# I.0 Introduction

The U.S. Department of Energy's Hydrogen and Fuel Cells Program (the Program) includes a comprehensive range of research, development, and demonstration (RD&D) activities that enable the widespread commercialization of hydrogen and fuel cell technologies across diverse applications. The Program is coordinated across the U.S. Department of Energy (DOE or the Department), incorporating activities in the offices of Energy Efficiency and Renewable Energy (EERE)—led through the Fuel Cell Technologies Office (FCTO)—Science (SC), Nuclear Energy, and Fossil Energy (FE). Every year, the Program publishes an Annual Progress Report documenting progress, accomplishments, and technology status with respect to performance metrics.

In Fiscal Year (FY) 2016, Congress appropriated approximately $119 million for the DOE Hydrogen and Fuel Cells Program in addition to $30 million for solid oxide fuel cell related activities. More detailed discussions of Program activities and plans can be found in the Hydrogen and Fuel Cells Program Plan, as well as in the plans of the program offices—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.[1]

Just last year, Hyundai and Toyota both introduced their fuel cell electric vehicles (FCEVs) for commercial sale, and several auto manufacturers, including Honda, GM, Daimler, and BMW, are working toward commercial production of FCEVs in the near term. In California, hydrogen is a fueling option at 25 retail gas stations (and counting) and there are plans for several fueling stations to be opened soon in the Northeast United States. The industry also celebrated the second annual National Hydrogen and Fuel Cell Day with a week of events, activities, and media announcements across the country.

In 2016, the Program enabled a new hydrogen refueling advanced technology demonstration station as well as the first-ever government FCEV fleet in Washington, D.C. The Program launched the H2@Scale national lab big idea concept, enabling the value of hydrogen across transportation, stationary, and industrial sectors. There are more than 580 patents and more than 30 commercial technologies in the market due to Program funding. Another 65 technologies may be commercialized within the next three to five years.

## PROGRESS AND ACCOMPLISHMENTS BY KEY ACTIVITY

This report includes more than 1,000 pages of accomplishments achieved by DOE-funded projects in the last year. The following summaries include only a few examples. More details can be found in the individual program introductions, subsequent project reports, and in the corresponding 2016 Annual Merit Review and Peer Evaluation Report.[2]

### Fuel Cells

The Fuel Cells program supports RD&D of fuel cell technologies for transportation applications, as well as enabling stationary and early market applications, with a primary focus on reducing cost and improving durability.

**Cost**

One of the most important metrics used to guide the program's R&D efforts is the projected high-volume manufacturing cost for automotive fuel cells, which is tracked on an annual basis. The program is targeting a cost reduction to $40/kW by 2020. Long-term competitiveness with alternative powertrains is expected to require further cost reduction to $30/kW, which represents the program's ultimate cost target. This year, the preliminary cost projection for an 80-kWnet automotive polymer electrolyte membrane (PEM) fuel cell system based on next-generation laboratory technology and operating on direct hydrogen is $53/kWnet when manufactured at a volume of 500,000 units/year, and $59/kWnet when manufactured at 100,000 units/year. For comparison, the expected cost of automotive PEM fuel cell systems that are based on current technology and planned for commercialization in the 2016 time frame is approximately $230/kWnet when manufactured at a volume of 1,000 units/year.[3]

[1] https://www.hydrogen.energy.gov/roadmaps_vision.html
[2] https://www.hydrogen.energy.gov/annual_review16_report.html
[3] https://energy.gov/eere/fuelcells/downloads/mass-production-cost-estimation-direct-h2-pem-fuel-cell-systems-0

To enable vehicle commercialization, fuel cell systems must also meet the program's durability targets. These targets vary by application; for automotive systems, DOE has set a 2020 target of 5,000 hours (Figure 1) and in 2016 increased its ultimate durability target to 8,000 hours. This increase serves to more accurately represent the durability requirement in terms of miles driven (150,000 miles) for a larger range of drivers (e.g., specifically capturing requirements for people who drive at a lower average speed). As of late 2016, the current average lab-tested durability status is approximately 3,900 hours.

### FC-PAD Consortia

To simultaneously address performance and durability challenges, the program continues to build upon its Fuel Cell Performance and Durability (FC-PAD) Consortium, which was launched in FY 2015. The consortium coordinates work under the thrust areas defined in Figure 2 and has been highlighted as a comprehensive, cohesive, and valuable new asset to the program and its stakeholders across industry, academia, and national labs.

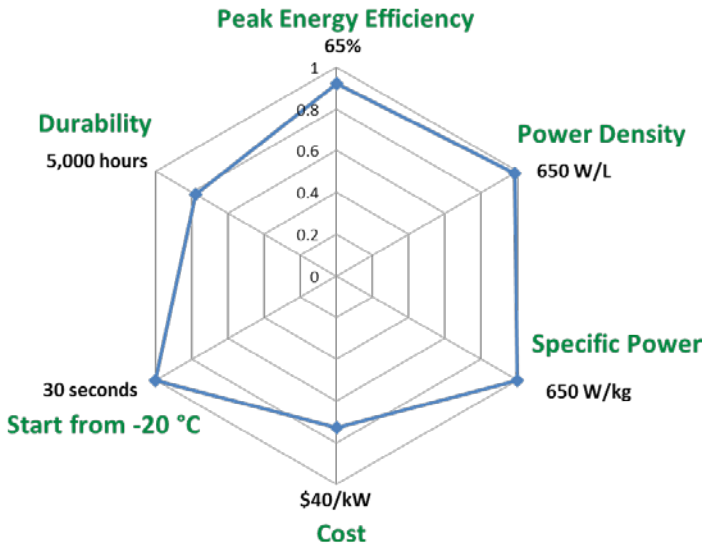
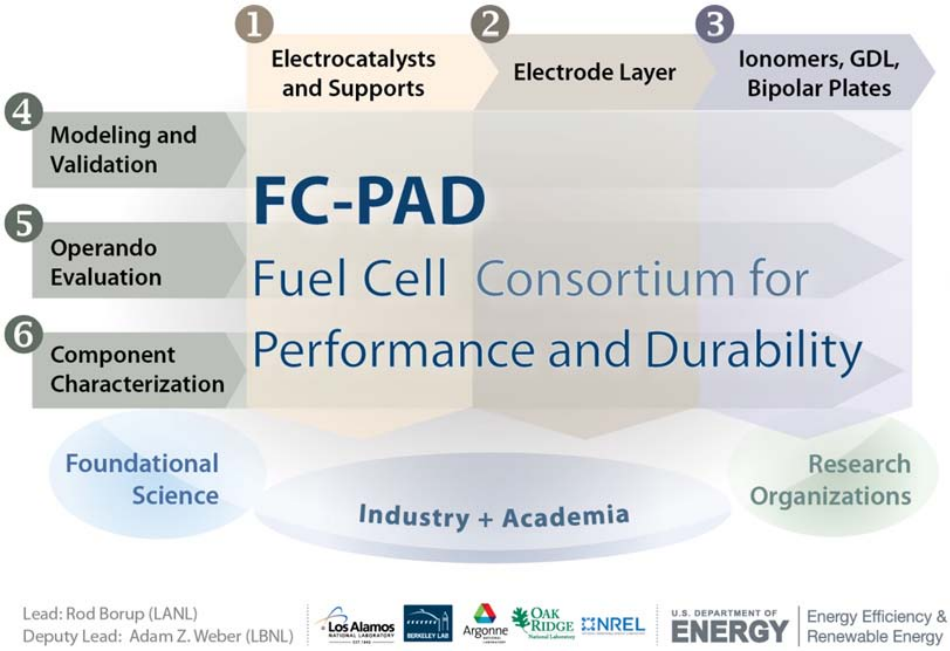



**FIGURE 1.** Fuel cell 2020 targets versus status (blue) for light-duty vehicle applications (the status is indicated as a fraction of the targets)




GDL – gas diffusion layer; LANL – Los Alamos National Laboratory; LBNL – Lawrence Berkeley National Laboratory

**FIGURE 2.** FC-PAD is structured across six components and cross-cutting thrusts

**ElectroCat**

Launched in FY 2016, the Electrocatalysis Consortium (ElectroCat) is an initiative to accelerate the development of catalysts made without platinum group metals for use in automotive fuel cell applications. ElectroCat's activities are primarily focused in the areas of (1) high-throughput capability development, (2) multi-scale modeling, and (3) catalyst synthesis and characterization methods. The first two activity areas will enable researchers to test potential catalyst materials at an unprecedented pace and do so in an informed manner. The third activity area will play a foundational role in developing the consortium toolset, aiding consortium partners in catalyst and electrode development, and maximizing the benefit of the consortium overall. ElectroCat is co-led by Argonne National Laboratory (ANL) and Los Alamos National Laboratory (LANL).

**Characterization and Analysis**

In FY 2016, microstructural and microchemical studies continued to provide insight into materials comprising membrane electrode assemblies, offering valuable information into the stability and durability of specific components during operation. Studies were primarily focused on three-dimensional electron tomography of electrocatalysts, supports, and fully intact catalyst layers.

System material-derived contamination of the fuel cell has also been studied and has led to a public dataset of materials providing leaching indices, identities and quantities of contaminants, and recommended testing procedures to assess contamination. These materials include structural plastics, hoses, lubricants, adhesives, and seals. Researchers correlated a high "leaching index" to membrane electrode assemblies degradation and lower material cost (see Figure 3). Based on these findings, the project identified a cleaner polyphthalamide (PPA) structural material that resulted in no significant increase in material cost yet afforded higher performance (see Figure 4). The publicly available balance-of-plant material screening data tool and extensive database have had approximately 1,400 site visits since May 2013 (see http://www.nrel.gov/hydrogen/system_contaminants_data/).

