuel cell technologies improved somewhat, with steadily increasing demonstration of technology performance and reliability, and a generally favorable market environment with low interest rates for capital investments. However, a bankruptcy filing by ClearEdge Power and relatively steady (rather than increasing) valuations for most fuel cell companies signaled some continuing struggles for the industry.

Key finance and partnership developments in 2015 included:

- FuelCell Energy announced a $30 million deal with PNC Energy Capital, LLC, to finance fuel cell projects, including a 1.4 MW fuel cell plant for the University of California, Irvine Medical Center. The financing allows the company the option to retain project ownership, leading to greater ultimate revenues over time.[35]
- Constellation and Bloom Energy announced an agreement to develop 40 MW of Bloom Energy fuel cell projects for commercial and public sector customers in California, Connecticut, New Jersey, and New York.[36]
- FuelCell Energy and E.on Hanse announced a program to offer decentralized combined heat and power solutions with MW and multi-MW Direct FuelCell® power plants to its existing and prospective customer base.[37]
- On January 6, 2015, Toyota announced that it would allow royalty-free use of about 5,680 patent licenses related to fuel cell stacks, and an additional 3,350 patents concerning fuel-cell system control technology through the initial market introduction period of FCEVs. About 290 of these items will be related to high-pressure hydrogen storage tanks.[38]

U.S. government support for hydrogen and fuel cell technology development efforts remained relatively constant from recent years, with $105.5 million requested in FY 2017 for the Fuel Cell Technologies Office, slightly more than in FY 2016 (see Figure 5). However, this is approximately half the historical peak funding level of over $200 million.

As shown in Figure 6, the current budget for fuel cell technologies is approximately 4.9% of the DOE Energy Efficiency and Renewable Energy (EERE) FY 2015 budget request of $2.3 billion.

Research and Development

Research and development activities around hydrogen and fuel cell technologies continued at a steady pace in industrial, government lab, and university settings. Key activities included:

- The Hydrogen Station Equipment Performance (HyStEP) device was completed as a station field testing and commissioning device.[39] The device was developed and validated by DOE, Sandia National Laboratories, and the National Renewable Energy Laboratory, and delivered to California for field-testing of station fueling performance at retail hydrogen stations. CARB is now taking on HyStEP project management.
- FuelCell Energy initiated a new DOE-funded project for a combined "reformer-electrolyzer-purifier" (REP) for hydrogen production, based on its molten carbonate fuel cell technology, and with the potential for high production efficiency. The system utilizes a waste heat source to assist with the first partial reforming step, and then produces high-purity hydrogen from further full reformation, water-gas shift, and electrolysis steps.[40]
- FuelCell Energy is pursuing additional "tri-generation" opportunities based on its successful installation in Fountain Valley, California. The site is producing power and waste heat for local use at the Orange County Sanitation District's wastewater treatment plant, along with

Key Activity	FY 14 Approp.	FY 15 Approp.	FY 16 Approp.	FY17 Request
Fuel Cell R&D	33,383	33,000	35,000	35,000
Hydrogen Fuel R&D[1]	36,545	35,200	41,050	44,500
Manufacturing R&D	3,000	3,000	3,000	3,000
Systems Analysis	3,000	3,000	3,000	3,000
Technology Validation	6,000	11,000	7,000	7,000
Safety, Codes and Standards	7,000	7,000	7,000	10,000
Market Transformation	3,000	3,000	3,000	3,000
Technology Acceleration	0	0	0	13,000[2]
NREL Site-wide Facilities Support	1,000	1,800	1,900	N/A
Total	**92,928**	**97,000**	**100,950**	**105,500**

Other DOE Offices	FY 14 Approp.	FY 15 Approp.	FY 16 Approp.
Basic Energy Sciences	19,922	18,499	18,499[3]
Fossil Energy (SECA)	25,000	30,000	30,000
ARPA-E (FC-related)	33,000	0	TBD
Total	**77,922**	**48,499**	**48,499**

[1] Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

[2] Combines Manufacturing R&D, Technology Validation, Market Transformation

[3] Estimated FC-related BES funding (based on FY15)

FY 2016 DOE Total: ~$150M

Figure 5. Recent DOE Funding for Hydrogen and Fuel Cells R&D
Source: U.S. DOE, Fuel Cell Technologies Office

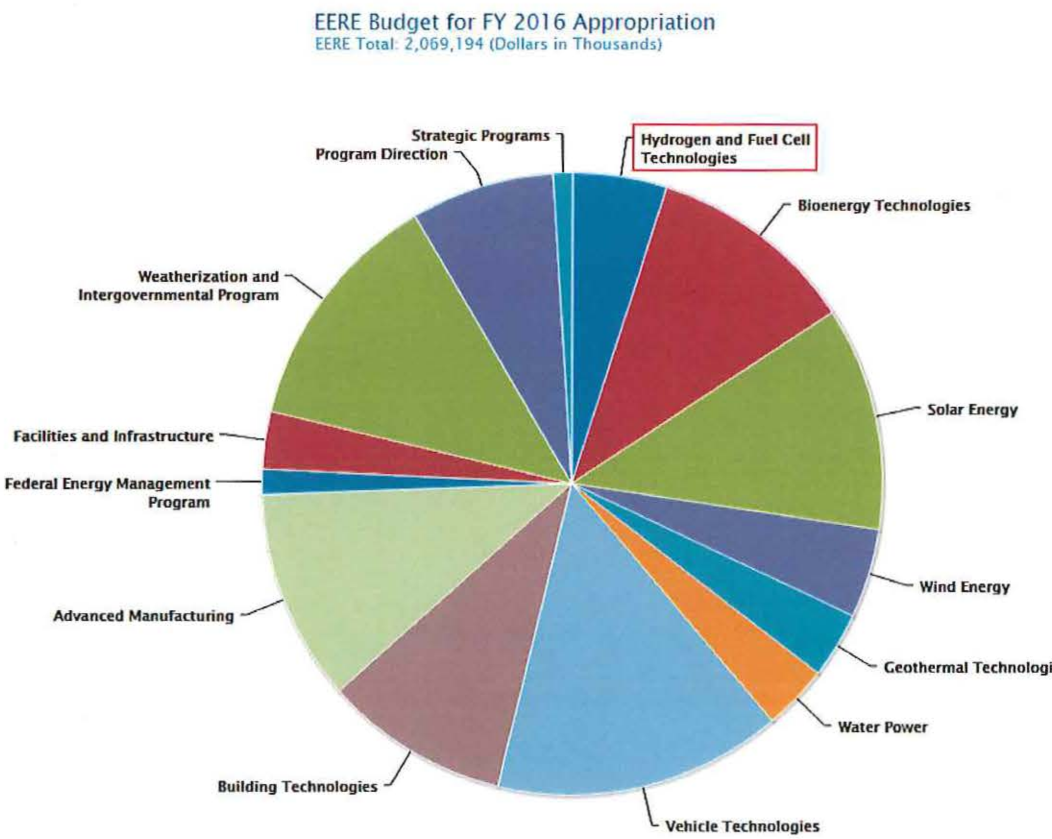

Figure 6: DOE EERE Funding Allocations across Program Areas
Source: U.S. DOE, http://www5.eere.energy.gov/office_eere/program_budget_formulation.php

hydrogen for FCEV refueling, based on the use of low-carbon biogas as a feedstock. A 1.2 MW FCE molten carbonate system can co-produce up to 800 kg per day of hydrogen that can then be purified for vehicle applications.

Important areas for additional R&D include:

- Additional reductions in catalyst material costs for membrane electrode assemblies (MEAs) for low-temperature fuel cell and electrolyzer systems, while maintaining durability over time
- Better system integration and reduced components costs for lowered balance-of-plant costs
- Improvements in manufacturing processes and yield rates for electrolyzer and fuel cell system manufacturing
- Reduced component costs, improved compressors, and improved metering/metrology for hydrogen refueling stations
- Improved systems for continuous monitoring of impurities and contaminants in hydrogen and reformate gas streams, with lowered costs

Figure 7 presents the current cost and durability status and targets for various fuel cell market sectors.

Studies and Reports

Several key reports were released in 2015. These include:

- The DOE's *Fuel Cell Technologies Market Report 2014*[41]
- The DOE's *State of the States: Fuel Cells in America 2015*, 6th edition[42]
- The *2015 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*, California Air Resources Board, July 2015[43]
- An annual joint report by CEC and ARB on "Time and Cost Needed to Attain 100 Hydrogen Fueling Stations in California," December 2015[44]
- The California Hydrogen Business Council's report *Power-to-Gas: The Case for Hydrogen*[45]
- The Fuel Cell and Hydrogen Energy Association (FCHEA) 2014 *State Policy Activity Wrap-up: Fuel Cells & Hydrogen*[46]
- FCHEA's *Business Case for Fuel Cells 2015* report[47]
- E4Tech's *Fuel Cell Industry Review 2015* report[48]

NREL and other labs under the direction of DOE have been exploring concepts for hydrogen used in large-scale, in an expanded array of industrial and power-sector markets. Figure 8 depicts how hydrogen and fuel cells can be provided at-scale to impact these sectors.

Fuel Cell Type	Cost & Durability Status[a]	Cost & Durability Target[a]
Backup Power (Direct Hydrogen)	$6,100/kW[b] 8,000 hours (h)	$1,000/kW 10,000 h
Medium Scale CHP (natural gas)	$4,500/kW[c] 40,000—80,000 h	$1,000/kW 80,000 h
APUs (1-10 kW, system)	$2,100/kW 3,000 h	$1,000/kW 20,000 h
Buses	$800,000 +20,000 h	$600,000 25,000 h
Automotive	~$53/kW 3,900 h (on road)[d]	$30/kW ($40/kW by 2020) 8,000 h
Portable Power (100-200 W)	$15/W 2,000 h	$5/W 5,000 h

a. Unless otherwise noted, all data is from the U.S. DOE, 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, June 2016; equipment cost.

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c. DOE Hydrogen and Fuel Cells Program Record 11014, "Medium-Scale CHP Fuel Cell System Targets," https://www.hydrogen.energy.gov/pdfs/11014_medium_scale_chp_target.pdf.

d. DOE Hydrogen and Fuel Cells Program Record 15014, "On-Road Fuel Cell Stack Durability," https://www.hydrogen.energy.gov/pdfs/15014_fuel_cell_stack_durability.pdf -high-volume modeled cost.

