I. INTRODUCTION

I.0 Introduction

The U.S. Department of Energy's Hydrogen and Fuel Cells Program (the Program) engages in comprehensive efforts across a range of technical and non-technical areas to enable the widespread commercialization of hydrogen and fuel cell technologies. 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, Nuclear Energy, and Fossil Energy. The Program's efforts are aligned with the Administration's "all-of-the-above" approach to energy and the President's Climate Action Plan and will spark the type of innovation that drives economic growth and creates American jobs, while moving our economy toward cleaner, more efficient forms of energy that will cut our reliance on foreign oil.

With emphasis on applications that will most effectively strengthen our nation's energy security and improve our efforts to cut carbon emissions, the Program conducts research, development, and demonstration (RD&D) leading to critical improvements in hydrogen and fuel cell technologies, as well as diverse activities to overcome economic and institutional obstacles to commercialization.

The year 2015 was a landmark year for hydrogen and fuel cells. After decades of research and development (R&D) and the demonstration of various generations of prototype fuel cell electric vehicles (FCEVs) by a number of global automakers, this year saw the first commercial FCEVs in history, being *sold* to regular consumers. These accomplishments are directly in line with directives in the Energy Policy Act of 2005: "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" (Public Law 109-58, Title 8, Sec. 805). To garner more public visibility, Congress established the first National Hydrogen and Fuel Cell Day in 2015—on October 8th (chosen for the atomic mass of hydrogen, 1.008)—with industry, government, and laboratories across the nation commemorating accomplishments and progress on that inaugural day. Against that backdrop, DOE continued to make substantial progress toward its goals and objectives, working with industry and other stakeholders to enable the widespread, commercially viable adoption of hydrogen and fuel cell technologies.

In Fiscal Year (FY) 2015, Congress appropriated approximately $117 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; Office of Fossil Energy's Hydrogen from Coal RD&D Plan; and the Office of Science's Basic Research Needs for the Hydrogen Economy.[1]

In addition to summarizing examples of key R&D accomplishments, this report highlights major programmatic accomplishments, including launching the $1 Million H2 Refuel H-Prize; demonstrating the world's first fleet of hydrogen fuel cell airport ground support equipment; establishing national-laboratory-led consortia in key R&D areas; and supporting the public-private partnership, H2USA, through national-laboratory-led efforts developing financial assessment tools for hydrogen infrastructure and critical equipment to validate the performance of hydrogen stations as they come on line.

PROGRESS AND ACCOMPLISHMENTS BY KEY ACTIVITY

This report documents 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 sub-program introductions, subsequent project reports, and in the corresponding 2015 Annual Merit Review and Peer Evaluation Report.[2]

Fuel Cells

The Fuel Cells sub-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. Efforts include R&D of fuel cell stack components, system balance-of-plant (BOP) components, and subsystems, as well as system integration. The sub-program seeks a balanced, comprehensive approach to fuel cells for near-, mid-, and longer-term applications.

[1] www.hydrogen.energy.gov/roadmaps_vision.html
[2] http://www.hydrogen.energy.gov/annual_review15_report.html

Cost

One of the most important fuel cell metrics is the projected high-volume manufacturing cost for automotive fuel cells, which the sub-program tracks on an annual basis. This year, the cost of an 80-kW_{net} automotive polymer exchange membrane (PEM) fuel cell (FC) system based on next-generation laboratory technology and operating on direct hydrogen was projected to be \$53/kW_{net} when manufactured at a volume of 500,000 units/year (Figure 1) and \$60/kW_{net} when manufactured at 100,000 units/year. (For comparison, the expected cost of automotive PEM fuel cell systems that are based on current technology is approximately \$280/kW when manufactured at a volume of 20,000 units/year.)[3]

To enable commercially competitive fuel cell vehicles, the sub-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 sub-program's ultimate cost target.