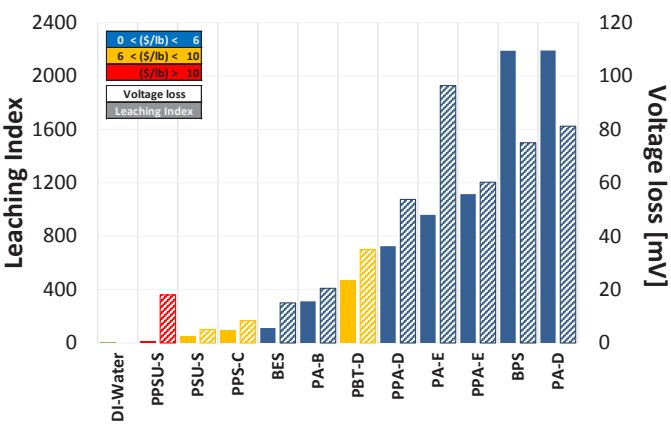



**FIGURE 3.** Leaching index for various materials increased with decreasing material cost (see the acronym list in Section XII for the full material names)

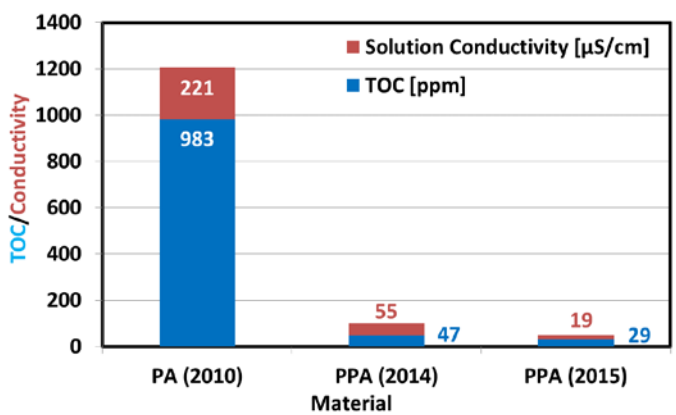



**FIGURE 4.** 25x improvement in combined total organic carbon (TOC) and solution conductivity for a cleaner PPA (2015) material

## Hydrogen Production

In FY 2016, the Hydrogen Production program continued efforts to develop technologies that will enable the long-term viability of hydrogen as an energy carrier for a range of applications, with a focus on hydrogen from low-carbon and renewable sources. Progress continued in several key areas, including electrolysis, photoelectrochemical, biological, and solar-thermochemical hydrogen production. A world-record efficiency of greater than 16% was demonstrated for III-V semiconductor photoelectrochemical tandem devices in FY 2016. This was enabled through the use of an inverted metamorphic multijunction, which dramatically reduced voltage loses at

interfaces. This result represents an important step forward in demonstrating solar-to-hydrogen conversion efficiencies of >20% using photoelectrochemical devices.

Following a widely attended workshop on advanced water splitting in 2016, the program launched the HydroGEN advanced water splitting materials consortium as part of DOE's Energy Materials Network to accelerate materials discovery and development critical to advanced water splitting technologies for renewable hydrogen production. HydroGEN identified technical and analytical resources available at the national laboratories to support state-of-the-art renewable hydrogen production research. HydroGEN also developed a website to provide public information on its available expertise and capabilities.[4]

Launched in 2014, the two-year, $1 million H2 Refuel H-Prize competition challenges America's engineers and entrepreneurs to develop affordable systems for small-scale, non-commercial hydrogen fueling. One team, SimpleFuel, was selected by an independent panel of judges and safety experts to reach the finalist stage. To win the $1 million prize, they need to show that their system can meet a challenging set of targets, including requirements for cost, availability, safety, and hydrogen purity. Testing began in September 2016, and the outcome is expected to be announced in early 2017. This effort will complement the current focus by states and industry to deploy retail hydrogen fueling stations and will incentivize opportunities for small-scale hydrogen generation.

## Hydrogen Delivery

The goal of the Hydrogen Delivery program is to reduce the costs associated with delivering hydrogen to a point at which its use as an energy carrier in fuel cell applications is competitive with alternative transportation and power generation technologies. In FY 2016, significant progress was made by the Hydrogen Delivery program on several important fronts.

Station technologies, in particular compression and onsite storage, are a key area of focus for the program. Efforts in this area aim to improve the reliability and reduce the cost of the technologies. In FY 2016, the program worked with the California Air Resources Board (CARB) to successfully deploy the Hydrogen Station Equipment Performance (HyStEP) testing device in California, including execution of a contract between Sandia National Laboratories (SNL) and CARB for the loan of the device to collect the data needed to validate California stations as part of the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project. Additionally, all relevant designs and control software for the duplication of the device have been made publically available through the H2Tools website.

Also in FY 2016, an 875 bar stationary pressure vessel design was approved by the American Society of Mechanical Engineers. Initial results from hydrogen assisted fatigue crack growth data (under compressive loading) indicate that compressive loading has a comparable effect on hydrogen-assisted fatigue crack growth as low load ratios in tension.

Liquefaction represents more than 50% of the cost of hydrogen delivered via the liquid pathway and requires significant energy consumption. In FY 2016, the liquefaction of propane from room temperature using magnetocaloric materials was demonstrated at a laboratory scale. Additionally, the implementation of a bypass loop in an eight-layer magnetocaloric system increased the system cooling by 25%.

## Hydrogen Storage

The Hydrogen Storage program's objective is to develop technologies that provide sufficient onboard hydrogen storage to allow fuel cell devices to provide the performance and run-time demanded for the applications. In the near term, automotive companies plan to commercialize FCEVs that use 700 bar compressed hydrogen storage systems onboard, with system cost being one of the most important challenges to commercialization.

In FY 2016 the program's materials-based storage portfolio launched a major new effort: the Hydrogen Materials–Advanced Research Consortium (HyMARC). Comprised of a core team of three national laboratories (SNL—lead, Lawrence Livermore National Laboratory, and Lawrence Berkeley National Laboratory [LBNL]), the HyMARC team is addressing the scientific gaps impeding the advancement of solid-state storage materials for storage of hydrogen onboard vehicles. Better

[4] https://www.h2awsm.org/

onboard hydrogen storage could lead to more reliable and economic hydrogen fuel cell vehicles. Launched as part of DOE's Energy Materials Network, HyMARC research activities will focus on the thermodynamic and kinetic limitations of storage materials, including mass transport, surface chemistry, and processes at solid–solid interfaces.

Five new projects were selected in 2016 to collaborate with the HyMARC national laboratory core team to develop specific hydrogen storage materials with potential to meet the performance requirements for onboard FCEV hydrogen storage. These projects will be led by University of Missouri–St. Louis, University of Hawai'i at Mānoa, The Pennsylvania State University, Liox Power Inc., and ANL.

The Hydrogen Storage program continued efforts to develop and improve hydrogen storage materials in FY 2016 with potential to meet the 2020 onboard storage targets. For the first time, teams validated the adsorption of two hydrogen molecules bound to a single open metal site in a sorbent material, as confirmed by neutron powder diffraction. The program also initiated a multi-laboratory, round-robin study on volumetric uptake in sorbents, which includes national laboratories, universities, industry, and international participants, to identify sources of error in volumetric uptake measurements, the results of which will be disseminated to the adsorption community to improve data reliability.

FY 2016 marked the last year of the Hydrogen Storage Engineering Center of Excellence (HSECoE), which covered the program's materials engineering efforts. This year the HSECoE completed the evaluation of the HexCell and the Modular Adsorption Tank Insert, two sorbent prototype systems designed to achieve higher hydrogen adsorption densities, and finalized the validation of the framework models for the metal hydride, chemical hydrogen, and sorbent systems. Other models that were finalized through the HSECoE include the metal hydride acceptability envelope and finite element models and the tank volume/cost estimator model. A major milestone achieved during FY 2016 was making these models and resources accessible through the HSECoE.org website for use by the materials-based hydrogen storage R&D community. A subset of the HSECoE partners (National Renewable Energy Laboratory [NREL], Pacific Northwest National Laboratory, and Savannah River National Laboratory) made improvements to the performance of the modelling package and incorporated an improved graphical user interface that is better suited for end users.

## Manufacturing R&D

The Manufacturing R&D program supports activities needed to reduce the cost of manufacturing hydrogen and fuel cell systems and components. Advances in the enhancement of domestic hydrogen and fuel cell supply chains as well as in the quality control of fuel cell materials in FY 2016 include the following.

- Four regional Technical Exchange Centers were established, located at the National Fuel Cell Center at the University of California, Irvine; NREL; Connecticut Center for Advanced Technology; and Ohio Fuel Cell Coalition. The regional Technical Exchange Centers will collect and categorize regional hydrogen and fuel cell information that will be included in a national web-based database to facilitate purchases of hydrogen and fuel cell components and systems.
- Virginia Clean Cities at James Madison University set up a nationwide online database known as HFC NEXUS: The U.S. Hydrogen and Fuel Cell Directory.[5] HFC Nexus is a business-to-business directory that helps suppliers connect with buyers. The website includes information on a number of different company types, such as automakers, integrators, and suppliers; users can also search for products such as catalysts, electrodes, and hydrogen pump/ejectors (see Figure 5). Recently, Virginia Clean Cities added a feature called MatchMaker that lists organizations that are seeking or offering products, goods, services, etc., in hydrogen and fuel cell markets. Its goal is to help organizations connect with each other in the supply chain to improve communications and speed up development of these critical technologies.
- In 2015, Mainstream Engineering began a Tech Transfer Opportunity project through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. Mainstream Engineering proposed to develop a low-cost optical detector for continuous analysis of membranes for PEM fuel cell membrane electrode assemblies based on a licensing agreement with NREL. In 2016, Mainstream demonstrated an optical system that detected 40 out of 40 100-µm pinhole defects in real time on NREL's continuous roll-to-roll web line running a Nafion 211 membrane at speeds of up to 30 ft/min. With post processing, all defects were successfully identified at web line speeds up to 100 ft/min.