Figure 7: Cost and Durability Status and Targets for Various Fuel Cell Market Sectors

Initial analysis shows that pursuit of these concepts could greatly reduce greenhouse gas (GHG) emissions by displacing the use of fossil fuels, if implemented in large scale in this multi-faced manner.[49] An example of this type of concept is in Arezzo, Italy, where a network of underground pipelines provides hydrogen fuel for metallurgy and other purposes.[50]

Conclusions

The overall outlook for hydrogen and fuel cell technologies is promising. Recent years have seen a proliferation of commercial and research developments and also noteworthy progress in stationary and backup power, transportation fuel, and grid-support applications. Hydrogen and fuel cell technologies are recognized as important solutions for achieving international goals to reduce GHG emissions for climate stabilization per the landmark Climate Accords, signed in Paris in December 2015.[51]

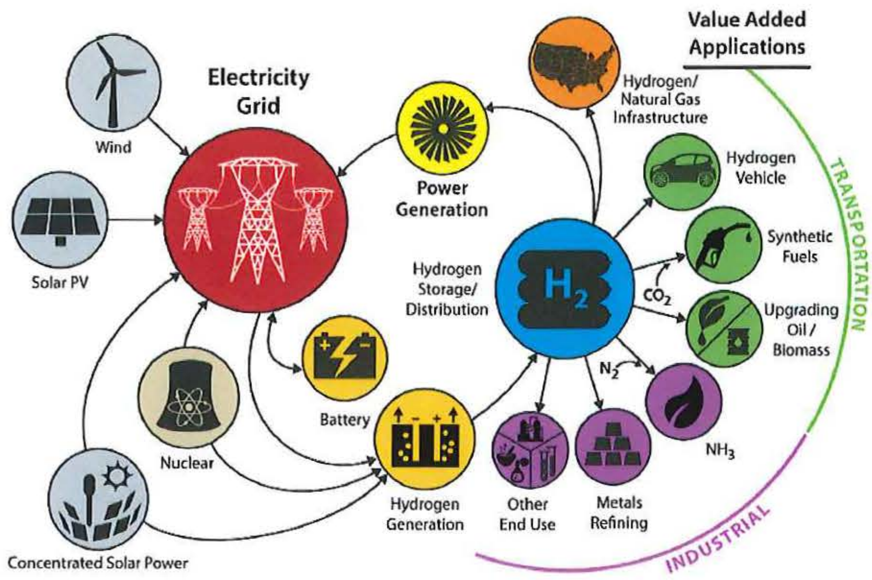

Figure 8: Conceptual Diagram for Hydrogen at Scale
Source: Pivovar et al, DOE National Lab Big Idea available in 2016 AMR Proceedings at https://www.hydrogen.energy.gov/pdfs/review16/2016_amr_h2_at_scale.pdf

While hydrogen and fuel cell technology solutions may not be the most economical in each application they can serve, they have the potential to simultaneously serve more value streams than the competing technologies in each application. These value streams include:

- Transportation applications: FCEVs offer the clean operation and rapid acceleration of other electric vehicles, but with faster refueling and longer driving ranges.
- Electric grid support: fuel cell systems offer clean power in areas where local air quality is an issue, and can also provide various grades of waste heat and enhanced power reliability for host sites.
- Energy storage: Hydrogen can provide long-term energy storage, potentially helping to maximize the benefits of renewable energy systems.
- Natural gas system support: power-to-hydrogen and power-to-methane can utilize stranded intermittent renewable energy to supplement local natural gas-based fuel supplies.
- Industrial applications: hydrogen is already widely used in industrial settings, but there are additional opportunities to expand the use of hydrogen for chemical manufacture, ammonia production, metals production and processing, enhancement of liquid fuels, and to take advantage of hydrogen produced as a co-product of industrial processes such as chlor-alkali production.

Concepts such as these point to a much larger potential role for hydrogen and fuel cell technologies in the future. However to achieve this, continued government support for these emerging technologies is still critically needed until they become more mature and established.

In this regard, the sunset of the 30% ITC for fuel cell system installation at the end of 2016 is expected to have a dampening effect on the market commercialization of stationary fuel cell systems. The Fuel Cell Motor Vehicle Tax Credit of up to $8,000 on light-duty FCEVs is also set to expire at the end of 2016, after only a two-year prior extension. FCEVs and stationary fuel cell systems are only beginning to make inroads into major markets, and the potential for sudden expiration of these credits represents a significant risk to continued market development. Extending both of these complementary programs to promote the further introduction of fuel cell systems while their costs are steadily declining should be considered.

In conclusion, 2015 was a milestone year for hydrogen and fuel cell systems in the U.S. Much progress is being made, but greater momentum is needed for these technologies to provide the larger benefits they are capable of in 2020 and beyond. An explicit plan including measurable progress milestones should be provided in 2016–2017 for how the 2020 EPACT Title VIII goals will be successfully achieved, with commensurate funding commitments including those identified through the 2015 FAST Act.

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Department of Energy
Washington, DC 20585

November 30, 2016

Mr. Frank Novachek, Chair
Hydrogen and Fuel Cell Technical Advisory Committee
1800 Larimer Street, Suite 1600
Denver, Colorado 80202

Dear Chairman Novachek,

Thank you for your August 2016 letter to Energy Secretary Moniz and the accompanying *2015 Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)*. The Department values the input of the Committee and appreciates this thorough and detailed report on the status of hydrogen and fuel cells.

As you mention, we were able to continue significant progress in hydrogen and fuel cell technologies in 2015. Through our investment in research and development, we have seen the cost of fuel cells cut in half in the past nine years, while achieving a four-fold increase in durability. The Hydrogen and Fuel Cells program also helped to double the number of patents in fuel cell technologies since 2007, while also helping to double the number of fuel cell related technologies deployed in the commercial market between 2007 and 2015. However, as your report also points out, challenges remain in developing a sufficient and robust hydrogen refueling infrastructure for fuel cell electric vehicles (FCEVs), and your recommendations identify ways in which the program can work to resolve some concerns.

We agree that the deployment of hydrogen refueling infrastructure continues to be a challenge. The Hydrogen and Fuel Cells program held a meeting in June 2016 with stakeholders from both the National Laboratories and H2USA to identify the barriers and opportunities for hydrogen infrastructure deployment. We are also developing an internal hydrogen infrastructure roadmap and released a request for information to obtain feedback on deployment of hydrogen fueling stations, delivery infrastructure, and activities to pursue in both the near and longer term. Our investment in H2FIRST (Hydrogen Fueling Infrastructure Research and Station Technology) illustrates our commitment to addressing challenges with hydrogen infrastructure. Now that FCEVs are commercially available, the revision of the Department's Clean Cities strategic vision plan will include additional focus on hydrogen and fuel cell technologies, such as funding opportunity announcements and station locations on Department-provided fueling-infrastructure maps.

The Committee also recommends that the federal tax credit for fuel cell electric vehicles be extended beyond 2016 to continue to enable fuel cell commercialization and help achieve Title VIII goals for 2020. While the Department does not set the Federal tax credits, we are working with our colleagues in the legislative branch to provide information related to these policies.

Finally, the Department recognizes that additional funding would provide more flexibility in allowing us to achieve the 2020 Title VIII goals. We continue to support the President's "all of the above" energy strategy by maintaining a consistent and substantial budget for hydrogen and fuel cell technologies. The Fiscal Year (FY) 2017 budget request is approximately $105 million, which is slightly higher than FY2016 levels. Given budget constraints, I am pleased to inform you that we have launched three new consortia as part of DOE's Energy Materials Network in support of the President's Materials Genome Initiative and advanced manufacturing priorities: HydroGEN, ElectroCAT, and HyMARC. By using both computational and high-throughput combinatorial techniques to identify promising technologies, we will accelerate materials discovery and development to address the most challenges such as renewable hydrogen production, identification of platinum group metal-free catalysts, and hydrogen storage materials.

The Department values the advice and commitment of the Committee in its efforts to continue to improve our programs and activities related to hydrogen and fuel cells. In response to your request for an explicit plan for how the 2020 EPACT Title VIII goals will be successfully achieved, the Department will work to develop a strategy to outline efforts currently underway to work toward these goals.

Please extend my sincerest gratitude to the Committee members for their hard work and their valuable contributions to the Department and its mission.

Sincerely,

David J. Friedman
Acting Assistant Secretary
Energy Efficiency and Renewable Energy

Frank and Committee,
Keep up the great work and keep pushing. I've never seen a path to 80% reductions that doesn't include H_2, so I know the next Secretary and Assistant Secretary will need your counsel. Please also keep helping Sunita and Reuben think creatively about how we can get H_2 to $2 or even $1/gge.
Thanks again for your advice,
DJF

APPENDIX B

HTAC 2016 Annual Report and Cover Letter and Department of Energy Response

The Hydrogen and Fuel Cell Technical Advisory Committee
Washington, D.C.

June 29, 2017

The Honorable Rick Perry
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave. SW
Washington, D.C. 20585

Dear Mr. Secretary:

On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), I hereby submit the Committee's 2016 Annual Report. The HTAC duties, under Title VIII of the Energy Policy Act of 2005, SEC. 807, are to review and make recommendations to you, the Secretary, on: (1) the implementation of programs and activities under Title VIII; (2) the safety, economical, and environmental consequences of technologies for the production, distribution, delivery, storage, or use of hydrogen energy and fuel cells; and (3) the Department of Energy (DOE) plan under section 804. The enclosed report summarizes the Committee's observations and recommendations in this regard.

The success of our Committee has been enabled by our very cooperative working relationship with your Department's Fuel Cell Technologies Office (FCTO). The progress made this year in the areas of fuel cell and hydrogen technologies clearly demonstrates their commitment, and that progress is even more evident when comparing the state of these technologies to that during the early days of President Bush's Hydrogen Fuel Initiative. The Office effectively orchestrates the Department's ongoing efforts on fuel cell durability, costs, advanced research and manufacturing, codes and standards and infrastructure. It also provides important leadership for other programs, including H2USA, the public-private partnership focusing on fueling infrastructure for fuel cell electric vehicles (FCEVs). The HTAC has received sustained support and strong engagement from key members of your leadership team over the past several years, particularly the Office of Energy Efficiency and Renewable Energy (EERE) Deputy Assistant Secretary for Sustainable Transportation, Reuben Sarkar, and FCTO Director, Sunita Satyapal. We also valued the opportunity to meet and speak with your then newly appointed Acting Assistant Secretary for EERE, Daniel Simmons during our May 5 meeting in Washington, DC. The Committee very much appreciates the advice they provide on how our Committee can best advise both you and the Department to help it complete its mission to support commercial hydrogen and fuel cell deployment within the United States.

Observations/Recommendations from 2016 HTAC Annual Report and Supporting Efforts

Be assured that as we share our observations and recommendations with you, the Committee stands ready to support you and the Department in addressing the challenges during this critical period. We respectfully request that you consider the following points, as you balance the many priorities facing you.

- ***The hydrogen and fuel cell industries made steady progress in 2016, in advancing hydrogen and fuel cell system utilization.*** *Noteworthy were ongoing R&D developments and growing sales in the stationary, transportation, backup, off-grid, military and material handling sectors.*
- ***The U.S. has led the world in developing fuel cell and hydrogen technologies, but our leadership position is now potentially at risk.*** *Most commercial advances in the areas of FCEVs, stationary power, and hydrogen technologies are now from outside the U.S., creating a growing gap in leadership and competitiveness. The importance of federal support in these areas cannot be understated.*
- ***Securing industry commitments to high volume manufacturing requires clear and stable policy.*** *FCEVs and associated refueling infrastructure investments are capital intensive and require a predictable environment, with a pathway to positive long-term economic returns. Commitments in line with those for Battery Electric Vehicles would send a clear signal of that promise and encourage the sharing of R&D between these complementary technologies.*
- ***The Committee reasserts that the U.S. is still not on track to meet the 2020 EPACT Title VIII goals for FCEVs.*** *Evidence shows that even the 2015 Title VIII goals have still only partially been met, and only in California where state zero emission vehicle (ZEV) mandates (with favorable "travel provisions" that are well aligned with the Title VIII goals) exist.*
    - *DOE support is critical to continue efforts in material and process integration and technology acceleration in order to meet the 2020 goals. Rapid learning cycles and manufacturing scale economies are essential prerequisites to overcome challenges in reducing costs to competitive levels.*
    - *DOE support is also critical to ensuring positive retail hydrogen fueling experiences, especially during early stage vehicle and fueling infrastructure deployments.*
    - *Extending federal FCEV tax credits and power generation investment tax credits is an essential enabler to promoting fuel cell commercialization and achieving Title VIII goals.*
    - *The Department should provide an explicit plan in 2017-2018, including measureable milestones, stating how the 2015 and 2020 Title VIII goals will be achieved and how the plan will be funded.*
    - *The Clean Cities Program should continue its emphasis on actively promoting and educating consumers on FCEV and hydrogen technologies along with promoting compressed natural gas, biofuel, renewable diesel, and electricity solutions.*
- ***The Committee finds the Department's updated draft Hydrogen and Fuel Cells Program Plan to be comprehensive and should be effective in meeting its objectives with appropriate resource commitments.***

In addition to the 2016 HTAC Annual Report, I have enclosed a report of the HTAC's Safety and Event Response Subcommittee, which provides an assessment of the current status of resources and practices that support a comprehensive, consistent, and coordinated response to hydrogen safety-related events. This assessment was deemed necessary by the Committee because of the potential for even a single safety related fueling event to negatively influence public perception about hydrogen fuel cell vehicles. Ms. Catherine Dunwoody (Assistant Chief, Monitoring and Laboratory Division, for the California Air Resources Board) led this Subcommittee. She and her cross-cutting team of experts worked with the goal of enabling 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. The recommendations from the report are summarized below.