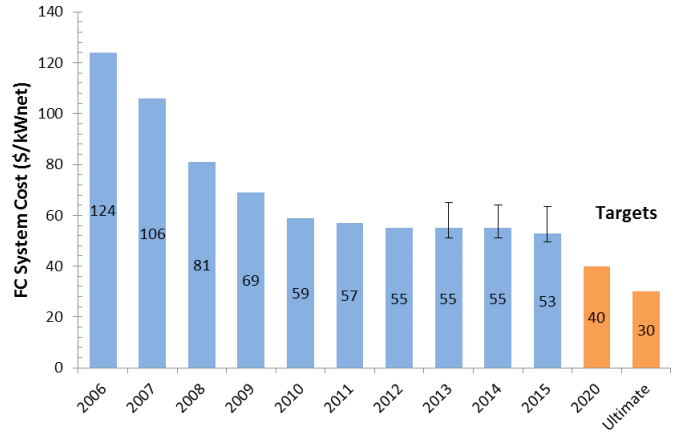


FIGURE 1. Modeled cost of an 80-kW_{net} PEM fuel cell system based on projection to high-volume manufacturing (500,000 units/year) (Source: FY 2015 Fuel Cell System Cost Record: http://www.hydrogen.energy.gov/program_records.html#fuel_cells)

Development of Best Practices and Protocols Impacting the Electrocatalyst Research Community

In addition to progress in fuel cell performance, cost, and durability, a key accomplishment in 2015 was finalization of standard protocols for rotating-disk electrode (RDE) testing to assess catalyst activity. This is an example in which the Program can impact the broader scientific community and bring together both basic research scientists and the applied research stakeholders to enable accurate and reproducible measurements that can subsequently be evaluated and taken to the next stage of development.

RDE testing is a standard tool to evaluate catalyst performance before determining whether membrane electrode assemblies (MEAs) should be fabricated, and it is widely used by thousands of researchers across academia, industry, and national labs worldwide. However, as brought to our attention by the Naval Research Laboratory (NRL), results can be highly irreproducible even when identical catalysts are used. A key to obtaining high and reproducible oxygen reduction reaction (ORR) activity measurement using the RDE technique is the formation of a uniform catalyst film on a glassy carbon electrode. However, uniformity of the film and hence results depend on how the film is deposited. As noted by NRL and coworkers, rotational drying can be used to eliminate the "coffee ring" structure typically seen when using stationary drying (Figure 2).[4] Discrepancies in activity values reported between research groups and the

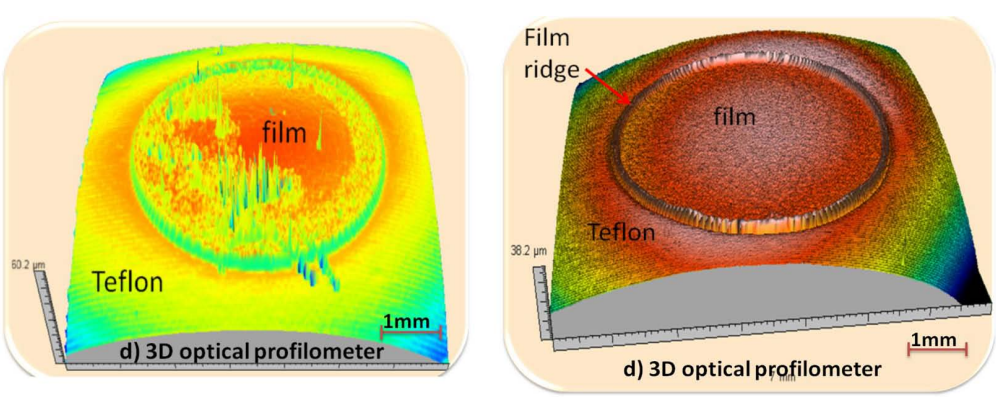


FIGURE 2. View of uniform film (right) vs. coffee ring structure and lack of uniformity (left)

[3]DOE Program Record #15015, http://www.hydrogen.energy.gov/pdfs/15015_fuel_cell_system_cost_2015.pdf
[4]Y. Garsany, I.L. Singer, K.E. Swider-Lyons, S.S. Kocha, Impact of film drying procedures on the RDE characterization of Pt/VC electrocatalyst, *J. Electroanal. Chem*. 662 (2011) 396–406.

fact that improved protocols have not been uniformly adopted result in inaccurate and unreliable catalyst screening and benchmarking being reported in the literature. For example, activity values reported over the last decade for the same catalyst tested in different laboratories have varied by as much as 200%.

The National Renewable Energy Laboratory (NREL) and Argonne National Laboratory (ANL) established standardized RDE test protocols and best practices to allow for more precise and reproducible data and reliable comparisons to be made by catalyst and fuel cell developers when evaluating novel synthesized catalysts in small quantities. Figure 3 shows reproducible results at three different laboratories using catalysts from three different suppliers. Details on the protocols can be found in the references below.[5] Given the importance of reporting accurate results in the literature, the new protocols and best practices are highlighted here for broader awareness.