[5] http://hfcnexus.com/

**FIGURE 5.** HFC Nexus is a business-to-business directory that helps suppliers connect with buyers

## Basic Research

The Basic Energy Sciences (BES) program in the DOE Office of Science supports a number of fundamental scientific research projects addressing critical challenges related to hydrogen storage, hydrogen production, and fuel cells. These basic research efforts complement the applied R&D projects supported by the other offices in the Program. Progress in any one area of basic science is likely to spill over to other areas and bring advances on more than one front.

The subjects of basic research most relevant to the Program's key technologies are:

- Hydrogen Production: approaches such as photobiological and direct photochemical production of hydrogen.
- Hydrogen Storage: nanostructured materials; theory, modeling, and simulation to predict behavior and design new materials; and novel analytical and characterization tools.
- Fuel Cells: nanostructured catalysts and materials; integrated nanoscale architecture; novel fuel cell membranes; innovative synthetic techniques; theory, modeling, and simulation of catalytic pathways, membranes, and fuel cells; and novel characterization techniques.

By maintaining close coordination between basic science research and applied R&D, the Program ensures that discoveries and related conceptual breakthroughs achieved in basic research programs will provide a foundation for the innovative design of materials and processes that will improve the performance, cost, and reliability of fuel cell

technologies and technologies for hydrogen production and storage. This coordination is accomplished at the program level through bi-monthly coordination meetings between the participating offices within DOE, and at the researcher level through joint meetings of principal investigators who are funded by the participating offices.

In June 2016, the Program included a number of presentations and posters from BES-funded researchers on fundamental-science-related topics at the Annual Merit Review and Peer Evaluation Meeting in conjunction with presentations by EERE- and Advanced Research Projects Agency-Energy-funded researchers.

## Technology Validation

The Technology Validation program demonstrates, tests, and validates hydrogen and fuel cell technologies and uses the results to provide feedback to R&D activities. In addition to validating FCEV and hydrogen infrastructure technologies, continuing efforts include the real-world evaluation of fuel cell bus technologies at various transit authorities and monitoring performance of fuel cells in stationary power, backup power, and material handling equipment (MHE) applications.

**Fuel Cell Electric Vehicles**

- Over the last 10 years, NREL has completed analysis of more than 220 on-road FCEVs that have accumulated almost 6.4 million miles.
- Fuel cell durability has steadily and significantly improved over the last decade, to over 4,100 hours (and counting).
- The maximum vehicle odometer reading achieved to date is 190,300 miles (approximately 10% of vehicles have passed 100,000 miles).
- The maximum fuel cell operation hours achieved to date is 5,605.

**Fuel Cell Electric Buses**

- Eleven fuel cell power plants achieved operation time in excess of 12,000 hours—one of these systems logged more than 22,600 hours in service (surpassing the 2016 target of 18,000 hours), and three additional systems surpassed 16,000 hours.
- Reliability has shown a marked increase over time, reaching the ultimate targets for both bus miles between road calls and fuel cell system miles between road calls, and fuel-cell-related issues made up only 15% of the road calls during the period.

**Hydrogen Stations**

- The HyStEP (Hydrogen Station Equipment Performance) device was developed to accelerate commercial hydrogen station acceptance and commissioning by measuring hydrogen dispenser performance against SAE J2601 protocols. The device has been used at three stations and has provided consistent, reliable performance tests for over 45 fills, including leak checks, sensor and instrument checks, Infrared Data Association communications checks, and original equipment manufacturer test fills.
- Station Operational Status System (SOSS) is a client app for use on a cell phone or vehicle dashboard that mitigates the early-stage problem of customers arriving at a station that is unavailable for fueling. In FY 2016, another 20 open retail stations were added to the existing seven for a total of 27 stations that are currently participating in SOSS.
- In the hydrogen station data collection and analysis project, data from state-of-the-art hydrogen fueling facilities were collected and analyzed by NREL. Based on this data, fills greater than 1 kg with pre-cooling at -40°C had an average fueling rate of 0.87 kg/min, and time to fill was 3.7 min.

## Market Transformation

To ensure that the benefits of the Program's efforts are realized in the marketplace, the Market Transformation program continues to facilitate the growth of early markets for fuel cells used in stationary, specialty vehicle, and truck fleet applications. Program activities are helping to reduce the cost of fuel cells by enabling economies of scale through early market deployments; these early deployments also help to overcome a number of barriers, including the lack of operating performance data, the need for applicable codes and standards, and the need for user acceptance. The

program also partners with other federal agencies and stakeholders to deploy fuel cell systems in applications such as marine cargo transport operations.

One of the key accomplishments of the Market Transformation program in FY 2016 was deploying the world's first zero emissions electric generator for on- and off-board ship auxiliary power. This project, being conducted in collaboration with the U.S. Maritime Administration, is demonstrating the value proposition of using fuel cell power for specialty marine needs, particularly auxiliary power, where variable loads make fuel cells more energy-efficient than conventional generators such as diesel engines. This year the marine power system was tested in real operating conditions at a port facility to power refrigerated shipping containers that need continuous power both on- and off-board ocean-going vessels. The system being demonstrated is two to three times more efficient than incumbent internal-combustion-engine-powered units, particularly at lower power loads.

## Education

Although the Program relies on prior-year resources for the Education program's activities, leveraging other resources for education and outreach continues to be important for hydrogen and fuel cell technology. With the advent of commercial systems, industry has taken the lead on education, but stakeholders still rely on DOE for providing technically accurate and objective information to key target audiences that are directly and indirectly involved in the use of hydrogen and fuel cells. In FY 2016, the Program published more than 130 success stories through news articles, blogs, press releases, and media announcements and conducted 13 webinars, averaging more than 150 attendees per webinar. The FCTO monthly newsletter reached more than 15,000 subscribers.

## Safety, Codes and Standards

The Safety, Codes and Standards program identifies needs and performs high-priority R&D to provide an experimentally validated, fundamental understanding of the relevant physics, critical data, and safety information needed to define the requirements for technically sound and defensible hydrogen and fuel cell codes and standards. During the past year, the program continued to identify and evaluate safety and risk management measures that can be used to define the requirements and close the gaps in codes and standards in a timely manner.

- In FY 2016, the Hydrogen Risk Assessment Model (HyRAM) version 1.0 was released for public use and is available to download online.[6]
- To advance infrastructure deployment, experimental efforts were initiated to help inform separation distances for liquid hydrogen. H2Tools.org, which was launched in June of 2015, received over 80,000 page views in its first year. Of those site visits, just over 50% are from outside the United States, including visits from the United Kingdom, Canada, India, Japan, and Germany.
- Through in-person and online training and resources, we have reached more than 36,000 code officials and first responders to date.
- Additional information was added to the community resource tool H2Tools.com, including codes and standards resources and permitting guides, landing pages for the H2FIRST project and the HyStEP device, and Vehicle Emergency Response Guides.

Source: H2Tools.org

## Systems Analysis

The Systems Analysis program focuses on examining the economics, benefits, opportunities, and impacts of hydrogen and fuel cells through a consistent, comprehensive, analytical framework. The team made several significant contributions to the Program during FY 2016.

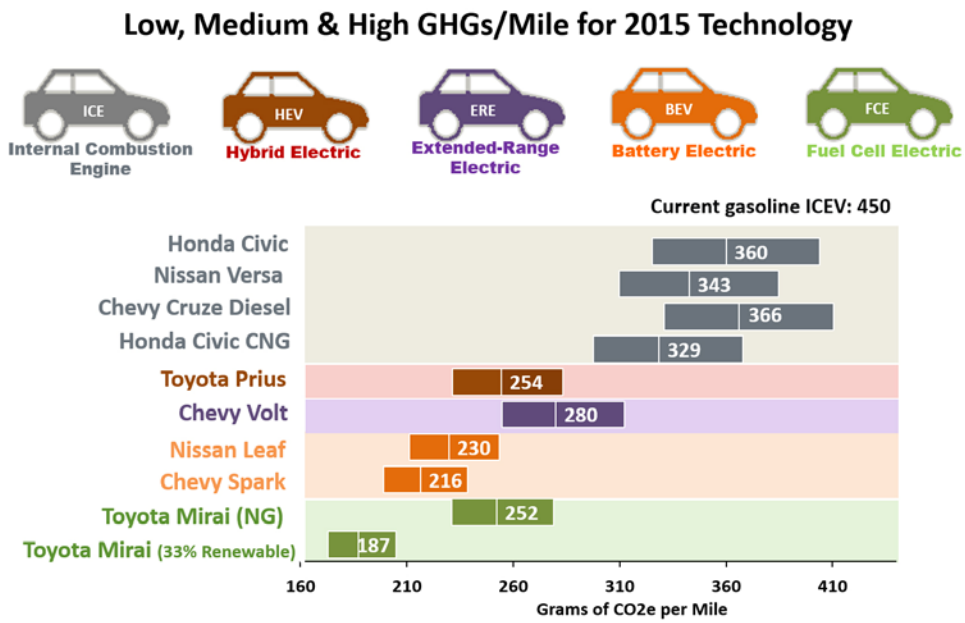
On June 1, the United States Driving Research and Innovation for Vehicle efficiency and Energy sustainability (U.S. DRIVE) Cradle-to-Grave Working Group published a report entitled "Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025–2030) Technologies."[7] The study provides a comprehensive cradle-to-grave analysis of the cost, greenhouse gas (GHG) emissions, levelized cost of driving, cost of avoided greenhouse gas emissions, and technology

[6] http://energy.sandia.gov/transportation-energy/hydrogen/quantitative-risk-assessment/hydrogen-risk-assessment-model-hyram/
[7] https://greet.es.anl.gov/publication-c2g-2016-report

readiness level of key fuel and vehicle technology pathways. Co-authors are from ANL; DOE's Vehicle Technologies, Fuel Cell Technologies, and Bioenergy Technologies Offices; NREL; the Electric Power Research Institute; Fiat Chrysler Automobiles; General Motors; Chevron; and Ford Motor Company.