- ***Recommendation #1: Maximize the Role of the Hydrogen Safety Panel (HSP)***

  DOE should develop a strategic plan that ensures continuation of safety and event response R&D activities that are fundamental to overall Program success. This includes a key element to position the HSP as a trusted resource on hydrogen safety and invest in marketing to make the HSP more visible. The plan should also provide resources to enable the HSP to develop relationships with safety officials at the local, state, and national levels. At the same time, state and privately funded projects should also budget for HSP involvement,

- ***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.

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

  Hydrogen stations should be able to recover and reopen from safety-related incidents on a timeline similar to incidents at gasoline stations. Helping to establish clear event response decision tree procedures and response timelines is important in this regard.

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

  Hydrogen fuel is on a trajectory to be as familiar as gasoline fuel as we move toward low-carbon, zero-emission fuels. Federal and State agency coordination is critical to achieving that end, and enhanced efforts should be made to connect Federal and State level programs for shared learning and knowledge transfer.

Hydrogen and fuel cells have an integral role in your portfolio approach to ensuring our nation's energy security. As such, The HTAC respectfully asks that that appropriate resources continue to be dedicated to this program to meet its congressional intent and to help the country achieve its energy security goals. We look forward to continuing our service to you, your Department of Energy team, the Fuel Cell Technologies Office, and the nation in advancing this important subset of the 21st Century U.S. energy system. We welcome your feedback and any ideas about how we can best support you.

Sincerely yours,

Frank J. Novachek

Chairman, HTAC
On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee

2016 HTAC ANNUAL REPORT SUMMARY

This Annual Report of the United States (U.S.) Department of Energy (DOE) Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) highlights worldwide advances and challenges in 2016 regarding hydrogen and fuel cell commercialization, policy, regulations, standardization, financial climate, and research and development (R&D).

Progress in 2016 has moved hydrogen and fuel cells toward greater realization of their potential to provide reliable and efficient power, serve as an energy storage medium, and create U.S. manufacturing jobs. There were growing shipments in commercial markets, including motive, stationary and portable applications, and new technical milestones and cost reductions were reached through ongoing research, development & demonstrations (RD&D) conducted by national laboratories, industry and academia. Continued investment in R&D and vehicle fueling infrastructure will enable these technologies to fully contribute to the nation's energy security and domestic economic resilience. Highlights from 2016 include:

- **Progress on the DOE "Hydrogen at Scale" (H2@Scale) concept** introduced in 2015. H2@Scale addresses the potential of hydrogen production to enable resiliency of the power generation and transmission sectors, while simultaneously serving multiple domestic industries and reducing U.S. emissions. Preliminary analysis performed by the national laboratories on the H2@Scale concept indicated that wide-scale use of electrolytic hydrogen can reduce U.S. petroleum consumption by about 1.2 billion barrels per year. An in-depth analysis is now underway to project future price points of electrolytic hydrogen, and thereby more accurately estimate future demand and value proposition.
- **Introduction of a third commercial fuel cell electric vehicle (FCEV), the Honda Clarity Fuel Cell**, to California customers in December 2016. Toyota and Hyundai have sold or leased more than 1,000 FCEVs in the U.S. and nearly 3,000 worldwide through late 2016.[1]
- **The addition of 18 retail hydrogen stations in California**, with a total of 25 hydrogen stations operating in the state at the end of the year.[2]
- **An announcement by Toyota and Air Liquide of the locations of the first four northeast public hydrogen stations, to be sited in Connecticut, New York, and Massachusetts.** These are the first in an initial 12-station refueling network that will span 300 miles across five states to support the introduction of FCEVs.[3]
- **Development of the Hydrogen Station Equipment Performance (HyStEP) testing device to validate operation of new hydrogen stations**. The open-source designs, developed by Sandia National Laboratories and the National Renewable Energy Laboratory, can be used to accelerate hydrogen fueling station deployment.[4]
- **The sale of approximately 50,000 Ene-farm residential fuel cell systems in Japan**, with a total of 190,000 Ene-farm fuel cells installed since 2009.[5]
- **Ten percent growth in natural gas fuel cell power generation installations, dominated by U.S. companies and technology.**[6]

Despite ongoing progress, challenges remain for the hydrogen and fuel cell industry. These challenges include:

- Reducing hydrogen cost from renewable resources below $2/kilogram, a key to the success of H2@Scale.
- Additional reductions in catalyst material costs for membrane electrode assemblies (MEAs) for low temperature fuel cell and electrolyzer systems.
- Better system integration and reduced component costs for lower balance-of-plant costs.
- Improvements in manufacturing processes and yield rates for electrolyzer and fuel cell system manufacturing.
- Reduction in components costs, improved compressors and metering/metrology for hydrogen refueling stations.
- Lower cost and simpler systems for continuous monitoring of impurities and contaminants in hydrogen gas streams.

In addition, two federal tax credits expired at the end of 2016: the 30 percent Investment Tax Credit (ITC) for stationary fuel cell systems and forklifts; and the Fuel Cell Motor Vehicle Tax Credit of up to $8,000. Expiration of these incentives is expected to significantly slow adoption.

Evidence suggests the U.S. is still not on track to meet the 2020 goals for hydrogen FCEVs and refueling infrastructure set by the U.S. Energy Policy Act of 2005 (EPACT) Title VIII. In response to the Committee's recommendation on this issue in 2015, DOE committed to provide the Committee a strategy paper outlining a pathway toward those goals. The Committee stands ready to provide feedback on that paper once it is developed.

The hydrogen and fuel cell industries made steady progress in 2016, with ongoing R&D developments and growing sales in the stationary, transportation, backup, off-grid, military and material handling sectors. Significant developments include:

- Three automakers now sell commercial FCEVs in the U.S. (California), Asia, and Europe. In California, 1,074 FCEVs were sold or leased in 2016, up from 112 FCEVs sold or leased in 2015.[7] Worldwide sales approached 3,000 units.
- Twenty-five retail hydrogen stations were open in California at the end of 2016, up from six in 2015, and more stations are in development.[8] Ninety-two new stations were opened worldwide.[9]
- Twenty-four fuel cell buses carry transit riders in the U.S. (California, Delaware, Massachusetts, Michigan, Ohio) and more deployments are planned. Fuel cell bus durability reached 23,000 hours, surpassing the DOE and FTA 2016 target of 18,000 hours, and range has reached up to 340 miles, more than 13 percent above the 2016 target.[10] Average fuel economy is 1.4 to 1.9 times higher than conventional diesel buses.[11]
- The number of fuel cell residential combined heat and power (CHP) units in Japan is approaching 200,000 with about 50,000 Ene-farm systems deployed in 2016.
- The H2@Scale concept moved beyond the National Lab team and DOE offices to include industrial/other stakeholders. The concept describes the potential for multi-sector energy benefits of wide-scale renewable hydrogen production.
- The California Fuel Cell Partnership (CaFCP) released a Medium & Heavy-Duty Fuel Cell Electric Truck Action Plan. Categories selected as the most feasible near-term vehicle platforms are the Class 4-6 urban "last mile delivery" trucks and Class 7-8 short haul/drayage trucks.

Unfortunately, 2016 also saw the expiration of the federal Investment Tax Credit (ITC) for most non-solar renewable energy technologies, including fuel cells and hydrogen. A federal FCEV tax credit of up to $8,000 also expired at the end of 2016. The expiration of these incentives is expected to significantly slow adoption rates.

Industry Metrics

Key industry metrics, reported in an annual assessment by E4Tech, *The Fuel Cell Industry Review 2016*, show worldwide fuel cell shipments increased by two-thirds on a megawatt basis, growing from 298 megawatts (MW) to 478 MW. On a unit basis, global fuel cell shipments grew from almost 61,000 units in 2015 to more than 65,000 in 2016. The increase in unit shipments, combined with a large increase in megawatts shipped, indicates many shipments were larger units.[12]

North American unit shipments grew slightly, from 6,900 fuel cells in 2015 to 7,300 in 2016, but on a megawatt basis, North America almost doubled the previous year's shipments, growing from 108 MW in 2015, to 209 MW in 2016.[13]

Asia supplied almost 54,000 of the total global shipments of more than 65,000 fuel cell units. Asia also shipped almost 246 MW, more than half of the 2016 global total of 478 MW.[14]

In 2016, FCTO reported other milestones, including:[15]

- More than 4 million passengers on fuel cell buses;
- More than 11,000 fuel cell forklifts in operation;
- More than 1,100 FCEVs sold or leased in the U.S.;
- More than 1.5 million hydrogen refuelings;
- The finding that 10-kW solid oxide fuel cell (SOFC) systems in volume production (50,000 units annually) would meet the DOE 2020 equipment cost target.[16]

Fuel cell technology was originally developed in the U.S. Despite aggressive, well-funded competition from Europe and Asia, U.S. products and technology still hold a strong position. Fully commercializing fuel cell technologies will mean significant high-wage job growth and economic gains for American companies. Figure 1 highlights the impact of DOE's fuel cell and hydrogen RD&D activities and U.S. job potential.

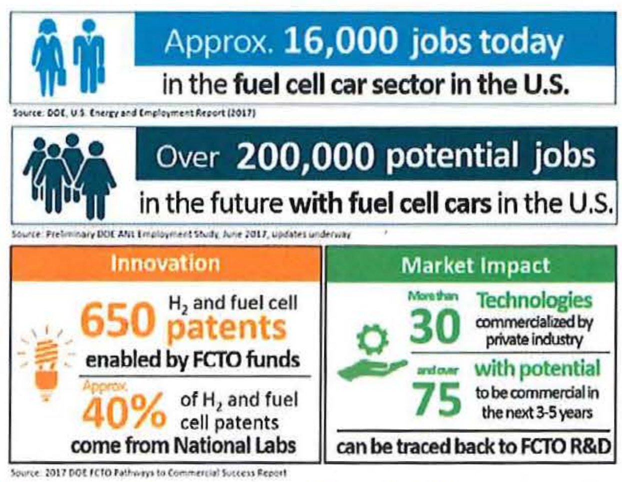


Figure 1: Fuel Cell Technologies Office (FCTO) Program Impact: H2 and Fuel Cells. *Source: DOE FCTO*

EPACT 2020 Goals

2016 accomplishments are important as the year 2020 approaches – a milestone year highlighted in Title VIII of the U.S. Energy Policy Act of 2005 (EPACT), which set forth the following goals for FCEV commercialization:

1) "To enable a commitment by automakers no later than year 2015 to offer safe, affordable, and

technically viable hydrogen fuel cell vehicles in the mass consumer market and to enable production, delivery, and acceptance by consumers of model year 2020 hydrogen fuel cell and other hydrogen-powered vehicles that will have, when compared to light duty vehicles in model year 2005: 1) fuel economy that is substantially higher; 2) substantially lower emissions of air pollutants; and 3) equivalent or improved vehicle fuel system crash integrity and occupant protection;" and

2) "To enable a commitment not later than 2015 that will lead to infrastructure by 2020 that will provide: 1) safe and convenient refueling; 2) improved overall efficiency; 3) widespread availability of hydrogen from domestic energy sources; and 4) hydrogen for fuel cells, internal combustion engines, and other energy conversion devices for portable, stationary, micro, critical needs facilities, and transportation applications."

Considerable progress has been made toward these goals since 2005, and the 2015 commitments have been partially met. Efforts such as H_2USA have brought industry and government together working in important ways toward these goals. FCEVs by three manufacturers have now been fully safety certified and offered for sale or lease; more are expected in the 2018–2020 timeframe. In the U.S. this progress has been mostly driven by state-level zero emission vehicle (ZEV) programs. Support does not appear to be adequate to spur the momentum needed to achieve the 2020 EPACT goals.