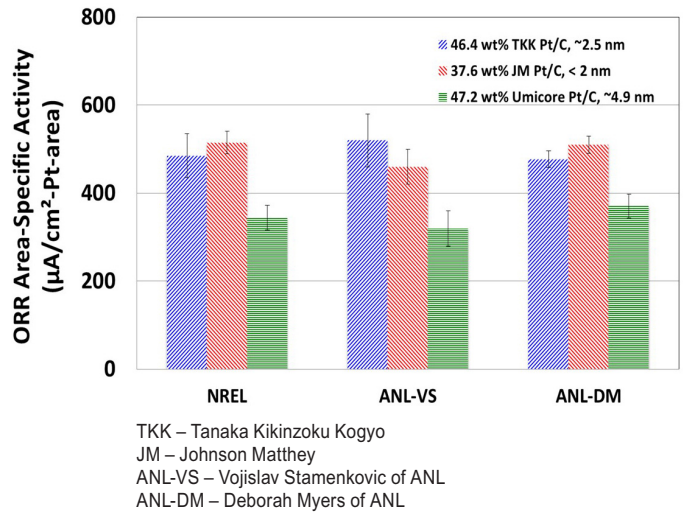


FIGURE 3. Catalyst activity results demonstrating reproducibility

Catalyst and MEA Advances

FY 2015 saw additional improvements in the integration of fuel cell components based on nano-structured thin film catalysts into high-performance MEAs. Power output per gram of platinum group metal (PGM) at rated power increased to 6.5 kW/gPGM (improved from 2.8 kW/gPGM in 2008 and 6.2 kW/gPGM in FY 2014) and is on track to achieve the 2020 target of 8 kW/gPGM.

Since catalysts comprise nearly half of the high-volume cost of automotive fuel cells, catalysis R&D continues to be a focus. Last year marked a significant step towards developing cathode catalysts with ultra-low platinum content with the development of $PtNi_3$ nanoframe catalysts at ANL. Synthesized by a novel spontaneous corrosion and annealing procedure, the resultant Pt-coated nano-framework, when integrated in an MEA, increased MEA performance by three-fold in comparison to a Pt/C catalyst under low-loading conditions (Figure 4).

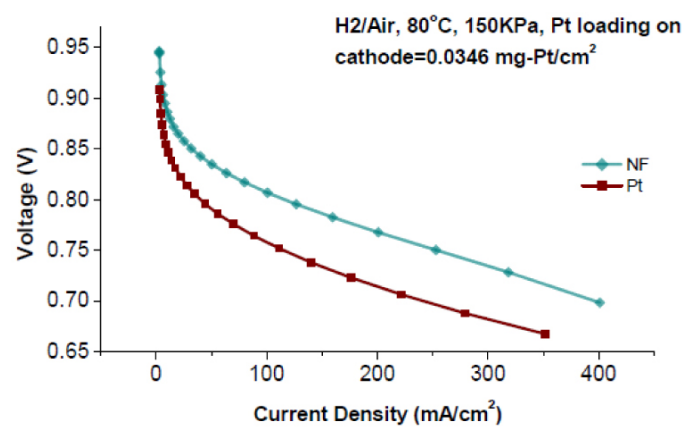


FIGURE 4. Performance of the nanoframes (NFs) relative to a traditional Pt/C catalyst (V. Stamenkovic, P. Yang et al., *Science*, 343 (2014) 1339)

This year also brought advances in catalyst design that resulted in further improvements over last year's nanoframe project, including the development of catalysts based on non-precious metals like iron that were coordinated into carbon and nitrogen-containing matrices. Current densities as high as 110 mA/cm^2 were achieved in air with these PGM-free catalysts, representing a significant improvement over the benchmark of 75 mA/cm^2 set in FY 2014, and demonstrating good progress toward achieving the targeted performance levels for platinum-based catalysts with less costly metals. Durability studies of these materials are underway, but initial ex situ testing has already demonstrated high stability.

Finally, the sub-program established a lab-led consortium project—Fuel Cell Performance and Durability (FC-PAD)—to further advance progress in improving performance and durability of fuel cell systems. Funding opportunities for adding industry, university, and other national lab projects to FC-PAD are planned for FY 2016.

[5]S. Kocha, et al., *Journal of The Electrochemical Society*, **162** (10) F1144–F1158 (2015); *Journal of The Electrochemical Society*, **162** (12) F1384–F1396 (2015). http://www.hydrogen.energy.gov/pdfs/review14/fc111_kocha_2014_o.pdf

Hydrogen Production

In FY 2015, the Hydrogen Production sub-program continued to focus on developing technologies to 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.