**Lifecycle Analysis Record**

In FY 2016, the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model was used to compare the GHG emissions associated with current gasoline, hybrid electric, battery electric, and fuel cell vehicles versus future versions of gasoline and alternative fuel vehicles based on expected technology advancements. As shown in Figure 6, the lifecycle GHG emissions of the current alternative vehicles are 20%–50% less than those of the current gasoline internal combustion engine vehicle. The GHG emissions of the future versions of these vehicles are 20%–50% lower than those of the current versions.




CNG – compressed natural gas; NG – natural gas

**FIGURE 6.** Well-to-wheels GHG emissions of hydrogen FCEV pathways compared to gasoline internal combustion engine vehicle pathways

**Analysis of Current Hydrogen Cost and Targets**

The current delivered cost of hydrogen was assessed relative to the early market cost target, which was developed to guide and prioritize R&D for the Program. Figure 7 shows the current delivered cost of hydrogen is \$13/gge–\$16/gge compared to the early market hydrogen cost target of \$7/gge, untaxed and dispensed at the pump, and the ultimate target of <\$4/gge. This current hydrogen cost was documented in DOE Hydrogen Program Record #15012, which was peer-reviewed by a panel that included industrial gas suppliers.[8]

**Program Benefits**

The implementation of fuel cell technology R&D has resulted in a cumulative GHG emissions reduction of over one million metric tons of $CO_2$. Figure 8 shows that the largest GHG reduction has resulted from the stationary fuel cell penetration in the power market. Fuel cell applications in the transportation sector have produced lower GHG reductions due to their lower market penetration to date. The ANL GREET model was used to perform this analysis.

[8] https://www.hydrogen.energy.gov/pdfs/15012_hydrogen_early_market_cost_target_2015_update.pdf

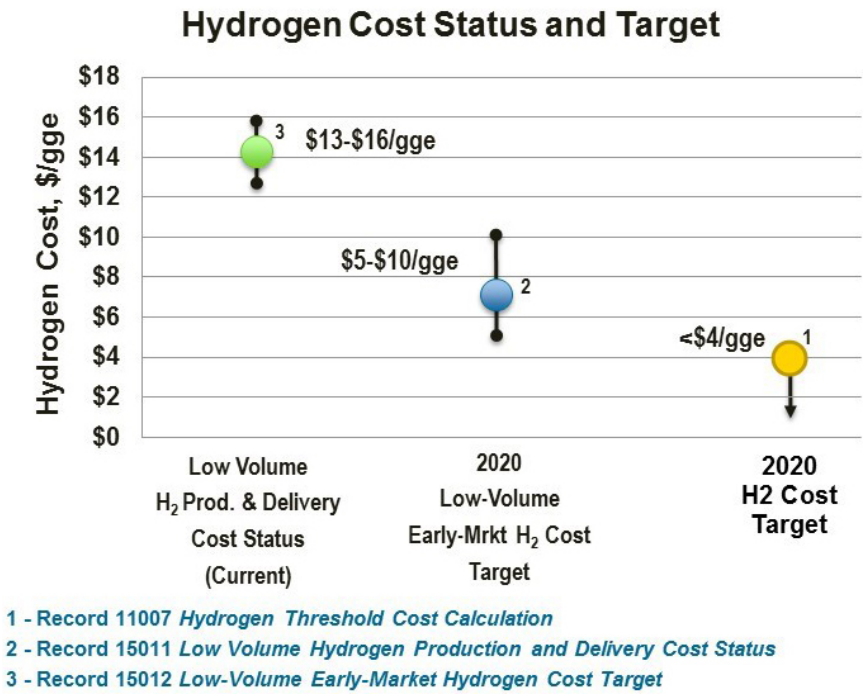



**FIGURE 7.** Hydrogen cost status and targets

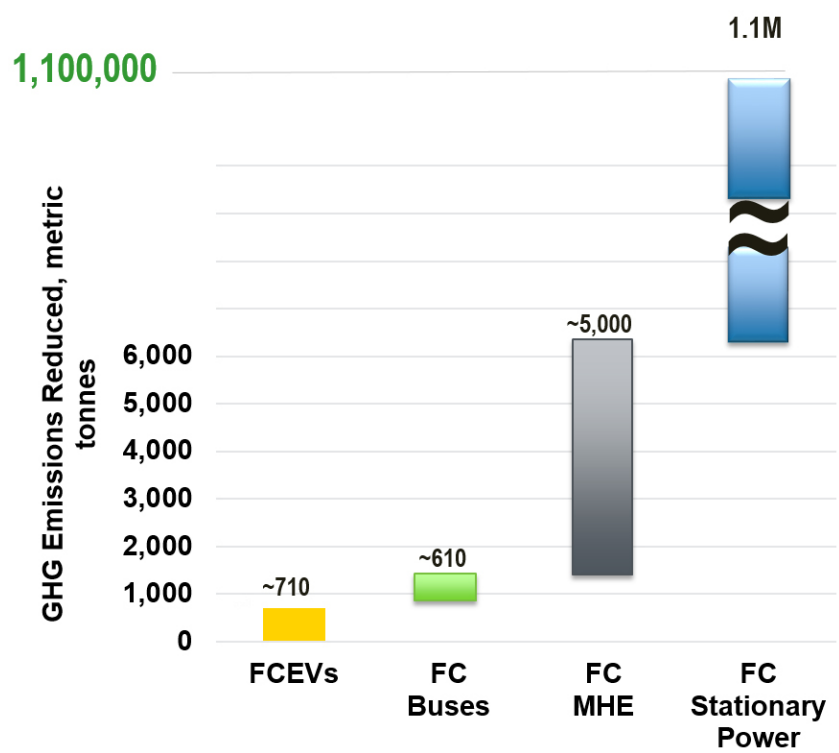



**FIGURE 8.** Cumulative GHG emissions reductions from fuel cell (FC) deployments

## OTHER PROGRAM ACTIVITIES AND HIGHLIGHTS FROM FY 2016

### Tracking Commercialization

Key indicators of the robustness and innovative vitality of an RD&D program are the number of patents granted and the number of technologies commercialized. The Program continued to assess the commercial benefits of funding by tracking the commercial products and technologies developed with the support of FCTO. As shown in Figure 9, R&D efforts funded by FCTO have resulted in more than 580 patents, more than 30 commercial technologies that cumulatively entered the market, and 65 technologies that are projected to be commercialized within three to five years (as of October 2014).[9]

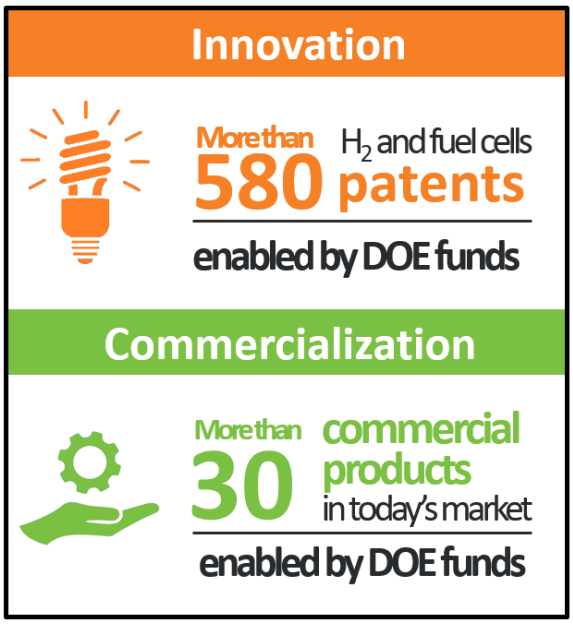



**FIGURE 9.** R&D efforts funded by FCTO have resulted in more than 580 patents, more than 30 commercial technologies in the market, and 65 technologies that are projected to be commercialized within three to five years (as of October 2014)

### Awards & Distinctions

During the last year, a number of researchers within the Program were recognized through various awards. For example:

- ANL's nanofibrous catalyst for fuel cells project was among four ANL entries named as finalists for the 2016 R&D 100 Awards.
- Jesse Adams of FCTO was recognized with a USCAR Research Partner Award at its 16th Annual USCAR Recognition Event by the United States Council for Automotive Research LLC (USCAR), the collaborative automotive technology company of General Motors, FCA US LLC, and Ford Motor Company.
- Adam Weber of LBNL was awarded the International Association of Hydrogen Energy's Sir William Grove Award for Leadership in Electrochemical Area.
- Robert Kolasinski of SNL has been selected as one of only 49 scientists to receive significant funding for research as part of DOE's Early Career Research Program.
- Siti Khatum Kamarudin, Deputy Director of the Fuel Cell Institute at Universiti Kebangsaan in Malaysia, has been included in the 2015 edition of "Highly Cited Researchers" by THOMSON Reuters.
- FCTO researcher Piotr Zelenay of LANL was one of four researchers selected as 2015 Laboratory Fellows.
- For a second consecutive year, NREL has been selected as the Outstanding Co-Op Employer by the University of South Carolina Career Center.
- Andrew Baker, a Ph.D. candidate at LANL, received the 2nd place 2015 Bernard Baker Student Award during the Fuel Cell Seminar and Energy Exposition in Los Angeles, California, on November 19, 2015.
- Peter Dudenas, a student researcher at LBNL, won first place at the PEFC (Polymer Electrolyte Fuel Cells) 15 Student Poster Competition at the Electrochemical Society Meeting in October 2015 for his excellent scientific contributions in the field of polymer electrolyte fuel cell research.
- Katrina Groth and Ethan Hecht of SNL were recognized in October 2015 at the IA-HySafe International Conference on Hydrogen Safety with the inaugural Robert Schefer Best Paper award.
- Dr. Thomas A. Zawodzinski was selected as a fellow of the American Chemical Society POLY division and awarded a Royal Academy of Engineering Distinguished Visiting Fellowship to spend one month in England, hosted by Imperial College.