In response to the Committee's recommendation on this issue in 2015, Acting Assistant Secretary David Friedman committed to developing a strategy paper outlining steps toward the 2020 goals. The Committee stands ready to provide feedback on that strategy once it is developed.

Significant Challenges Remain

The efficiency and environmental advantages of hydrogen and fuel cells are well demonstrated and the economic and manufacturing potential is well understood. Significant strides have been made over the last decade to improve electrolyzer and fuel cell performance and durability, and to lower costs. Fuel cells are now making inroads in early commercial markets (material handling, backup power, military, specialty products) and as an alternative option to conventional power generation.

Despite these successes, challenges remain. DOE has set technical goals and objectives to advance hydrogen production and fuel cell technologies for transportation, power generation and other market applications. The 2020 objectives include:[17]

- A 65 percent peak-efficient, direct hydrogen fuel cell power system for transportation that can achieve 5,000-hour durability (ultimately 8,000 hours) and be mass produced at a cost of $40/kW (ultimately $30/kW).
- Distributed generation and micro-CHP (combined heat and power) fuel cell systems (5 kW) operating on natural gas that achieve 45 percent electrical efficiency and 60,000-hour durability at an equipment cost of $1,500/kW.
- Medium-scale CHP systems (100 kW–3 MW) that achieve 50 percent electrical efficiency, 90 percent CHP efficiency and 80,000-hour durability at a cost of $1,500/kW for operation on natural gas and $2,100/kW when configured for operation on biogas.

The current status of technology development has been reported by DOE in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (updated September 2016).[18]

For light-duty vehicles, current cost modeling (2015) places the cost of an 80-kW net automotive fuel cell system based on next-generation technology and operating on direct hydrogen at $53/kW when manufactured at a volume of 500,000 units/year and $60/kW at a volume of 100,000 units/year.

For CHP systems, the plan finds that common challenges across all fuel cell types include decreasing cost and increasing durability and cell component stability. For PEM systems, challenges also include decreasing fuel processor costs and raising operating temperatures.

- While durability of residential micro CHP systems has been improved to 70,000 hours for PEM systems, the price of deployed systems (Germany, Japan) is approximately $22,000/kW for a 0.7-kW system, substantially higher than DOE cost targets.
- For medium-scale CHP/distributed generation (100 kW–3 MW), phosphoric acid fuel cells (PAFCs) and molten carbonate fuel cells (MCFCs) have demonstrated durability of >80,000 hours and >40,000 hours respectively. Increasing MCFC durability requires, among other things, a more robust cathode. Reducing PAFC costs requires increasing performance, durability and stability for catalysts and supports.
- Common technical challenges for MCFCs and PAFCs include reducing system conditioning time, developing low-cost manufacturing methods, and decreasing the cost of the fuel processor and cleanup system.
- SOFCs have demonstrated durability of >25,000 hours. High operating temperature can lead to compatibility and reactivity issues among cell and stack components, especially over extended operating times. The ability of the stack to survive repeated thermal cycling and the relatively long start-up times are additional challenges.
- DOE cost estimates for a 100-kW low temperature - PEM CHP system show that balance of plant, catalyst and fuel processor costs are the main contributors to system costs. Increasing the temperature of operation could help simplify the fuel processor, reduce costs, and provide higher quality waste heat.

Hydrogen R&D

DOE's hydrogen program has made significant R&D progress in hydrogen production, storage and delivery over the past several years. DOE continued to advance the Hydrogen at Scale Big Idea concept initiated in 2015. This project shows great potential for hydrogen and fuel cell technologies to enable resiliency of the power generation and transmission sectors, while simultaneously serving multiple domestic industries and reducing U.S. emissions.

- A workshop on the cross-cutting value proposition of H2@Scale was held November 16-17, 2016, at the National Renewable Energy Laboratory, with representation from 10 DOE offices and a total of about 170 attendees. The workshop was meant to guide the development of an H2@Scale roadmap, which is currently being drafted. The workshop report is now online: http://www.nrel.gov/docs/fy17osti/68244.pdf.
- Analysis has been completed on the technical potential of hydrogen demand and hydrogen supply from domestic resources (including renewable, nuclear, and fossil fuel feedstock). The technical potential of demand for refining, direct reduction of iron, ammonia production, use of hydrogen as a combustion fuel (via blending into the natural gas infrastructure), biofuels production, and transportation (i.e. FCEVs) has been determined to be 60 million metric tonnes per year.

The cost and durability of electrolyzers and other hydrogen production technologies need improvement to enable greater customer acceptance which will drive manufacturing volume and, in turn, enable further cost reductions. Growing markets can also stimulate infrastructure development and resolve other key challenges.

Reducing electrolytic hydrogen production costs below $2/kilogram would enable success of the H2@Scale concept and improve U.S. competitiveness within this market.

Natural gas can provide a cost effective hydrogen source for initial fueling infrastructure, but continued R&D is needed to bring renewable hydrogen to equal or lower generation costs (Figure 2). Factors such as the cost of feedstock electricity and technology utilization, or capacity factor, have a significant impact on electrolytic hydrogen production costs.

The initial costs for capital equipment, manufacturing processes, installation, and warranty associated with fuel cell and electrolyzer systems need to be reduced.

In spite of these challenges, fuel cell and hydrogen R&D conducted over the past decade has spurred significant and ongoing cost, performance and durability improvements. Today, hydrogen and fuel cell technologies are making inroads into several early market areas where reliability and efficient power generation are valued.

HTAC Activities In 2016

HTAC activities in 2016 included formation of three new HTAC subcommittees.

EXTERNAL COMMUNICATIONS: This subcommittee will develop a standard communications package that consolidates a vision, objective and supporting messages for implementing hydrogen & fuel cell technology.

Key Deliverables: The primary focus is to provide communications resources online, accessible by industry, government stakeholders and the public. The subcommittee has identified messaging gaps and subcommittee members have gathered content, organizing it into packages in the areas

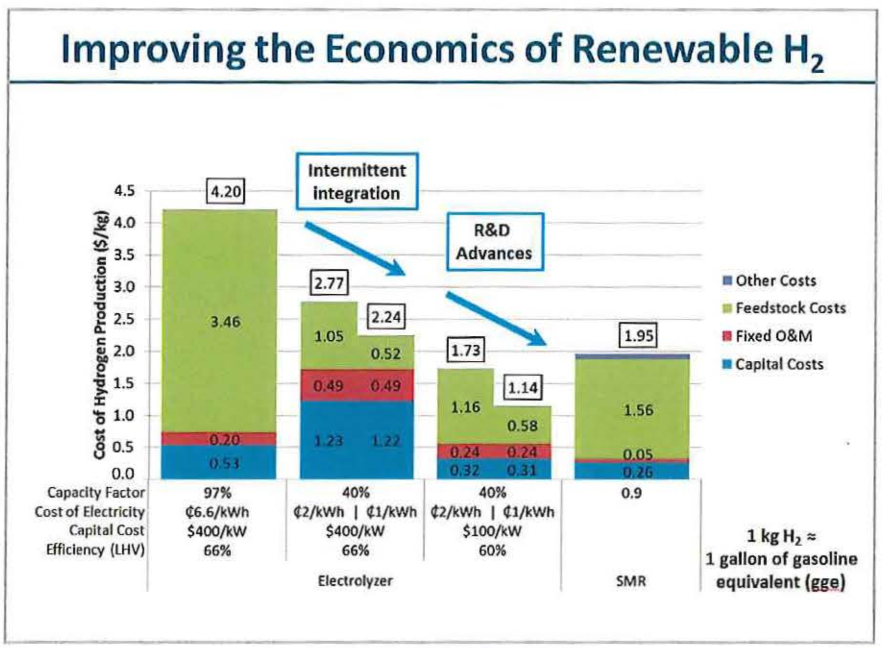


Figure 2. Improving the Economics of Renewable Hydrogen. *Source: U.S. Department of Energy*

of hydrogen, fuel cells, and electrolysis. A question-answer section will provide a streamlined location for users to review expert responses to frequently asked questions. The subcommittee plans to launch the site in 2017.

SAFETY/EVENT RESPONSE: The subcommittee has prepared a report identifying existing resources and resource gaps for responding to safety related events at retail hydrogen stations and recommended actions to address current and projected needs. The subcommittee's goal is to enable a comprehensive, consistent (to the extent practical) and coordinated response to hydrogen safety-related events to understand causes, address issues, share learnings, communicate status and maintain focus on advancing commercialization of hydrogen fuel.

Key Deliverables: The subcommittee has completed a final report that addresses technical, procedural and communications topics, identifies gaps, and offers the subcommittee's recommendations.

HYDROGEN AT SCALE CONCEPT REVIEW: The Committee actively monitored development of the H2@Scale concept. Project leads updated HTAC at both 2016 meetings. Individual members also participated in H2@Scale workshops held to solicit and incorporate feedback.

Hydrogen presents a unique potential to positively impact a number of areas. The H2@Scale value summary includes:

- Reducing greenhouse gas emissions and criteria pollutants across industrial, electrical, and transportation sectors. Analyses show that a 50 percent reduction in greenhouse gas emissions is possible by 2050.
- Supporting the needs of dynamic, variable power systems, including dispatchable, scalable storage. Additional benefits include energy security via energy diversity, resiliency and domestic energy production, manufacturing competitiveness and job creation, and decreased water requirements.

Figures 3 and 4 (next page) show the potential for sustainable hydrogen to support future energy needs across multiple sectors.

Commercialization Initiatives

Fuel cells are making significant inroads into an array of commercial sectors, including stationary power markets (primary and backup power), transportation markets (passenger vehicles, buses, trucks, rail, and forklifts), electricity grid-support applications, specialty (unmanned vehicles, aviation) and portable/off-grid applications (military, small electronics). Hydrogen, as an industrial chemical, also has broad impact for ammonia production, metal and semiconductor processing and refining of petrochemicals.

To help U.S. suppliers connect to original equipment manufacturers (OEMs) to improve the fuel cell industry supply chain, DOE supported the launch of Hydrogen Fuel Cell Nexus website in July. Managed by Virginia Clean Cities, the website serves as a business-to-business portal.[19]

Fuel Cells for Stationary Applications

Demand for stationary fuel cells continues to grow in both commercial and municipal applications. Systems finding markets range from micro-CHP systems to multi-MW power plants. More than 200 MW of stationary fuel cells were shipped globally in 2016, compared to 183 MW in 2015.[20]

- Bloom Energy has new or planned natural gas-powered fuel cell projects at more than 200 locations, including 40 MW at 170 customer sites for Exelon, 60 Home Depot stores integrated into Southern Company/ PowerSecure smart storage solutions, and 1.5 MW at five IKEA retail stores (Figure 5).
- Doosan Fuel Cell America partnered with Samsung C&T Corp. and Korea Hydro & Nuclear Power on a project that will supply power to 71,500 Korean homes. Seventy fuel cells will produce 30.8 MW of energy and heat.[21] Doosan also will deliver an 8-MW CHP system to Implats' South African platinum refinery.[22]
- FuelCell Energy installed a 5.6-MW CHP fuel cell power plant at Pfizer's Connecticut R&D facility.[23] FuelCell Energy has new or planned MW-scale fuel cell projects at wastewater treatment plants in Tulare and Riverside, California, and at two locations in Germany.[24]
- The European Commission's Fuel Cell and Hydrogen Joint Undertaking (FCH JU) announced it will provide almost 34 million € (US $36 million) to fund the PACE initiative, which will deploy 2,650 micro-CHP fuel cells in European to foster commercialization.[25]
- About 50,000 Ene-farm micro-CHP fuel cells were installed in Japanese homes in 2016, bringing the total installed since 2009 to more than 190,000 (Figure 5).[26]

Source: BloomEnergy.com *Source: OsakaGas.jp.co*

Figure 5: Bloom Energy fuel cells at IKEA store, Ene-farm system.