In October of 2014, the Program announced the launch of the $1 million H2 Refuel H-Prize, consistent with the H-Prize authorization in the Energy Independence and Security Act of 2009 and with feedback from numerous stakeholders and the Program's federal advisory committee. This two-year competition challenges America's engineers and entrepreneurs to develop affordable systems for small-scale, non-commercial hydrogen fueling. Successful entries will install and test systems that generate hydrogen from resources available at most homes, like electricity or natural gas, and provide the hydrogen to fuel vehicles. The team that demonstrates the best system will win the $1 million cash prize. Initial system designs were due October 29, 2015, and the winner will be announced in late 2016.[6] 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.

Efforts in the solar-thermochemical hydrogen (STCH) production area were directed toward performance characterization of water splitting by novel, non-volatile metal-oxide-based reaction materials and the development of new reactor concepts to optimize efficiency of the reaction cycles. Of particular note, more than 1,000 possible binary perovskites were screened, of which nearly 200 materials show potential for use in STCH production.

Also in FY 2015, the Program completed a stochastic analysis to establish the hydrogen fuel cost at which FCEVs will be competitive with internal combustion engine vehicles (ICEVs) in the near-term (2015–2020). The cost calculation was achieved by varying the price of gasoline, fuel economy values of ICEVs and FCEVs, and incremental cost of ownership of FCEVs within bounds determined by data from the Energy Information Administration, ANL's Autonomie vehicle simulation system, current state and federal incentives, and current sales prices of vehicles. The analysis determined that FCEVs are likely to be competitive with ICEVs at a hydrogen cost of about $7.00/gge.[7] The RD&D targets for the Program are being modified for consistency with this approach and result. The cost target for 2017 has been set at $12.00/gge (including production, delivery, and dispensing at low volumes).

Hydrogen Delivery

The goal of the Hydrogen Delivery sub-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 2015, the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project published "The Reference Station Design Report"[8] that describes the designs and costs of hydrogen stations that are expected to be viable in the near-term (Table 1). The report includes detailed piping and instrumentation diagrams, bills of material, and layouts for five stations. The report additionally describes the impact of several key variables (station utilization rate, capacity, number of hoses, and supply method) on capital costs, levelized costs of hydrogen, and station footprint. These analyses are then used to provide recommendations for future research on station components, codes and standards, and business practices. The project completed much of its analysis using the Hydrogen Refueling Station Analysis Model (HRSAM), which was created at ANL in FY 2015.

TABLE 1. Station Designs Detailed in H2FIRST Reference Station Design Report

Delivery Method	Daily Capacity (kg)	Target Market	Site Type	Installed Capital Cost ($K)	Fuel Cost ($/kg)
Gaseous	300	High Use	Gas Station or Greenfield	$1,265	$6.03
Gaseous	200	High Use		$1,179	$5.83
Gaseous	100	Intermittent		$1,098	$13.28
Liquid	300	High Use	Greenfield	$2,007	[a]
Future Liquid	300	High Use	5	$1,551	$7.46

[a] This station type was not available in HRSAM as of this analysis and fuel cost could not be estimated. It has been included in the current version of the model.

[6] http://energy.gov/eere/fuelcells/articles/h2-refuel-h-prize-guideline-update
[7] DOE Program Record #15015, http://www.hydrogen.energy.gov/pdfs/15015_fuel_cell_system_cost_2015.pdf
[8] H2FIRST Reference Station Design Task, http://www.nrel.gov/docs/fy15osti/64107.pdf

HRSAM allows a user to determine the levelized cost of hydrogen dispensing for a given fueling station design and projected utilization rate. The model estimates the costs of station equipment based on recent vendor data and allows users to simulate gaseous stations, along with near-term and futuristic liquid stations. By the end of FY 2015, a modified version of the Hydrogen Delivery Scenario Analysis Model will also be made publicly available. The model will incorporate recent cost data from vendors and applications to the California Energy Commission and will include the ability to simulate varying annual station utilization rates, near-term and futuristic liquid hydrogen stations, and impacts of market penetration on component costs.