[9] Pathways to Commercial Success, http://www.energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways

## Key Reports and Publications

Every year, the Program commissions a number of key reports, providing vital information to industry and the research community. Some of these are released on an annual basis—such as the Market Report (2015 Fuel Cell Technologies Market Report), the commercialization report (2015 Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Office), and the State of the States: Fuel Cells in America 2016 report—while others are published when studies are complete, projects have ended, or key milestones have been reached. Key examples include the following.

- The ***2015 Fuel Cell Technologies Market Report*** finds that hydrogen and fuel cells continue to grow at an unprecedented rate, with more than 60,000 fuel cells, totaling roughly 300 megawatts, shipped worldwide in 2015. The number of megawatts shipped grew by more than 65% compared to 2014.[10]
- ***State of the States: Fuel Cells in America 2016***, the seventh annual report on state activities, details fuel cell and hydrogen activities and policies in the 50 states and the District of Columbia.[11]
- ***Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Office***, the Program's annual commercialization report, indicates that FCTO efforts have successfully generated more than 580 patents, more than 30 commercial technologies, and 65 technologies that are expected to reach commercial scale within the next three to five years.[12]
- ***The Business Case for Fuel Cells*** illustrates how top American companies are using fuel cells in their business operations to advance their sustainability goals, save millions of dollars in electricity costs, and reduce carbon emissions by hundreds of thousands of metric tons per year.[13]
- The ***Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025–2030) Technologies*** was published by the U.S. DRIVE Cradle-to-Grave Working Group on June 1. The study provides a comprehensive cradle-to-grave analysis of the cost, greenhouse gas emissions, levelized cost of driving, cost of avoided greenhouse gas emissions, and technology readiness level of key fuel and vehicle technology pathways.[14]

## Workshops and Events

In FY 2016, the Program organized a number of workshops and events valuable to both stakeholders and DOE, including those listed below.

- On April 1, 2016, FCTO, NREL, and LANL hosted the ***Alkaline Membrane Fuel Cell Workshop*** in Phoenix, Arizona, to bring together experts to share information and identify the current status and R&D needs for alkaline membrane fuel cell technology.[15]
- On April 14–15, 2016, FCTO, LBNL, and Stanford University held the ***Advanced Water Splitting Materials Workshop*** in Stanford, California, to gather stakeholder input that was foundational in establishing DOE's Energy Materials Network HydroGEN consortium, which will accelerate the RD&D of advanced water splitting technologies for renewable hydrogen production.[16]
- On June 10, 2016, FCTO hosted a ***Cross-Cutting Hydrogen Station Infrastructure Review*** to evaluate FCTO's activities related to hydrogen station infrastructure, discuss the critical technical barriers to expanding hydrogen infrastructure and the strategies to overcome them, and gather feedback to better inform strategies to address RD&D needs for hydrogen infrastructure.[17]
- On July 11–12, 2016, EERE hosted the first **Sustainable Transportation Summit** in Washington, D.C. The summit brought together transportation and mobility leaders to discuss the technology, policy, and market

[10] http://energy.gov/eere/fuelcells/downloads/2015-fuel-cell-technologies-market-report
[11] State of the States: Fuel Cells in America 2016, https://energy.gov/eere/fuelcells/downloads/state-states-fuel-cells-america-2016
[12] Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Office, https://energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways
[13] The Business Case for Fuel Cells, https://energy.gov/eere/fuelcells/market-analysis-reports#mkt_business
[14] Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025–2030) Technologies, https://greet.es.anl.gov/publication-c2g-2016-report
[15] http://energy.gov/eere/fuelcells/downloads/2016-alkaline-membrane-fuel-cell-workshop
[16] http://energy.gov/eere/fuelcells/downloads/advanced-water-splitting-materials-workshop
[17] http://energy.gov/eere/fuelcells/downloads/cross-cutting-hydrogen-station-infrastructure-review

innovations that hold the potential to shape the transportation system of the future. The **H2USA Breakout Session** on July 12 featured three panels discussing H2USA and H2@Scale.[18] The first panel provided an overview of H2USA, a public-private collaboration among DOE, industry, state agencies, and other key stakeholders to address key challenges in deploying hydrogen infrastructure. The second panel covered stakeholder perspectives on hydrogen infrastructure. The third panel introduced a new DOE multi-lab initiative called H2@Scale, which offers the potential for renewable hydrogen as a flexible, clean energy carrier that can accelerate market penetration of renewables while also deeply decarbonizing our energy system.

- On August 24, 2016, FCTO hosted the ***Identifying Potential Pathways for Lower-Cost 700 bar Storage Vessels Workshop*** at USCAR in Southfield, Michigan, to identify and prioritize R&D strategies that have high potential to lower the costs of composite overwrapped pressure vessels for 700 bar hydrogen storage.[19]
- On September 27, 2016, FCTO held a ***Hydrogen and Fuel Cell Supply Chain Development Session*** as part of the 2016 Ohio Fuel Cell Symposium, in North Canton, Ohio, to enable a robust, high-quality, and low-cost domestic supply chain for the hydrogen and fuel cell industry across multiple applications.[20]
- On October 5, 2016, FCTO hosted a ***National Press Club*** briefing celebrating the week of National Hydrogen and Fuel Cell Day, in Washington, D.C. DOE Office of Energy Efficiency and Renewable Energy representatives spoke about the history and future plans of DOE's hydrogen and fuel cell program, beginning forty years ago with the national laboratories. Senator Byron Dorgan (ret.) also provided opening remarks. With the world's first commercial fuel cell cars now available, automakers and hydrogen infrastructure providers discussed their latest plans and progress.[21]
- On October 29, 2015, FCTO and Pacific Northwest National Laboratory hosted the ***Advanced Composite Materials for Cold and Cryogenic Hydrogen Storage Applications in Fuel Cell Electric Vehicles Workshop*** in Dallas, Texas, to gather input and discuss the state of knowledge on composite materials and processing for use at sub-ambient temperatures and to identify research needs and recommended development pathways for use of composite materials in sub-ambient-temperature, high-pressure applications.[22]

## New Funding Opportunity Announcements (FOAs) and Awards

The Program conducted FOAs and selected new projects consistent with the overall portfolio and congressional budget justification language and appropriations.

- **$14 million** in funding was awarded for the advancement of hydrogen fuel technologies. Specifically, these selections included advanced high-temperature water splitting, advanced compression, and thermal insulation technologies. Selected projects are located in Utah, Connecticut, Massachusetts, South Carolina, California, and Virginia.
- **$13 million** was awarded to advance fuel cell performance and durability and hydrogen storage technologies. Projects awarded under the FC-PAD consortium are located in Minnesota, Connecticut, Michigan, and Tennessee. Selected projects awarded under the HyMARC consortium are located in Illinois, Pennsylvania, Hawaii, and Missouri.
- **$4.75 million** was awarded to two projects for analysis and to support the Climate Action Champion's development of education and outreach programs to increase the deployment of FCEVs and hydrogen infrastructure. The city of San Francisco has been selected as the first Climate Action Champion to pursue hydrogen and fuel cell technologies for local transportation, and Strategic Analysis, Inc. was awarded new analysis projects.

The Program also participated in a number of SBIR/STTR FOAs and awards.

- The **2017 SBIR/STTR Phase I Release 1** FOA included two subtopics focused on hydrogen and fuel cell technologies. The fuel cell subtopic included novel, durable supports for low-platinum-group-metal catalysts for PEM fuel cells. The hydrogen delivery subtopic focused on metal hydride materials for compression.

[18] http://energy.gov/eere/fuelcells/downloads/2016-sustainable-transportation-summit-h2usa-breakout-session
[19] https://energy.gov/eere/fuelcells/downloads/doe-physical-based-hydrogen-storage-workshop-identifying-potential-pathways
[20] http://energy.gov/eere/fuelcells/downloads/2016-ohio-fuel-cell-symposium
[21] http://energy.gov/eere/fuelcells/downloads/lab-road-forty-years-fuel-cells-doe-national-press-club-briefing
[22] http://energy.gov/eere/fuelcells/downloads/advanced-composite-materials-cold-and-cryogenic-hydrogen-storage

- **2016 SBIR/STTR Phase II Release 1** award winners included three projects focused on catalysis for fuel cell and hydrogen production as well as hydrogen fuel contaminants detection. These projects were awarded through the Office of Basic Energy Sciences and are located in New Mexico, Ohio, and Connecticut.
- **2016 SBIR/STTR Phase I Release 1** award winners included four projects focused on durable and inexpensive polymer electrolyte membranes for transportation and stationary fuel cell applications. These projects were awarded through the Office of Basic Energy Sciences and are located in New Jersey, Virginia, Arizona, and Massachusetts.
- **2016 SBIR/STTR Phase I Release 2** topics included magnetocaloric materials development for hydrogen delivery and two technology transfer opportunities (TTOs). The first TTO is focused on developing a durable, high-activity electrocatalyst with low platinum content and low cost for PEM fuel cell applications. The second TTO is focused on safety sensors for hydrogen infrastructure applications.