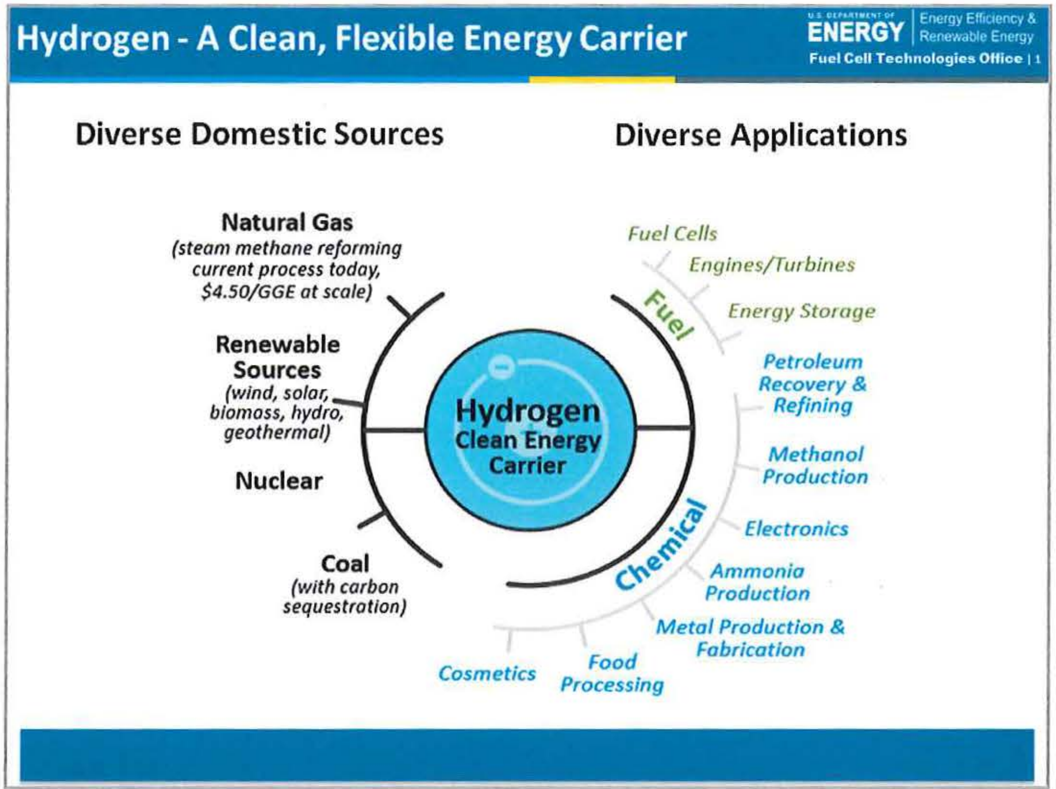
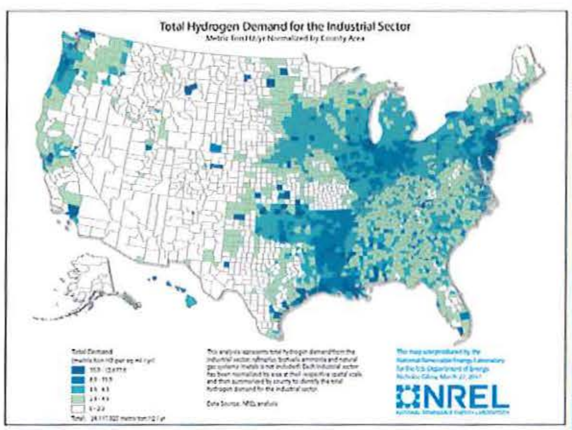


Figure 3. H2@Scale – hydrogen enables diverse feedstocks and applications. *Source: U.S. Department of Energy*

Initial Analysis: U.S. Hydrogen Demand Potential



Use	Market potential (million metric tonne H_2 / year)
Industrial Use	
Refineries & CPI[§]	8*
Metals	5
Ammonia	5
Natural Gas	7
Biofuels	4
Light Duty Vehicles	28
Other Transport	3
Total	**60**

Total market potential: 60 MMT/yr

Current U.S. market: ≈ 10 MMT/yr

Global H_2 production revenue: 6% CAGR, 2009-2016[1]

§ CPI: Chemical Processing Industry not including metals, biofuels, or ammonia
* Current potential used due to lack of consistent future projections
Light duty vehicle calculation basis: 190,000,000 light-duty FCEVs from http://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels
1. Global hydrogen Generation Market by Merchant & Captive Type, Distributed & Centralized Generation, Application & Technology- Trends & Forecasts (2011-2016)

NATIONAL RENEWABLE ENERGY LABORATORY 6

Figure 4. U.S. Hydrogen Demand Potential. *Source: U.S. Department of Energy*

Fuel Cells for Back-up Power Applications

More than 900 back-up power fuel cell systems have been deployed with DOE support, stimulating an more than 6,900 back-up power fuel cell shipments and orders with no DOE funding. These total more than 39 MW.[27]

In addition:

- Ballard Power Systems signed an agreement for a Chinese company to exclusively manufacture and sell Ballard's fuel cell backup power systems in China.[28]
- Proton Power signed a seven-year agreement with a German company for fuel cell emergency power units to be deployed in the Bavaria region of Germany.[29]

Fuel Cells for Passenger Cars

Automakers are selling and leasing increasing numbers of FCEVs around the globe.

- Three automakers now lease or sell FCEVs in California (Figure 6). Honda began deliveries of its 2017 Clarity in December. Toyota reduced the down payment and monthly lease payment on its 2017 Mirai FCEV, which was introduced in late 2015. Hyundai began leasing its Tucson FCEV in 2014 and has announced an update for 2018.[30]
- Several car companies committed to initial or next-generation commercial fuel cell vehicle rollouts, including Mercedes-Benz and Lexus.[31]
- Honda and GM announced a Fuel Cell System Manufacturing Joint Venture, based in Brownstown, Michigan. Production will begin sometime after 2020. This partnership's primary goal is system cost reduction.
- Nissan is researching and developing a SOFC-powered vehicle system that runs on bio-ethanol.[32]

Fuel Cells for Buses

Fuel cell buses are operating in revenue service in the U.S., Asia and Europe. Fuel cell buses are a particular interest in China, which has quickly become a world leader. Hyundai, New Flyer, Toyota, and Wrightbus announced plans to produce fuel cell buses. Other key developments include:

- The AC Transit fleet of 13 fuel cell buses is approaching 2 million miles and has carried more than 15 million passengers. The initial bus, built in 2003 and never expected to survive beyond 5,000 hours, has now exceeded 23,450 hours and remains in daily service. Four others are near or beyond the 20,000-hour mark.[33]
- The Federal Transit Administration (FTA) awarded Ohio's Stark Area Regional Transit Authority (SARTA) funds to buy three more buses, bringing its fuel cell bus fleet to 10 – the largest in the U.S. outside California.[34]
- The Fuel Cell Electric Bus Commercialization Consortium (FCEBCC) will deploy 20 fuel cell buses at two California transit agencies by December 2018. Ballard Power Systems will supply fuel cells for FCEBCC's 20 buses, for SARTA's 10 buses, and for California's Orange County Transportation Authority's (OCTA) American Fuel Cell Bus (Figure 7).[35] Ballard also is supplying modules for Solaris in Europe[36] and for 22 fuel cell buses operating in China.[37]
- The U.K. government awarded £2.8 million (US$3.6 million) to Birmingham City Council and Transport for London for 42 fuel cell buses.[38]
- Toyota and Wrightbus each announced they will make fuel cell-powered buses available in 2017. Toyota's bus features a high-capacity external power supply that can be used as a power source in an emergency.
- New Flyer of America's 60-foot electric heavy-duty transit bus, which incorporates a small Ballard Power Systems fuel cell operating as an on-board battery charger, will be tested at the FTA's proving grounds.[39]

Fuel cells are being utilized in a number of vehicles, including material handling vehicles, aircraft, ships, trucks, and unmanned vehicles. Among the 2016 announcements were:

- Plug Power announced new orders and deployments, including 96 additional fuel cells for forklifts in New Jersey's Newark Farmers Market, which already operates 240 units, and several orders from French companies.[40]
- A new class of ships, in 2022, from Royal Caribbean Cruises, will use fuel cell power generation. They will test fuel cells on an Oasis-class ship in 2017.[41]
- General Motors and the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) developed the off-road capable Chevrolet

Source: Toyota.com *Source: HyundaiUSA.com* *Source: Honda.com*

Figure 6: Toyota Mirai, Hyundai Tucson, and Honda Clarity FCEVs.

Colorado ZH_2 FCEV; it features an Exportable Power Take-Off unit to power activity away from the vehicle (Figure 7).[42] GM and the U.S. Navy have also partnered on fuel cells for unmanned undersea vehicles.[43]

- Kenworth is building a fuel cell truck for drayage operations at a Southern California port.[44]
- EasyJet disclosed plans to use fuel cells on aircraft for taxiing, saving up to 50,000 metric tons of fuel a year.[45]
- Alstom presented its Coradia iLint fuel cell-powered train, with a range of up to 500 miles per fueling (Figure 7). The train will be tested in 2017.[46] The German state of Schleswig-Holstein plans to electrify its entire railway network using fuel cell equipment by 2025.[47]
- H3 Dynamics unveiled a fuel cell-powered unmanned aerial vehicle (UAV) capable of 10 hour/300 mile flight.[48]

Hydrogen Production and Distribution

Milestones in hydrogen production and distribution include the opening of 13 retail hydrogen stations in California, for a total of 25 public stations at the end of 2016. True Zero announced its California stations had powered 2 million miles of FCEV driving, attaining this milestone just 60 days after reaching the first million. It took nine months to reach the first million.[49]

- Hydrogenics and StratosFuel will build a 2.5 MW renewable hydrogen plant, North America's largest, in Palm Springs, California, using wind and solar power.[50]
- Proton OnSite announced a 13 MW electrolyzer order for bus fueling in China and supplied an electrolyzer to produce renewable hydrogen for Switzerland's first public hydrogen station.[51]
- A demonstration hydrogen station was opened in Washington, D.C., through a partnership of Proton OnSite, SunHydro, Air Products, DOE and the National Park Service.[52]
- Toyota and Air Liquide will open four retail hydrogen refueling stations in 2017 in Connecticut, New York, and Massachusetts. The stations are part of a network of 12 retail hydrogen stations spanning 300 miles across five northeastern states that will support FCEVs.[53]
- Japan's Ministry of Economy, Trade and Industry outlined a plan for 160 hydrogen stations in 2021, growing to 320 in 2026. Toshiba, Tohoku Electric Power and Iwatani plan to produce enough hydrogen for 10,000 FCEVs annually using solar and wind power.
- Royal Dutch Shell, Kawasaki Heavy Industries, Iwatani and J-Power are partnering to produce hydrogen from low-quality brown coal in Australia and ship it to Japan markets.[54]
- H_2 MOBILITY, a joint venture of Air Liquide, Daimler, Linde, OMV, Shell, and Total, plan to develop up to 400 hydrogen stations in Germany by 2023.[55]

Hydrogen for Grid Support Applications

- FuelCell Energy announced a solid oxide electrolysis cells (SOEC) system that converts water into hydrogen during periods of excess electricity and low demand.[56]
- University of California, Irvine, engineers implemented the first U.S. power-to-gas (P2G) hydrogen pipeline injection, demonstrating how electricity from solar or wind can be used to make hydrogen and integrated into existing natural gas pipelines.[57]
- Japan's Obayashi and Kawasaki Heavy Industries, working with Kansai Electric Power, plan to use hydrogen to generate power in Kobe in 2018 via turbines using 80 percent natural gas and 20 percent hydrogen, with 100 percent hydrogen operation considered in the future.[58]

Policy, Regulations, Codes, and Standards

Policy and Regulations

Two federal tax credits expired at the end of 2016: 1) the 30 percent Investment Tax Credit (ITC) for stationary fuel cell systems and forklifts, and 2) the Fuel Cell Motor Vehicle Tax Credit of up to $8,000 on light-duty FCEVs. Expiration of the incentives is expected to slow adoption rates.