Finally, the H2FIRST project's major accomplishment in FY 2015 was to develop a prototype device that could be used to validate hydrogen fueling station performance (HySTEP – Hydrogen Station Test Equipment Performance device). HySTEP will allow station owners and operators to validate station performance and save millions of dollars over time by avoiding the need for automakers to individually take FCEVs to each station to verify fueling performance. The HySTEP unit is now undergoing testing at NREL and will be shipped to California for service in FY 2016. State agencies in California have already committed cost share for its implementation, demonstrating an effective partnership between federal and state programs.

Hydrogen Storage

The Hydrogen Storage sub-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 fact, two automotive original equipment manufacturers have started to offer FCEVs for lease or commercial sale this year in California with 700 bar compressed hydrogen systems onboard the vehicle.

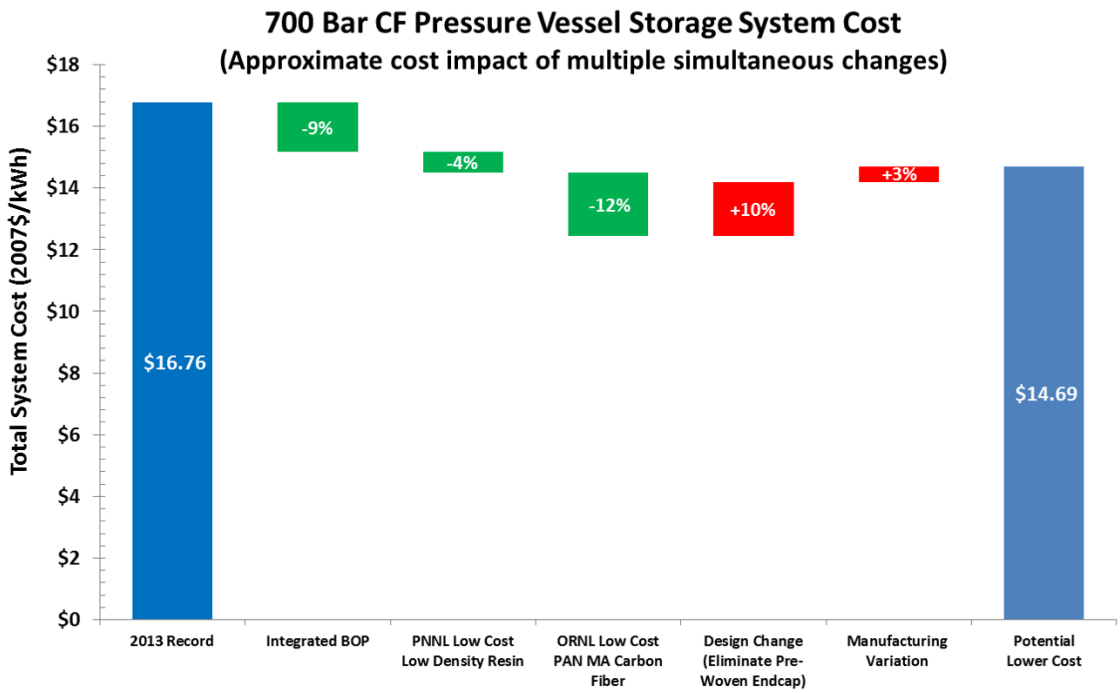
In FY 2015, the Program updated the cost projections for 700 bar compressed hydrogen storage systems to $14.69/kWh, an overall cost reduction of approximately $2/kWh from the baseline cost of $16.76/kWh established in FY 2013. The analysis reflects recent technology advancements to reduce the cost of carbon fiber (CF) precursor and resin and to integrate BOP components. The analysis also includes changes in the tank design to better reflect commercially manufactured pressure vessels, which increase projected costs. Specific changes to the 700 bar pressure vessel system cost calculation include use of a low-cost carbon fiber precursor based on high-volume textile fiber processes; BOP component revisions to reduce the number of fittings; and use of a low-cost, low-density resin. The analysis this year also explicitly accounts for cost increases associated with manufacturing design changes suggested by industry, including the removal of pre-woven endcaps and increased composite layer thickness to account for a more robust assessment of manufacturing variations. The relative cost impact of each component change is presented in Figure 5.

The Hydrogen Storage Engineering Center of Excellence is completing its Phase III activities, with a focus on evaluating two hydrogen adsorbent system designs that differ in heat exchanger concept and completing the validation and posting of their complete system models for use by the research community. The two prototype hydrogen adsorption systems have been built and are undergoing evaluation. One prototype (hexcell) uses a flow-through concept where excess hydrogen removes the heat of adsorption as it passes through the adsorbent that is packed within an aluminum hexagonal honeycomb structure. The second prototype uses a "Modular Adsorption Tank Insert" microchannel heat exchanger that is cooled by flowing liquid nitrogen through it.