## Requests for Information (RFIs)

The Program uses RFIs to solicit feedback from the stakeholder community in an open and transparent process that informs the Program's current activities and future plans. Key examples in FY 2016 included collecting feedback on:

- H2@Scale: determining RD&D necessary for clean hydrogen production to enable multi-sectoral deep decarbonization (November 2016)
- Hydrogen infrastructure RD&D: identifying project priorities to address deployment barriers (August 2016)
- Hydrogen technology showcase and training facility (July 2016)
- Medium- and heavy-duty fuel cell electric truck targets (July 2016)
- Cost reduction and performance improvements of overwrapped pressure vessel systems for compressed hydrogen for onboard vehicle applications (June 2016)
- Research, development, and business strategy needs for hydrogen and automotive PEM fuel cells (April 2016)
- Advanced thermal insulation and composite material compatibility for cold/cryogenic compressed gas fuel storage for onboard vehicle applications (November 2015)

## Webinars

The Program held a number of webinars throughout the year, providing valuable information to the entire stakeholder community. The complete list of FY 2016 webinars is shown below; all are archived on the Program's website.[23]

| Date | Title | Summary |
|---|---|---|
| August 30, 2016 | International Hydrogen Infrastructure Update | Discussed the status of international hydrogen infrastructure deployment. The webinar introduced the current status of the technology in several countries, including Japan and Germany. Several perspectives on global hydrogen refueling infrastructure initiatives were also provided. |
| July 28, 2016 | H2@Scale – A Potential Opportunity | Focused on the role of hydrogen at the grid scale and the efforts of a large, national laboratory team assembled to evaluate the potential of hydrogen to play a critical role in our energy future. Facts about hydrogen were shared, as was the vision of how it will fit into our future energy system. The R&D needs to enable this future were also discussed. |
| May 26, 2016 | Hydrogen Fuel Cells for Small Unmanned Air Vehicles | Highlighted the Naval Research Laboratory's (NRL's) incorporation of fuel cells into its small unmanned air vehicles, and the resulting fuel and energy saving benefits. NRL has contributed to fundamental and applied fuel cell technology research for well over a decade and has collaborated with FCTO through interagency working groups. |
| April 26, 2016 | Overview of HyRAM (Hydrogen Risk Assessment Models) Software for Science-based Safety, Codes and Standards | Provided an introduction to the new HyRAM research software developed by SNL and supported by FCTO. The HyRAM toolkit was designed to address key barriers to hydrogen infrastructure deployment, including limited access to safety data, lack of models describing hydrogen behavior, and challenges using technical data to revise standards. |

[23] http://energy.gov/eere/fuelcells/2016-webinar-archives

| Date | Title | Summary |
|---|---|---|
| March 14, 2016 | Detectape – A Localized Visual Detector for Hydrogen Leaks | Discussed DetecTape, a color-changing, self-fusing silicone tape designed to detect hydrogen gas leaks in fuel cells, transmission, storage, and generation facilities. Hydrogen equipment operators can use the tape to quickly identify precise leak locations and initiate maintenance protocols, expediting the restoration of equipment while maintaining a safe workplace. |
| February 25, 2016 | Update to the 700 bar Compressed Hydrogen Storage System Cost Projection | Strategic Analysis (SA) presented results of its cost analysis of onboard compressed hydrogen storage systems (updating its 2013 analysis, which serves as the baseline). The hydrogen storage systems analyzed are 700 bar pressure vessels made of a carbon fiber composite wrapped polymer liner (Type IV). The webinar familiarized participants with SA's Design for Manufacturing and Assembly approach, explained what processes and materials are used to manufacture composite storage vessels, and discussed the improvements in hydrogen storage systems that have led to cost reductions. |
| January 21, 2016 | Potential Strategies for Integrating Solar Hydrogen Production and Concentrating Solar Power: A Systems Analysis | Discussed an analysis conducted by SNL exploring potential synergies that could be realized by integrating solar hydrogen production and concentrating solar power (CSP) technologies. The webinar presented the results of the analysis, including a discussion of the conditions that may favor the integration of hydrogen production and CSP. |
| January 12, 2016 | Assessing Steel Pipeline and Weld Susceptibility to Hydrogen Embrittlement | Understanding the impact of hydrogen on structural steel (commonly referred to as "hydrogen embrittlement") is critical to the design of equipment used in hydrogen service, such as compressors, storage vessels, and pipelines. This webinar discussed the breadth of testing performed at SNL and the effects of hydrogen gas on steel pipelines and welds. The webinar also demonstrated how measured fatigue crack growth laws can be applied to calculate minimum wall thickness needed for steel hydrogen pipelines. |
| January 7, 2016 | FCTO Consortia Overview (HyMARC and FC-PAD) | Provided an overview of the Fuel Cell Consortium for Performance and Durability (FC-PAD) and the Hydrogen Materials—Advanced Research Consortium (HyMARC), including a summary of the organization of these consortia, their planned scientific activities, and the role of individual projects selected to work with these consortia through the FY 2016 FOA. |
| December 10, 2015 | Hydrogen Equipment Certification Guide | Introduced the Hydrogen Equipment Certification Guide, a document intended to aid in equipment approval until listed equipment are available for the entirety of equipment and components. The webinar also started a public comment phase of the document for soliciting stakeholder feedback in preparation for a September 2016 release. |
| December 1, 2015 | Northeast States' Hydrogen Economy | Focused on state efforts to support the regional development of hydrogen infrastructure for the deployment of FCEVs in the Northeast United States. The presentation identified strategies, methods, and policies being employed in the Northeast states, from Maine to Maryland, to coordinate stakeholders, manage information, reduce potential barriers, and create new market opportunities for logical deployment of high-efficiency FCEVs. |
| October 13, 2015 | Reference Designs for Hydrogen Fueling Stations | The goal of the H2FIRST Reference Station Design Task is to accelerate acceptance of near-term hydrogen infrastructure build-out by exploring the advantages and disadvantages of various station designs. This webinar discussed the process and findings of the work, recommended future R&D topics, and outlined planned next steps for the Reference Station Design Task. |

The Program published multiple blogs focused on hydrogen and fuel cell activities.

| Date | Title | Summary |
|---|---|---|
| October 12, 2016 | ON THE VERGE OF A HYDROGEN TIPPING POINT? | Across the country this past week, scientists and engineers have been celebrating National Hydrogen and Fuel Cell Day. Aptly chosen to represent the atomic weight of hydrogen (1.008), National Hydrogen and Fuel Cell Day was celebrated for the first time on October 8, 2015, and this year we're keeping the momentum going. |
| October 6, 2016 | 3 QUESTIONS WITH A 'FOUNDING FATHER' OF HYDROGEN AND FUEL CELLS: BYRON MCCORMICK | In honor of National Hydrogen and Fuel Cell Day on October 8, we sit down with Byron McCormick, one of the "founding fathers" of hydrogen and fuel cells, to talk about his experiences during his more than 50 year career. Byron began his career in 1974 at Los Alamos National Laboratory, where he first explored the possibility of using fuel cells in vehicles. |
| July 19, 2016 | 5 THINGS TO KNOW WHEN FILLING UP YOUR FUEL CELL ELECTRIC VEHICLE | Filling up your fuel cell electric vehicle is just as easy as filling up a gasoline-powered car. The Energy Department's Office of Energy Efficiency and Renewable Energy offers five tips to follow when filling up at a hydrogen fuel station for the first time. |

| Date | Title | Summary |
|---|---|---|
| July 11, 2016 | D.C. SHOWCASES CUTTING-EDGE HYDROGEN FUELING STATION DEMO | The Department of Energy and the Department of Interior's National Park Service have officially opened a new technology demonstration hydrogen refueling station in Washington, D.C. This hydrogen station should help grow and advance the benefits of hydrogen power as a fuel, and highlight the benefits of fuel cell electric vehicles firsthand throughout the region. |
| June 30, 2016 | FIRST-EVER SUSTAINABLE TRANSPORTATION SUMMIT TO TALK FUTURE OF TRANSPORTATION, ENERGY, AND MOBILITY | The inaugural 2016 Sustainable Transportation Summit will serve as a forum to share ideas and perspectives on opportunities to accelerate the commercialization and deployment of advanced transportation technologies and smart mobility systems over the next decade. |
| June 8, 2016 | A CLOSER LOOK AT HYDROGEN REFUELING | What's the difference between a hydrogen refueling dispenser and a traditional gasoline dispenser that you see at your local gas station? Not that much, actually... |
| June 6, 2016 | 10 QUESTIONS WITH HYDROGEN AND FUEL CELL EXPERT GLENN RAMBACH | Glenn Rambach is a world-renowned expert in the hydrogen and fuel cell industry. He talks about the history of fuel cells, what he's seen in his 45-year career, and what he thinks the future has in store for fuel cell electric vehicles. |
| June 3, 2016 | ANNUAL MERIT REVIEW EVALUATES IMPACT OF SUSTAINABLE TRANSPORTATION PROJECTS | Nearly 400 Energy Department activities and projects will be judged by reviewers from a variety of scientific backgrounds at the Vehicle Technologies Office and Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting in Washington, D.C., which is free of charge and open to the public. |
| May 23, 2016 | FUEL CELL ELECTRIC VEHICLES GETTING A BOOST IN SAN FRANCISCO | Last week, the city of San Francisco was named the first Climate Action Champion to be focused on hydrogen and fuel cells in the United States by the Energy Department's Fuel Cell Technologies Office. |
| May 9, 2016 | FUEL CELL COMPANIES COMMIT TO HIRING VETERANS THROUGH JOINING FORCES INITIATIVE | In April 2015, the First Lady participated in an event celebrating how far we have come and announcing new private-sector commitments to train or hire 90,000 veterans and military spouses. At the event, two Fuel Cell Technologies Office-supported companies were acknowledged for their commitment to these efforts. |
| February 2, 2016 | Energy Secretary Moniz at the 2016 Washington Auto Show | This video of Energy Secretary Moniz at the 2016 Washington Auto Show describes how the Energy Department played a role in the resurgence of the auto industry by supporting advanced vehicle technologies that boost fuel efficiency and grow America's clean energy economy. |
| January 27, 2016 | PHOTO GALLERY: 2016 WASHINGTON AUTO SHOW | Scroll through the photos to see some of the Energy Department-supported technologies that are lowering carbon pollution and moving America's economy forward. |
| January 22, 2016 | THE YEAR OF THE FUEL CELL: LOOKING BACK TO GET AHEAD | As EERE hits the ground running in 2016, let's take a minute to celebrate our hard work in 2015 that advanced hydrogen and fuel cells to where they are today. From research and development, to real-world deployment, 2015 was a landmark year for the hydrogen and fuel cell industry. |
| January 13, 2016 | Fuel Cell Technologies Office: 2015 Recap and the Year Ahead | At the beginning of 2016, Sunita Satyapal, Director of the Fuel Cell Technologies Office, reflects on the Program's 2015 accomplishments and highlights some of the plans for 2016. |
| December 3, 2015 | COLORADO JOINS THE HYDROGEN AND FUEL CELLS RACE | When one thinks of clean energy, they often think of California, which is committing up to $100 million over five years to build 100 hydrogen stations across the state, as the biggest mover and shaker. But Colorado is quickly gaining ground when it comes to hydrogen and fuel cells. |
| October 23, 2015 | TAKE A TEST DRIVE IN THE WORLD'S FIRST COMMERCIAL FUEL CELL SUV | The Department of Energy hosted an exciting and unique visitor last week: the world's first commercially available, zero emissions fuel cell electric sport utility vehicle (SUV). The first-of-its-kind vehicle was brought to Washington, D.C., by Hyundai executives from South Korea who were in the United States as part of South Korean President Park Guen-hye's delegation visiting the president of the United States. |
| October 8, 2015 | STACKED FOR SUCCESS: CELEBRATING NATIONAL HYDROGEN AND FUEL CELL DAY | Do you know the atomic weight of hydrogen? It's 1.008, which makes today, October 8, a great day to celebrate National Hydrogen and Fuel Cell Day! But at the Department of Energy, we're not just celebrating the confluence of the calendar and the periodic table. We're starting to see a hydrogen future to our roads today. |