State policy developments include:

- Ongoing and new state-level FCEV purchase incentives, including in California ($5,000, and a new $7,000 incentive for low income drivers), Connecticut

Source: GM.com   Source: Alstom.com   Source: Ballard.com

Figure 7: GM/TARDEC's ZH2 vehicle, Alstom's fuel cell train, and Orange County's American Fuel Cell Bus.

(increased to $5,000 from $3,000), Massachusetts ($2,500), Pennsylvania ($1,000), and New York (up to $2,000, starting in 2017).

- Continuation of capital cost support for stationary fuel cell systems under California's Self-Generation Incentive Program, New York's Fuel Cell Program, and Pennsylvania's Alternative and Clean Energy Program.
- New policies that support stationary fuel cells, such as tax incentives, feed-in tariffs and sustainable energy goals, were implemented in five states (Connecticut, Delaware, Massachusetts, New York, and Rhode Island).

Noteworthy policy events in 2016 in the United States included a June 23 Congressional Fuel Cell and Hydrogen Policy Briefing on Capitol Hill, celebration of the second National Hydrogen and Fuel Cell Day on October 8, and a November 17 Hydrogen and Fuel Cell Forum in Hartford, Connecticut.

Codes and Standards

Codes and standards activities during the year include:

- Publication of the International Organization for Standardization (ISO) TS 19880-1 for hydrogen fueling stations, a first step towards standardizing hydrogen filling stations, superseding guidance developed as the earlier ISO TS 20100, published in 2008. The scope covers the processes from hydrogen production and delivery to compression, storage and fueling.[59]
- Publication of CSA Group's standard HGV 4.9, *Hydrogen fueling stations,* the first standard published for an entire hydrogen fueling station.[60]
- Passage of legislation in Connecticut allowing hydrogen-fueled vehicles to be parked under grade level.[61]

Financial Climate

Key finance and partnership agreements in 2016 include:

- FuelCell Energy and Exxon Mobil agreed to pursue a new application of carbonate fuel cells that captures carbon dioxide more efficiently than conventional technology, with the potential to substantially reduce capture costs for natural gas-fired power generation.[62]
- Cenovus Energy contracted with FuelCell Energy for front-end design and engineering for a fuel cell system to capture CO_2 from flue gas of boilers used to make steam in oil sands production at a 14-MW natural gas-fired co-generation facility in Alberta, Canada.[63]
- A strategic alliance was formed between Bloom Energy, Southern Company and its subsidiary PowerSecure, for project investment and joint-technology development.
- Hydrogenics and SinoHytec established a strategic partnership for the delivery of fuel cells designed for the Chinese market. The power systems will be integrated into buses and trucks in China.[64]
- Plug Power and two Chinese companies signed a Memorandum of Understanding to develop fuel cell and hydrogen fueling solutions for China's industrial electric vehicle market. The project's long-term goal is to deliver 13,500 industrial fuel cell vehicles over three years with a widespread hydrogen fueling network.[65]
- FuelCell Energy entered into a long-term loan facility with Hercules Capital for up to $25 million.[66]

Research and Development

Research and development activities focusing on hydrogen and fuel cell technologies continues at a steady pace in industrial, government lab, and university settings.

The U.S. DOE continued to advance the H2@Scale Big Idea concept initiated in 2015. This project shows great potential for hydrogen and fuel cell technologies to support multiple demands in transportation and industry (Figure 8), enabling dramatic emission reductions across many sectors/industries.

DOE's Advanced Research Projects Agency-Energy (ARPA-E) announced two new projects:

- The Integration and Optimization of Novel Ion-Conducting Solids (IONICS) projects will work to create high performance solid ion conductors that allow ions to be mobile and store energy, serving as a lower cost, high-performance alternative to parts used today.[67]
- The Renewable Energy to Fuels through Utilization of Energy-dense Liquids (REFUEL) program supports research on technologies that use renewable energy to convert air and water into cost-competitive liquid fuels.[68]

In addition:

- Researchers at UCLA and Caltech demonstrated how altering nanoscale wires from a smooth surface to a jagged one could dramatically reduce the amount of precious metal used as fuel cell catalysts.[69]
- Researchers at Sandia National Laboratories patented a polyphenyline membrane for PEM fuel cells that operates over a wide temperature range and lasts three times longer than comparable commercial products.
- Researchers at Stanford University developed solar cells that, after electrolysis, capture and store 30 percent of the energy from sunlight into stored hydrogen.[70]

Important areas for additional R&D include:

- Additional reductions in catalyst material costs for MEAs for low temperature fuel cell and electrolyzer systems, while maintaining durability over time.
- Optimized porous transport layers for electrolyzers to enable high current density and high catalyst utilization.
- Improved membranes for high efficiency and durability over a range of operating conditions.

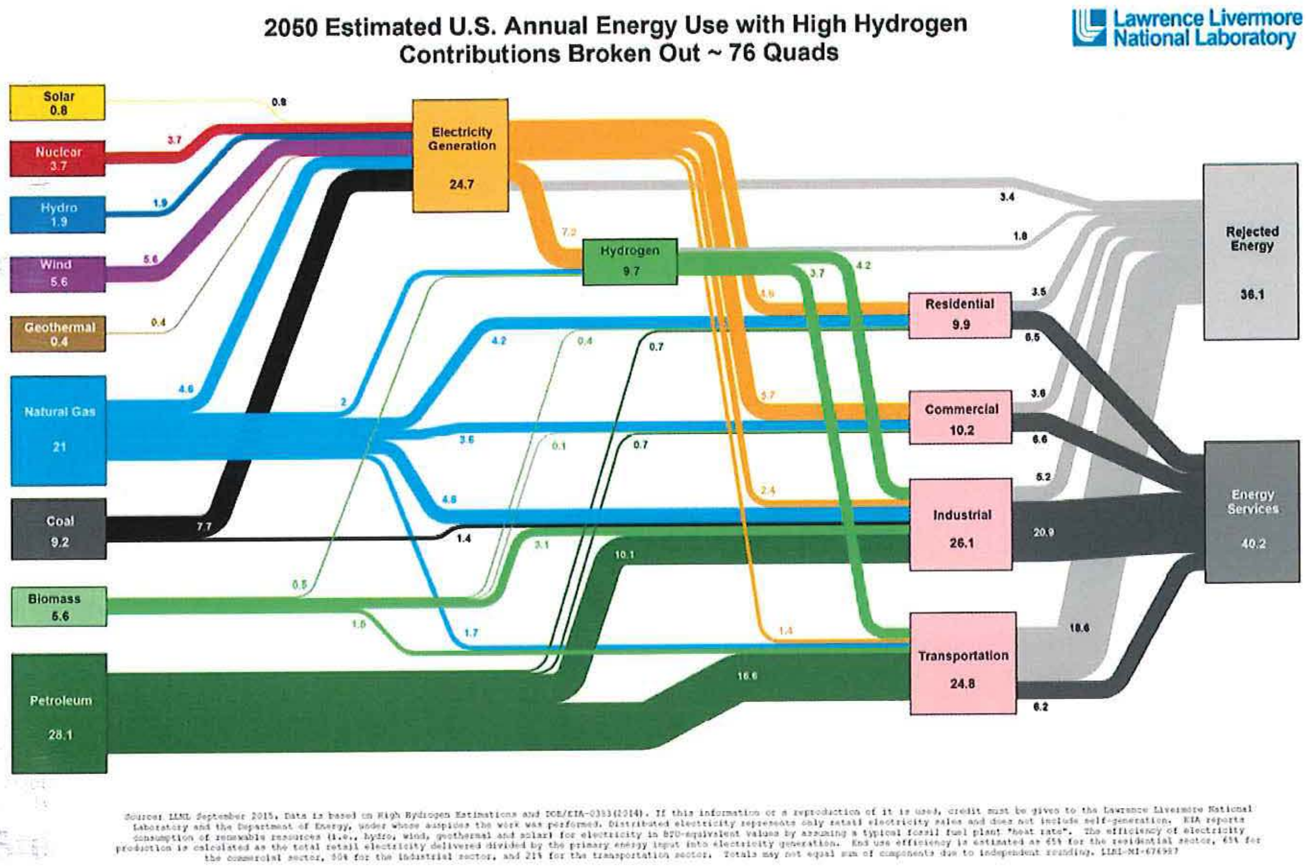


Figure 8: H2@Scale – Hydrogen Enables Diverse Feedstocks and Applications. *Source: U.S. Department of Energy*

- Better system integration and reduced component costs for lowered balance-of-plant costs.
- Improvements in manufacturing processes and yield rates for electrolyzer and fuel cell stacks and systems.
- Reduced component costs, improved compressors, and improved metering/metrology for hydrogen refueling.
- Improved and simpler systems for continuous monitoring of impurities and contaminants in hydrogen and reformate gas streams, with lowered costs.

Figure 9 presents the current cost and durability status and targets for various fuel cell market sectors.

Studies and Reports

Key reports were released in 2016 include:

- The DOE's *2015 Fuel Cell Technologies Market Report*[71]
- The DOE's *State of the States: Fuel Cells in America 2016*[72]
- The National Renewable Energy Laboratory (NREL)'s *Fuel Cell Buses In U.S. Transit Fleets: Current Status 2016*[73]
- California's *2016 ZEV Action Plan*[74]
- The California Air Resource Board's *2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*[75]
- The California Fuel Cell Partnership's *Medium & Heavy-Duty Fuel Cell Electric Truck Action Plan for California*[76]
- The Northeast Electrochemical Energy Storage Cluster (NEESC) analysis *Economic Impact of the Northeast Hydrogen and Fuel Cell Industry*[77]
- The Fuel Cell and Hydrogen Energy Association's *2015 State Policy Activity Wrap Up: Fuel Cells & Hydrogen*[78]

Federal R&D Budget

U.S. government support for hydrogen and fuel cell technology development efforts has remained relatively constant in recent years, with $101 million in funding allocated for FY 2017 for the Fuel Cell Technologies Office, about the same as in FY 2016. However, this is approximately $100 million lower than the historical peak funding level of over $200 million.

Budget details are shown in Figure 10.

Fuel Cell Type	Cost & Durability Status[a]	Cost and Durability Target[a]
Backup Power (direct hydrogen, 1-10 kW)	$6,100/kilowatt (kW) 8,000 hours (h)	$1,000/kW 10,000 h
Medium Scale CHP (natural gas, 100 kW – 3 MW)	$1,200 - 4,500/kW 40,000-80,000 h	$1,000/kW 80,000 h
APUs (diesel, 1-10 kW, system)	$2,100/kW 3,000 h	$1,000/kW 20,000 h
Buses	$800,000 +20,000 h	$600,000 25,000 h
Automotive (direct hydrogen, 80 kW, system)	~$53/kW 4,100 h (on road)[b]	$30/kW ($40/kW by 2020) 8,000 h
Portable Power (100 – 200 watts)	$15/watt 2,000 h	$5/kW 5,000 h

[a] Unless otherwise noted, all data is from the U.S. DOE, Fuel Cell technologies Office, Multi-Year Research, Development and Demonstration Plan, 2016 Fuel Cells section, https://energy.gov/sites/prod/files/2016/10/f33/fcto_myrdd_fuel_cells.pdf.

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Figure 9: Cost and Durability Status and Targets for Various Fuel Cell Market Sectors.