In FY 2015, the sub-program awarded five new individual projects and set the foundational framework for future materials efforts in hydrogen storage using a lab-led consortium approach: HyMARC (Hydrogen storage Materials Advanced Research Consortium).

Manufacturing R&D

The Manufacturing R&D sub-program supports activities needed to reduce the cost of manufacturing hydrogen and fuel cell systems and components. FY 2015 saw a number of advancements in the manufacture of fuel cells, including new algorithms for automated defect detection (Figure 6). The Program also expanded its previous demonstration of optical inspection for fuel cell electrodes by developing algorithms that can automatically detect defects of various types from the real-time inspection data. The algorithms were shown to have no false positives on sample materials from General Motors. This work supports improved technology transfer to industry and addresses Program milestones for MEA inspection.



PNNL – Pacific Northwest National Laboratory; ORNL – Oak Ridge National Laboratory; PAN MA – polyacrylonitrile with methyl acrylate

FIGURE 5. Revised projected costs for 700 bar compressed hydrogen storage systems for light-duty vehicles at 500,000 systems per year, comparing analyses between 2013 and 2015

Aligned with EERE's Lab Impact Initiative, the Program offered NREL's optical defect detection technology as a Tech Transfer Opportunity (TTO) through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. TTOs provide opportunities for small businesses to commercialize technologies by licensing national lab intellectual property. This TTO, which is one of the first within EERE, was awarded to Florida-based Mainstream Engineering to develop a low-cost optical detector for continuous analysis of membranes for PEM fuel cell MEAs based on a licensing agreement with NREL.

Also in FY 2015, the Program demonstrated its reactive impinging flow (RIF) technique in which the reactive gas ($H_2/O_2/N_2$) flows onto conductive fuel cell roll goods; heat from the chemical reaction is then detected. Lab researchers modeled the RIF process with gas diffusion electrode material and predicted changes in the material's temperature (due to reactive excitation and heat generation) as a function of the width of the defect for three different defect depths—results can be seen in Figure 7. Clearly, at any defect width, the more the catalyst layer thickness is reduced, the higher the temperature change from the bulk material. If the lines are extrapolated down to $\Delta T = 1$ K or 2 K, the width of the minimum detectable defect can be determined. This work is highlighted as an example that can have broad impact across the manufacturing community through improved quality control and manufacturing processes. Rather than funding the development of just one specific catalyst, for instance, the limited funding for the sub-program focuses on enabling technologies or processes that can advance widespread commercialization across areas.

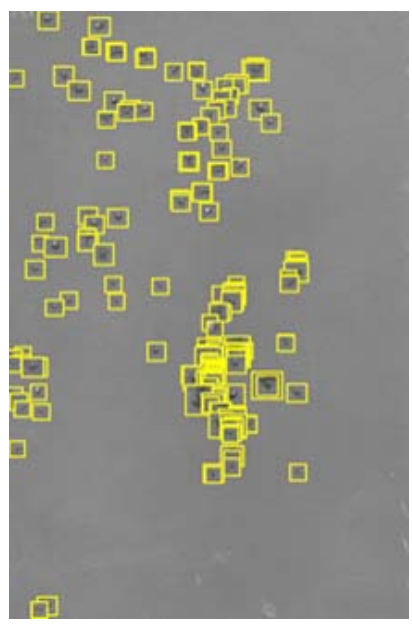


FIGURE 6. Image of intentionally created scuffs and scratches on fuel cell membrane. Defects were detected using optical reflectance. The scanning system operated on sheet materials at 10 feet per minute. Algorithms were developed and demonstrated for automated detection as illustrated by the yellow boxes. The debris images (dots) were magnified 10x for ease of viewing.