## INTERNATIONAL ACTIVITIES

### International Partnership for Hydrogen and Fuel Cells in the Economy

The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) includes 18 member countries (Australia, Austria, Brazil, Canada, China, France, Germany, Iceland, India, Italy, Japan, the Netherlands, Norway, the Republic of Korea, the Russian Federation, South Africa, the United Kingdom, and the United States) and the European Commission. The IPHE is a forum for governments to work together to advance worldwide progress in hydrogen and fuel cell technologies. IPHE also offers a mechanism for international R&D managers, researchers, and policymakers to share program strategies. IPHE members embarked upon a second 10-year term in November 2013. An independent secretariat was established in 2015, and the current Chair of IPHE is from France. The United States continues its strong role as Vice Chair. In FY 2016, the IPHE Steering Committee met in Grenoble, France (December 2015), and in Berkeley, California (May 2016), to share progress and plans related to hydrogen and fuel cells.

### International Energy Agency

The United States is also involved in international collaboration on hydrogen and fuel cell R&D through the International Energy Agency's Technology Collaboration Programs (TCPs), and is a member of both the Advanced Fuel Cells TCP and the Hydrogen TCP. The TCPs provide a mechanism for member countries to share the results of R&D and analysis activities. The DOE Hydrogen and Fuel Cells Program is a strong contributor to numerous International Energy Agency tasks and activities in the Advanced Fuel Cells and Hydrogen TCPs.

In May 2016, Wiley published a book, Fuel Cells Data, Facts, and Figures, edited by Detlef Stolten, R. Can Samsun, and Nancy L. Garland of the Systems Analysis Annex of the Advanced Fuel Cells TCP. [24] The short chapters, some written by DOE staff and researchers, provide economic data for cost considerations and a full overview of demonstration data, and cover topics such as fuel cells for transportation, fuel provision, and codes and standards.

## EXTERNAL COORDINATION, INPUT, AND ASSESSMENTS

### H2USA Partnership

To help address the challenge of hydrogen infrastructure, in 2013 DOE co-launched H2USA, a public-private collaboration focused on the widespread commercial adoption of FCEVs. H2USA currently consists of more than 50 participants, including the state of California, as well as developers, car companies, and hydrogen providers.

In FY 2016, the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project, in support of H2USA, launched the Hydrogen Station Equipment Performance device, or HyStEP, to reduce the time to commission new stations from months to just one week. HyStEP acts as a surrogate for vehicles, eliminating the need for each automotive manufacturer to test separately. HyStEP is equipped with modular tanks and all of the instrumentation that automotive manufacturers would use in performing their own tests. HyStEP initially will be used to accelerate commissioning of refueling stations in California. Eventually, it could be used in other states as they develop hydrogen refueling networks.

HyStEP will help California meet its ambitious goal of commissioning up to 35 new refueling stations by the end of 2016, which translates to one new station every one to two weeks. The target is a hydrogen refueling network of more than 50 retail stations in this timeframe, primarily in the Los Angeles metro area, Orange County, and the Bay Area.

### Hydrogen and Fuel Cells Technical Advisory Committee (HTAC)

As required by the Energy Policy Act of 2005, HTAC was created in 2006 to advise the Secretary of Energy on issues related to the development of hydrogen and fuel cell technologies (including associated safety, economic, and environmental issues), and to provide recommendations regarding DOE's programs, plans, and activities. HTAC members include representatives of domestic industry, academia, professional societies, government agencies, financial organizations, and environmental groups, as well as experts in the area of hydrogen safety. HTAC met twice in FY 2016. In August 2016, HTAC released its eighth annual report, which summarizes progress in hydrogen and fuel

[24] https://www.amazon.com/Fuel-Cells-Data-Facts-Figures/dp/3527332405

cell technologies, domestic and international RD&D, and commercialization activities, and offers recommendations on the Department's hydrogen-related programmatic and policy initiatives.

The Committee established four new subcommittees in FY 2016. The Safety and Event Response Plan Subcommittee's goal is to enable a comprehensive, consistent, and coordinated response to hydrogen safety-related events, and the subcommittee will prepare a report identifying existing resources and resource gaps for responding to safety-related events at retail hydrogen stations, as well as recommended actions to address current and projected needs. The Near-Term Hydrogen Fueling Options Subcommittee will address fuel availability from the hydrogen fueling infrastructure perspective and provide an assessment of whether or not there are one or more paths to resolve this dilemma using existing or near-term technology and business approaches. The Hydrogen Enabling Resiliency, Renewables and Security Subcommittee was reengaged to provide feedback on a multi-lab idea currently under development. The proposed effort is on H2@Scale to enable renewables as well as to provide hydrogen as a fuel (or other value-added applications) or for ancillary services. Finally, the HTAC Oversight Framework Subcommittee will develop a framework from which to govern HTAC activities that provides clear linkage to Committee responsibilities as defined by Congress; grounding and context for HTAC discussion and deliberation; a foundation from which to identify areas for HTAC focus and structure Committee debates; consistency and continuity from year to year as membership and leadership changes; and organization for HTAC reviews, recommendations, and reporting.

## Federal Inter-Agency Coordination

The Hydrogen and Fuel Cell Interagency Task Force, mandated by the Energy Policy Act of 2005, includes senior representatives from federal agencies supporting hydrogen and fuel cell activities, with DOE/EERE serving as the chair. The Hydrogen and Fuel Cell Interagency Working Group (IWG), also chaired by DOE, supports the initiatives and actions passed down by the Interagency Task Force. The IWG meets monthly to share expertise and information, coordinate activities of federal entities involved in hydrogen and fuel cell RD&D, and ensure efficient use of taxpayer resources. One example of interagency collaboration was the development a federal fleet strategy for early adoption of FCEVs to drive initial demand, meet Executive Order GHG reduction goals, and lead by example. Four separate federal agencies—Veterans Affairs, Department of Defense, DOE, and National Aeronautics and Space Administration—each expressed interest in leasing FCEVs in California to make use of and help grow the nascent hydrogen infrastructure there.

Another example involves DOE and the U.S. Postal Service (USPS). The USPS has recently expressed interest in fuel-cell-powered material handling equipment for their Network Distribution Centers. The IWG held a webinar on the results of previous fuel cell forklift deployments within the Department of Defense and DOE, which led the USPS to move forward on its first deployment at their Capitol Heights (Maryland) Network Distribution Center. A third example is the opening of a hydrogen refueling station in the Washington, D.C., area. DOE and National Park Service worked together to establish the station at the National Park Service Maintenance Facility in the Brentwood neighborhood of Washington, D.C. Several IWG members attended the opening event representing their agencies, and events continue to be added to a ride-and-drive calendar that will provide education and outreach of this zero-emission technology to citizens and stakeholders throughout the National Capitol Region.

## FY 2016 Annual Merit Review and Peer Evaluation (AMR)

The Program's AMR took place June 6–10, 2016, in Washington, D.C., and provided an opportunity for the Program to obtain expert peer reviews of the projects it supports and to report its accomplishments and progress. Acting Assistant Secretary David Friedman kicked the meeting off, and Senator Byron Dorgan (ret.) gave the keynote plenary presentation. For the eighth time, this meeting was held in conjunction with the annual review of DOE's Vehicle Technologies Office. During the AMR, reviewers evaluate the Program's projects and make recommendations; DOE uses these evaluations, along with other review processes, to make project funding decisions for the upcoming fiscal year. The review also provides a forum for promoting collaborations, the exchange of ideas, and technology transfer. This year, approximately 1,800 participants attended, and more than 340 experts peer-reviewed 130 of the Program's projects. The report summarizing the results and comments from these reviews is available on DOE's website.[25] The 2017 Annual Merit Review and Peer Evaluation Meeting will be held June 5–9, 2017, in Washington, D.C.

[25] https://www.hydrogen.energy.gov/annual_review16_report.html

## Funds Saved through Active Project Management

The AMR is a key part of the Program's comprehensive approach toward active management of its projects. Termination of underperforming projects—identified through the AMR as well as through other go/no-go decisions (with criteria defined in the project scope of work)—helped the Program redirect $2.4 million in funding in FY 2016, $0.6 million in funding in FY 2015, $3.0 million in funding in FY 2014, and over $39 million since FY 2010. In addition, the Program implements EERE's robust Active Project Management policy to identify and resolve issues early and to mitigate risks in impactful ways, helping underperforming projects get back on track.