Hydrogen & Fuel Cells Budget

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
Fuel Cell Technologies Office | 1

Key Activity	FY 15	FY 16	FY17
	($ in thousands)		
	Approp.	Approp.	Enacted
Fuel Cell R&D	33,000	35,000	32,000
Hydrogen Fuel R&D[1]	35,200	41,050	41,000[1]
Manufacturing R&D	3,000	3,000	-
Systems Analysis	3,000	3,000	3,000
Technology Validation	11,000	7,000	-
Safety, Codes and Standards	7,000	7,000	7,000
Market Transformation	3,000	3,000	-
Technology Acceleration[2]	0	0	18,000[2]
NREL Site-wide Facilities Support	1,800	1,900	N/A
Total	97,000	100,950	101,000

Office	FY 2016
EERE	$101.0M
Basic Science	$24.7M
Fossil Energy, SOFC	$30.0M

FY 2016 DOE Total: ~$156M

New in FY17

[1] Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

[2] Combines Manufacturing R&D, Technology Validation, and Market Transformation

Figure 10: Recent DOE Funding for Hydrogen and Fuel Cells R&D. *Source: U.S. Department of Energy, Fuel Cell Technologies Office*

Conclusion

Fuel cell and hydrogen technologies continue to show progress and the overall outlook is promising. Fuel cells are making inroads in a variety of applications, including stationary, backup, off-grid and portable power, and in motive applications such as light- and heavy-duty vehicles, material handling, rail and unmanned systems. Hydrogen and fuel cell technologies are recognized as important solutions in providing grid support, in storing energy, and in delivering reliable and efficient, low emission power generation.

The expiration of the 30 percent ITC and FCEV tax credits, however, represent a significant risk to continued market development.

There is a worldwide race to foster fuel cell commercialization. Governments in Asia and Europe are supporting RD&D and early commercial deployment. China is fast becoming the leader in fuel cell buses. Japan's national energy strategy assigns hydrogen the central role, in partnership with renewable and advanced combustion systems.

Fuel cells are commercial today in some applications but like every game changing technology, early units are expensive. Where fuel cells may not yet be economical, for many individual applications, the technology offers more value streams than competitors. These include:

- Transportation applications: FCEVs offer the sustainable operation and rapid acceleration of other electric vehicles, but with faster refueling times and longer driving range.
- Electric grid support: Fuel cell systems offer clean, reliable distributed power, important in areas where local air quality is an issue, and can also provide various grades of waste heat and enhanced power reliability for host sites.
- Energy storage: Hydrogen can provide long-duration energy storage, which will be important in maximizing the benefits of high-penetration renewable energy systems.
- Natural gas system utilization and support: Fuel cell power generation overwhelmingly uses natural gas today but has the greatest fuel flexibility of any generating technology. Power-to-hydrogen and power-to-methane can utilize stranded intermittent renewable energy to supplement local natural gas-based fuel supplies.
- Industrial applications: Hydrogen is widely used today in industrial settings, but there are opportunities to expand the use of hydrogen for chemical manufacture, ammonia production, metals production and processing, enhancement of liquid fuels, and to take advantage of hydrogen produced as a co-product of industrial processes such as chlor-alkali production.

Commercializing fuel cells carries a big payoff in job growth, economic activity, competitiveness, and energy security. Fuel cell and hydrogen intellectual property originated in the United States and the U.S. has been the global leader in technology development. If the U.S. is to maintain its leadership, investment and innovation will be needed until the technologies and manufacturing capability have become more mature and established.

Evidence suggests that the U.S. is still not on track to meet the 2020 goals for hydrogen FCEVs and refueling infrastructure set by the U.S. Energy Policy Act of 2005 (EPACT) Title VIII. In response to the Committee's 2016 recommendation, DOE committed to developing a paper outlining efforts underway to work toward those goals.

The Committee re-asserts the need for an explicit plan to be provided in 2017 showing the pathway for achieving the 2020 EPACT Title VIII goals "endgame" for hydrogen and fuel cell technologies, with benchmarks and milestones required to reach this point. Achieving these goals will carry substantial benefits to American workers and industries and contribute to the Administration's jobs, infrastructure, and American manufacturing vision.

The Administration's 2018 budget blueprint stresses basic science and limited, early applied energy R&D activities. While the Committee supports early stage R&D, there is a critical need to continue efforts in material and process integration and technology acceleration in order to meet EPACT 2020 goals and to maintain U.S. competitiveness, and to meet competition from offshore companies and governments.

In conclusion, much progress is being made, but greater momentum is needed for these technologies to provide the benefits they are capable of in 2020 and beyond.

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Department of Energy
Washington, DC 20585

January 4, 2018

Mr. Frank Novachek, Chair
Hydrogen and Fuel Cell Technical Advisory Committee
1800 Larimer Street, Suite 1600
Denver, Colorado 80202

Dear Chairman Novachek:

Thank you for your June 2017 letter to Energy Secretary Rick Perry and the accompanying *2016 Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)* and the *Hydrogen Safety and Event Response Subcommittee Report.* The Department values the input of the Committee and appreciates these thorough and detailed reports. I am responding to your letter on behalf of Secretary Perry.

As you mention, it is exciting to see the progress that we have made on hydrogen and fuel cell technologies since the early days of President George W. Bush's Hydrogen Fuel Initiative. We are pleased that his vision of making fuel cell electric vehicles (FCEVs) available to consumers is now becoming a reality, with more than 2,200 FCEVs owned or leased by retail customers in the United States as of June 2017. Through DOE's research and development (R&D), we have seen the cost of fuel cells cut by 80% since 2002, while achieving a four-fold increase in durability to over 120,000 miles in the last decade. As of the end of fiscal year (FY) 2016, our Hydrogen and Fuel Cells Program funding has directly led to more than 650 hydrogen and fuel cell related patents from national labs, universities, and companies all over the Nation. However, as your report also points out, challenges remain in reducing the cost of FCEVs and in developing a sufficient and robust hydrogen refueling infrastructure. Your recommendations identify ways the program can work to resolve some concerns.

In addition to organizing workshops with technical experts to address challenges, we recently awarded the $1 million H2 Refuel H-Prize. Simple Fuel won the prize for their small-scale on-site hydrogen generation and fueling appliance, which complements the retail station strategy. Now that FCEVs are commercially available, we have also updated the Alternative Fuels Data Center to include information on hydrogen and FCEVs, including hydrogen station maps and infrastructure development information.

The Department of Energy (DOE) has maintained a consistent and substantial budget for hydrogen and fuel cell technologies. The FY 2017 enacted budget is approximately $105 million, which is a slight increase over FY 2016 levels. In line with the President's 2018 budget request, the Hydrogen and Fuel Cells Program is focusing resources on early-stage R&D that can achieve technology breakthroughs, particularly in hydrogen fuel. The private sector is expected to take the lead on later stage R&D, and commercialization activities.

The Department continues to focus on its lab-led consortia to address technical challenges, including three hydrogen and fuel cell related consortia that are part of DOE's Energy Materials Network (HydroGEN, ElectroCAT, and HyMARC). By using both computational and experimental techniques to identify promising technologies, we will accelerate materials discovery and development to address the most difficult challenges such as, identification of platinum-free catalysts, and hydrogen storage materials. In response to your request for an explicit plan for how the 2020 goals of Title VIII of the Energy Policy Act of 2005 (EPACT) will be achieved, the Department will work to develop a strategy to outline ongoing efforts towards these goals.

The Committee also recommends that the Federal tax credits for FCEVs and stationary fuel cell power generation be reinstated and that incentives for hydrogen refueling infrastructure be provided to continue to foster fuel cell commercialization and help achieve EPACT Title VIII 2020 goals. Please note that the Department does not set Federal tax incentives and our mission is R&D to enable technologies to be competitive in the long term without subsidies.

I would particularly like to thank the Committee for the Hydrogen Safety and Event Response report. The Department appreciates the importance of hydrogen safety and is taking steps to ensure continuity of critical hydrogen safety research by integrating key activities into the technology R&D programs. We plan to work with the private sector and other external stakeholder groups to determine how the work of the Hydrogen Safety Panel may best be continued.

The Department is also continuing to leverage public-private partnerships and work with other Federal and state agencies that can incorporate hydrogen into their programs. We also plan to release a call for Cooperative Research and Development Agreements for the private sector to work with national labs and enable a sustained and robust effort related to H2@Scale and hydrogen infrastructure. Our H2@Scale activities will focus on key challenges associated with wide-scale production and use of hydrogen to address critical national issues such as grid resiliency, energy security, domestic job creation, and leadership in manufacturing.

The Department values the advice and commitment of the Committee in its efforts to continue to improve our programs and activities related to hydrogen and fuel cells. Please extend my sincerest gratitude to the Committee members for their hard work and their valuable contributions to the Department and its mission.

Sincerely,

Daniel R Simmons
Principal Deputy Assistant Secretary
Energy Efficiency and Renewable Energy

APPENDIX C

HTAC Hydrogen Safety and Event Response Subcommittee Report

Hydrogen Safety and Event Response

Subcommittee Report

Hydrogen and Fuel Cells Technical Advisory Committee

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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 34 public hydrogen stations as of April 2017, of which 29 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, federal funding should also be available to support 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.

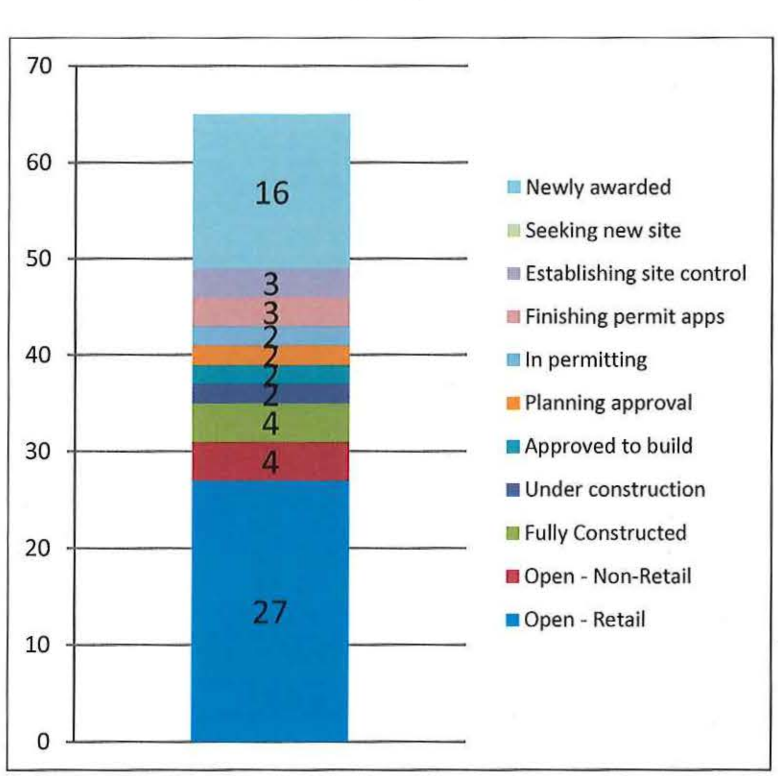


Figure 1. Status of California hydrogen stations, April 2017

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).

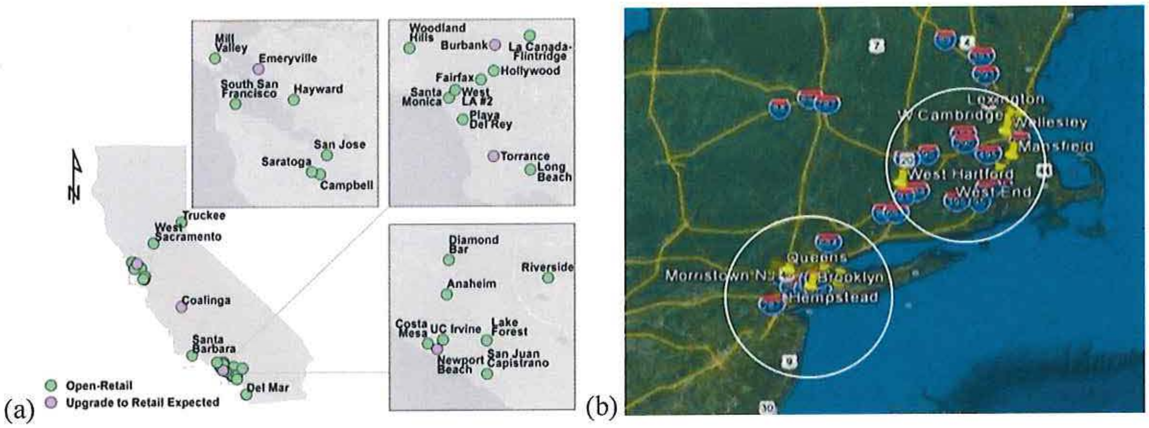


Figure 2. (a) Current status of open stations in California's Hydrogen Fueling Network. (b) Focus areas for the Northeast Network.