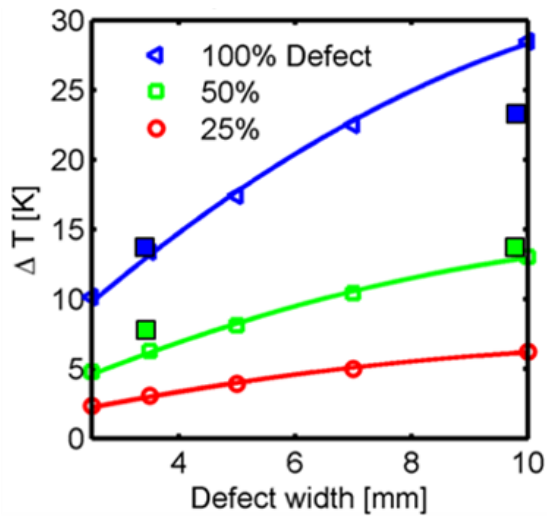


FIGURE 7. Change in temperature of gas diffusion layer material as a function of defect width following reactive excitation for three different defect thicknesses. 100% defect means that all the reactive material is gone and only a bare spot is left. 50% means that the thickness of catalyst layer is reduced by one half, and 25% means the thickness is reduced by one quarter. The solid symbols represent experimental data while the hollow symbols are model predictions. The solid lines were drawn to guide the eye through the modelled data points.

Basic Research

The Basic Energy Sciences (BES) program in the DOE Office of Science supports fundamental scientific research 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 as follows.

- 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.
- Hydrogen Production: Approaches such as photobiological and direct photochemical production of hydrogen.

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 lead to improvements in the performance, cost, and reliability of fuel cell technologies and technologies for hydrogen production and storage. This is accomplished in various ways—for example, through bi-monthly coordination meetings between the participating offices within DOE, and at the researcher level by having joint meetings with participation from principal investigators who are funded by the participating offices.

In June 2015, the Program's Annual Merit Review and Peer Evaluation meeting included presentations and posters from BES-funded researchers on fundamental-science-related topics in conjunction with presentations by EERE and Advanced Research Projects Agency-Energy funded researchers.

In FY 2015, the Office of Science re-competed the Joint Center for Artificial Photosynthesis and announced a future forum on electrochemical carbon reduction. Future efforts will include coordinated activities between EERE and BES.

Technology Validation

The Technology Validation sub-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 light-duty FCEV and hydrogen infrastructure technologies, continuing efforts include the real-world evaluation of fuel cell electric bus (FCEB) technologies at various transit authorities and monitoring performance of fuel cells in stationary power, backup power, and material handling equipment (MHE) applications.

Six major automakers (General Motors, Honda, Hyundai, Mercedes-Benz, Nissan, and Toyota) are demonstrating advanced light-duty FCEVs, with data being collected from up to 48 vehicles. During the data collection period of October 2012 through December 2014, the 48 FCEVs traveled over 2.4 million miles, demonstrating an average on-road fuel economy of 51 miles/kg and an average fleet voltage durability of 3,930 hours. A maximum of 5,605 fuel cell operation hours (which surpasses the 2020 DOE target of 5,000 hours) was also demonstrated. These results, along with previous ones, reveal that steady progress has been demonstrated over the past 10 years, with improvements especially in fuel cell durability, range, and fuel economy.

During FY 2015, data from 15 FCEBs at two transit agencies, AC Transit (Oakland, California) and SunLine (Thousand Palms, California), were collected and analyzed. FCEBs continue to show improved fuel economy (ranging from 1.7 to 2.1 times higher) compared to baseline (diesel and compressed natural gas) buses in similar service. The average fuel economy for the fuel cell power plants was 7.26 miles per diesel gallon equivalent (DGE), approaching the Federal Transit Administration's performance target for FCEB fuel economy of 8 miles per DGE. The top fuel cell power plant accumulated over 19,000 hours of operation, surpassing the DOE/U.S. Department of Transportation target of 18,000 hours for 2016, while 67 percent of fuel cell power plants accumulated over 8,000 hours. Values for fuel cell system miles between road calls—a measure of reliability—surpassed the 2016 target and were found to be approaching the ultimate target.

Over the period from the first quarter of 2009 to the fourth quarter of 2014, data collected on 10 hydrogen stations revealed that a cumulative amount of more than 62,700 kg of hydrogen was dispensed (43 percent improvement over the previous year's cumulative), with average dispensing rates of 0.6 kg/min. Average fill time was found to be 5.6 minutes, with 49 percent of fills taking less than five minutes, and 20 percent taking less than three minutes.