## DOE Cross-Cutting Activities

Hydrogen Energy Storage/Grid Integration: Hydrogen energy storage may provide a broad range of energy services and typically involves the production of hydrogen from electricity via electrolyzers. Increasing capacity for variable renewable energy technologies (e.g., wind and solar) on the grid is going to be a major challenge facing future deployment as these technologies make up a larger portion of the power generation mix. FCTO's project portfolio includes a joint project between NREL and Idaho National Laboratory, which involves demonstrating electrolyzer-based energy storage to support the grid through ancillary services and demand response, in addition to hydrogen production for retail sale to transportation technologies. FCTO is also supporting four projects within the Grid Modernization cross-cutting effort (involving various offices within EERE and the Office of Electricity), with an objective to help set the nation on a cost-effective path to an integrated, secure, and reliable grid. Two of these projects are foundational: LBNL is developing a siting and optimization tool for distributed energy resources, while Idaho National Laboratory is implementing smart technology solutions to enhance the reliability of the Idaho Falls Power distribution network. The other two projects relate more specifically to FCTO: LBNL is developing a tool to quantify and optimize interactions between hydrogen stations, vehicles, and the grid; NREL is developing optimal dispatch and control strategies to improve the management of fuel cell-integrated building systems.

Wide Bandgap (WBG) Semiconductors for Clean Energy Initiative: WBG semiconductor materials allow power electronic components to be smaller, faster, more reliable, and more efficient than their silicon-based counterparts. These capabilities make it possible to reduce weight, volume, and life-cycle costs in a wide range of power applications, including fuel cells and hydrogen production technologies. EERE's technology offices, through the Advanced Manufacturing Office, are working together to harness these capabilities to lead to dramatic energy savings in industrial processing and consumer appliances. The flagship of this cross-cutting effort is the "Power America" Institute, DOE's National Network for Manufacturing Innovation focused on accelerated development of next-generation WBG semiconductor products. In FY 2015 and FY 2016, FCTO identified numerous applications of hydrogen and fuel cell technologies that could benefit from the development of next-generation WBG power electronics, including fuel-cell-powered material handling equipment and FCEVs in the transportation sector and large-scale grid integration of fuel cells and electrolyzers in the stationary power sector. FCTO is working with Power America and with leading innovators in the WBG electronics industry to organize a workshop (being held in December 2016) to further explore opportunities for product development responsive to the market pull of these hydrogen and fuel cell technology applications.

Energy Materials Network (EMN): In FY 2014, FCTO initiated an effort to explore the use of high-throughput computational and experimental methods toward the accelerated discovery and development of critical materials for hydrogen and fuel cell technologies. This approach leverages the scientific methodologies of the President's Materials Genome Initiative launched in 2011. In FY 2015, several DOE offices identified complementary Materials Genome Initiative-related research interests in several key material domains, with plans to align their materials research through the establishment of broad research consortia supporting teams of industry, academic, and national lab partners and conducting focused research within these domains. Together, these consortia form the EMN, a resource network with capabilities in materials design, synthesis, characterization, manufacturing, and digital data management and informatics. In late FY 2016, FCTO established three EMN consortia: ElectroCat for the development of platinum-group-metal-free fuel cell catalysts, HyMARC for the development of viable materials-based hydrogen storage materials, and HydroGEN for the development of advanced water splitting materials for renewable hydrogen production. All three leverage the world-class research facilities and expertise at participating national laboratories, addressing challenges in theory, computation, synthesis, and characterization for accelerating RD&D in these three high-impact fields. In each EMN consortium, the extensive network of research capabilities is expected to support competitively selected collaborative research among industry, academia, and the national laboratories for accelerating progress toward commercialization.

## IN CLOSING ...

After the first oil embargo back in the mid-1970s, a group of national laboratory researchers met with leaders from the private sector and federal government at Los Alamos National Laboratory in New Mexico. They came together to brainstorm ideas, like hydrogen and fuel cells, that would ultimately revolutionize the transportation sector as we know it. Based on these ideas, General Motors temporarily relocated their fuel cell division to Los Alamos. Over time, national lab scientists helped teach industry scientists how to make optimized electrodes—the heart of the fuel cell—and eventually these partnerships led to major advancements. Forty years later we have commercial FCEVs on the road!

It's been a great year for fuel cells! Over the past year, Hyundai and Toyota both introduced their FCEVs, and Honda has plans to introduce this year. Several other companies also plan to release FCEVs very soon, including General Motors, Daimler, Honda, and BMW. In California, hydrogen is a fueling option at more than 25 retail gas stations, and there are plans for several fueling stations to be opened soon in the Northeast United States.

The Program's latest Fuel Cell Technologies Market Report[26] shows the fuel cell industry continuing to grow at an unprecedented rate, with more than 60,000 fuel cells, totaling roughly 300 megawatts, shipped worldwide in 2015. The number of megawatts shipped grew by more than 65% compared to 2014. This continues to uphold the consistent 30% annual market growth rate since 2010. EERE-funded R&D has resulted in more than 580 patents, more than 30 commercial technologies, and 65 technologies that are projected to be commercialized within three to five years.[27]

With so much FCTO-supported activity in the last year, only a few accomplishments are highlighted in the summary that follows.

DOE and the U.S. Department of Interior's National Park Service officially opened a new hydrogen fueling demonstration station in Washington, D.C., on July 11, 2016. Acting Assistant Secretary David Friedman attended the official opening of the station, along with a range of dignitaries and partners from industry, including several key automakers. Though not a public station, advances demonstrated through this project will enable public retail stations of the future.

The July 11 event celebrated not only the opening of the hydrogen fueling demonstration station, but also the delivery of two of the world's first commercially available FCEVs to DOE and U.S. Department of Interior fleets—a Hyundai Tucson Fuel Cell and a Toyota Mirai. As part of DOE's technology validation efforts, the technology advances embodied in these vehicles are demonstrated under real-world conditions, and data is collected to further advance research and development. This collaboration between DOE and the Department of Interior will showcase cutting-edge hydrogen generation technology and provide an opportunity to demonstrate FCEVs at federal agencies and the surrounding region.

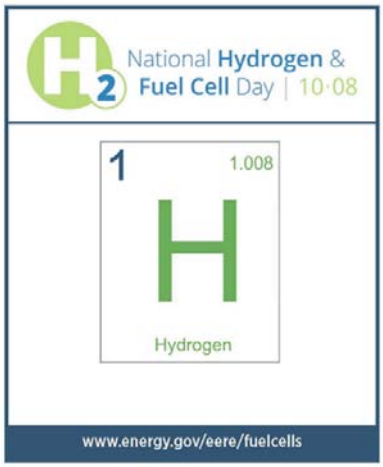
Also on July 11, sustainable transportation stakeholders came together to hear from distinguished transportation and mobility thought leaders, including the Secretary of Energy, as they shared their expertise and insights on Day 1 of the Energy Department's inaugural 2016 Sustainable Transportation Summit. Through a series of engaging keynotes and interactive plenary sessions, speakers focused on critical sustainable transportation topics, including deep decarbonization for U.S. transportation systems, consumer adoption of new vehicle technology, net-zero carbon fuels, and the future of mobility. Day 2 featured a panel on H2USA and another on H2@Scale.

In August 2011, the president of the United States challenged the private sector to hire 100,000 veterans and military spouses. The Joining Forces Initiative was created, a nationwide initiative calling all Americans to rally around service members, veterans, and their families. In April 2015, an event celebrated how far we have come and announced new private-sector commitments to train or hire 90,000 veterans and military spouses. At the event, two FCTO-supported companies were acknowledged for their commitment to these efforts: Air Liquide committed to making veterans 10% of their annual hires, and PDC Machines committed to making veterans or military spouses 8–10% of their workforce by 2020.

Across the country in October, scientists and engineers celebrated National Hydrogen and Fuel Cell Day. Aptly chosen to represent the atomic weight of hydrogen (1.008), National Hydrogen and Fuel Cell Day was celebrated for the first time on October 8, 2015, and this year EERE worked hard to keep the momentum going. Leading up to the big day, EERE celebrated with a number of events, including ride-and-drives, hydrogen station tours, informational presentations, and even a networking coffee hour at DOE. The week was also peppered with social media posts

[26] Fuel Cell Technologies Market Report, http://energy.gov/eere/fuelcells/downloads/2015-fuel-cell-technologies-market-report
[27] Pathways to Commercial Success, http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways

ranging from Tweets and Facebook posts to blogs and videos. In total, the hydrogen and fuel cell message was viewed over social media almost half a million times.




On September 12, 2016, FCTO released an RFI seeking feedback on the H2@Scale concept. Formed as part of an EERE Big Idea, H2@Scale is a concept that describes the potential of wide-scale renewable hydrogen production to enable the value of hydrogen across multiple sectors of the U.S. economy and dramatically reduce U.S. greenhouse gas emissions. Hydrogen is currently a feedstock for numerous industrial applications: petroleum refining, fertilizer production, biofuels production, and others (e.g., plastics, cosmetics, and food industries). Ten million metric tons of hydrogen are currently produced in the United States every year (95% of which is via centralized reforming of natural gas). Widespread use of technologies that are clean and/or renewable to produce hydrogen would be a paradigm shift that deeply decarbonizes current industries, along with emerging value-added applications, such as synthetic natural gas production or use of hydrogen in metals refining.

The Program also hosted an H2@Scale workshop on November 16–17, 2016, in Golden, Colorado, to identify the current barriers and research needs related to the H2@Scale concept. This workshop was meant to guide the development of a DOE roadmap on RD&D activities that can enable hydrogen as an energy carrier at a national scale. Proceedings from that workshop are now available.[28]

This is a critical time for fuel cells and hydrogen. The DOE Hydrogen and Fuel Cells Program will continue to work in close collaboration with key stakeholders and will continue its strong commitment to effective stewardship of taxpayer dollars in support of its mission to enable the energy, environmental, and economic security of the Nation. In support of these efforts, the following nearly 1,000 pages document the results and impacts of the Program in the last year.

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[28] http://energy.gov/eere/fuelcells/downloads/h2-scale-workshop