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.

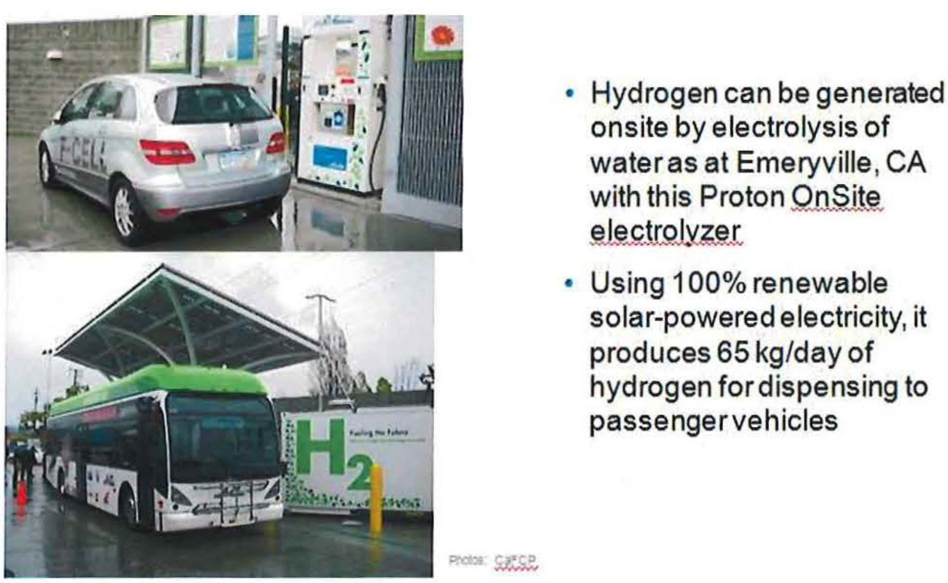


Figure 5. Onsite hydrogen generation by electrolysis at Emeryville, California, station

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.

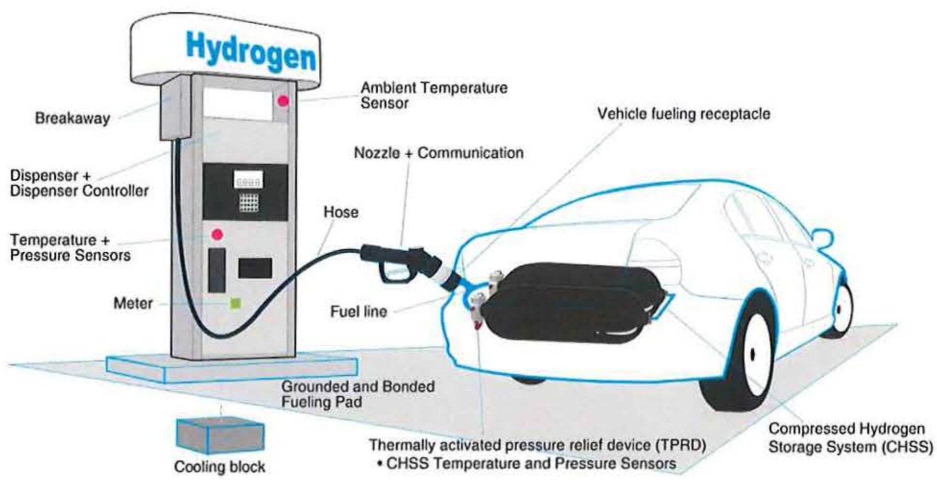


Figure 6. Hydrogen fueling diagram (courtesy of ISO) illustrating key components of a hydrogen fuel dispenser

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.

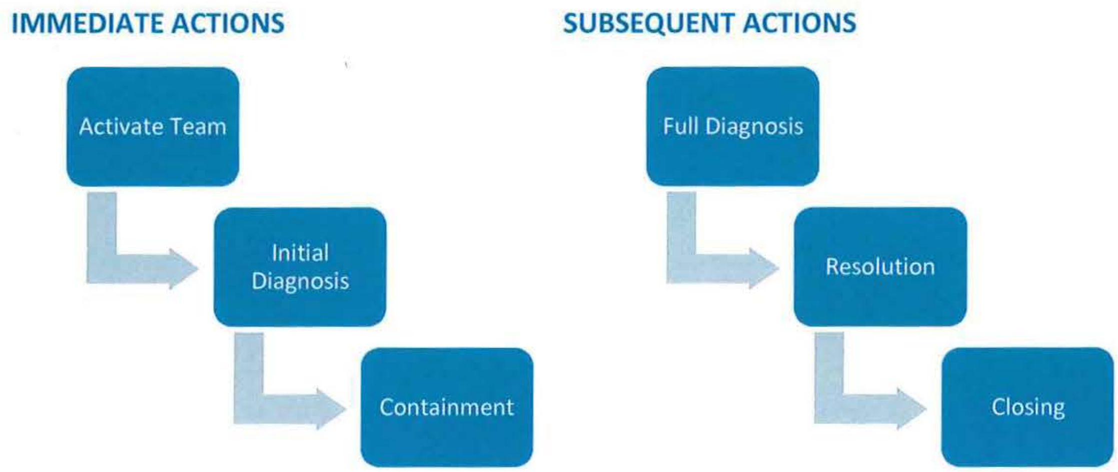


Figure 8. Phases of event response

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.

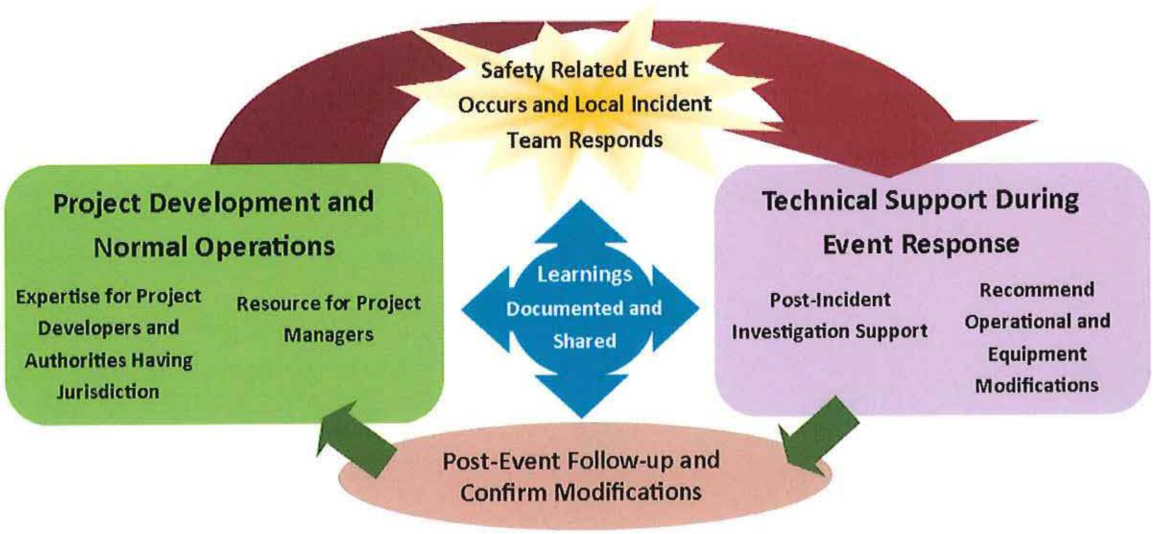


Figure 9. Potential support roles for Hydrogen Safety Panel within the cycle of normal operations and event response

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 HSP 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 HSP 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.

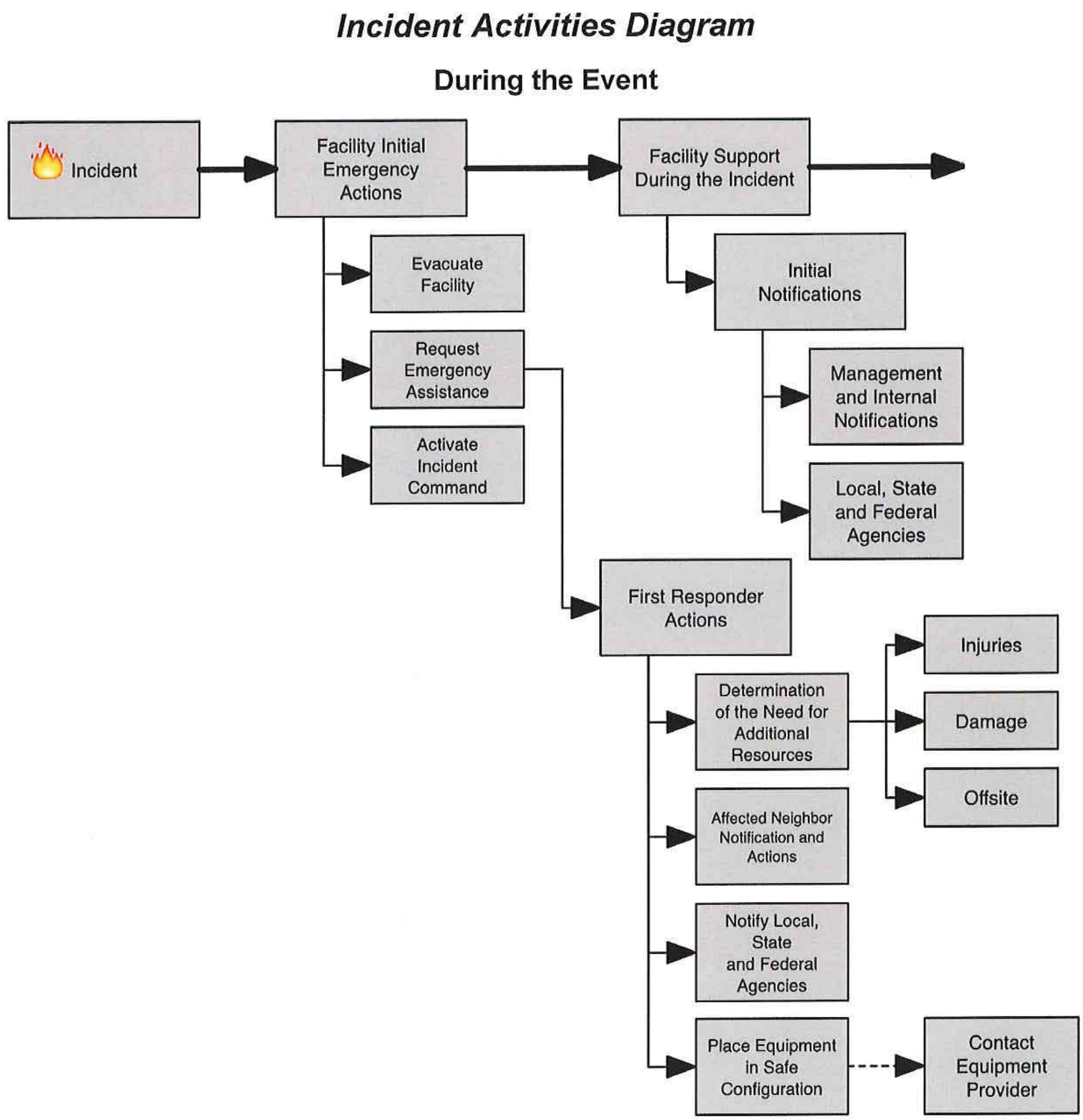
Appendix A. Existing Hydrogen and Fuel Cell Safety Electronic Resources

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