During the past year, the electrolyzer-based hydrogen fueling station at California State University, Los Angeles (CSULA), part of DOE's Technology Validation sub-program, was the first in the United States to receive the seal of approval for commercial sale of hydrogen fuel. The CSULA station may in fact have been the first in the world with the sufficiently high-accuracy metering technology required for the commercial sale of hydrogen—a requirement to ensure customers get the amount of fuel for which they pay. Although meter accuracy requires further improvement, the current status allows sale to the public using routine credit card purchases. Since then, California state funding has enabled two additional stations that can sell hydrogen fuel, with more on the way. Power meters, flow meters, and buffer tanks were installed, and performance evaluation data are being provided. Gas Technology Institute's West Sacramento, California, station—using liquid hydrogen and 900 bar ionic compression technology—was commissioned in December 2014, and instrumentation is now installed, allowing for data collection. These examples show how the Program enables first-of-a-kind real-world installations, taking technology from the laboratory to the field, followed by partner funding (such as California state agencies), resulting in further replication and deployment.

DOE has established a Grid Modernization program, a cross-cutting effort involving various offices within DOE, with the objective to help set the nation on a cost-effective path to an integrated, secure, and reliable grid that is flexible enough to provide an array of emerging services while remaining affordable to consumers. Hydrogen-based energy storage could provide value to many applications and markets, and electrolyzers may be utilized as a controllable electrical load that can provide real-time grid services. The Program is exploring these value-added services. An electrolyzer stack test bed was designed, built, commissioned, and is now in operation at NREL. The first-of-its-kind real-time digital simulator (RTDS)-to-RTDS communications network between labs was established for hardware-in-the-loop simulations with electrolyzer hardware.

Market Transformation

To ensure that the benefits of the Program's efforts are realized in the marketplace, the Market Transformation sub-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 Program in FY 2015 was deploying the world's first fleet of zero-emissions, hydrogen-powered airport ground support equipment (GSE) trucks. This project is demonstrating the value proposition of using fuel-cell-powered tow tractors as a cost-competitive and more energy-efficient solution compared to incumbent internal-combustion-engine-powered vehicles. In April 2015, the project commissioned a fleet of 15 GSE units, which are now operating at the Federal Express hub at the airport in Memphis, Tennessee. Federal Express has more than 1,300 baggage tow tractors at its Memphis facility to manage ~270 flights per day. In the long term, such early markets could offer the potential for hubs of hydrogen infrastructure for applications such as shuttle buses, fleet vehicles, rental cars, taxis, and retail consumer vehicles.

Finally, in coordination with the Technology Validation sub-program, two new efforts were initiated for fuel cells as range extenders and hybrid systems for parcel delivery vans with Federal Express and United Parcel Service. Similar to the strategy from previous years with forklifts and backup power units, the Program aims to develop and demonstrate fuel cell systems for other early markets that are commercially viable and help pave the way for broader deployment and creation of infrastructure. Another example is an SBIR Phase 1 project to assess the feasibility of fuel cell refuse trucks that could potentially provide the range currently not available with pure battery electric trucks.

Education

Although the Program relies on prior year resources for the Education sub-program's activities, education and outreach continue 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 both directly and indirectly involved in the use of hydrogen and fuel cells. In FY 2015 the Program published more than 100 success stories through news articles, blogs, press releases, and media announcements and conducted more than 20 webinars, averaging more than 150 attendees per webinar. Activities reached at least 3,000 people at key conferences and meetings, and the FCTO monthly newsletter reached more than 11,800 subscribers. The Program is also continuing to train middle school and high school teachers based on prior year funding through "H2 Educate!," reaching a total of 12,000 teachers in 35 states; 90% of participants have stated that the training resources increased the effectiveness of their lesson plans.

Safety, Codes and Standards

The Safety, Codes and Standards (SCS) sub-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 codes and standards. During the past year, the sub-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 2015, the Hydrogen Risk Assessment Models (HyRAM) were released for alpha testing by various stakeholders, including industry representatives. This software enables quantitative risk assessment (QRA) and performance-based design and incorporates hydrogen behavior models also developed through the Program. A model for release of liquid hydrogen was validated and will be used, along with the QRA tool, to inform separation distances in the 2019 code cycle for National Fire Protection Association 2/55.

The Program continues to share current safety information and knowledge with the community through the launch of H2Tools.org, which, in addition to consolidating existing resources (i.e., Hydrogen Lessons Learned Database), serves as a centralized resource for hydrogen safety information, news, and user-specific content. This is a major accomplishment because it allows for a "one stop shop" online rather than requiring stakeholders to navigate numerous other websites and resources.

The Program has now educated more than 35,000 code officials and first responders across the nation, allowing for greater familiarity with emerging hydrogen and fuel cell technologies. In addition, the efforts of the Program's Safety Panel have been commended by stakeholders worldwide for its work in assessing numerous projects and safety plans to ensure that a high degree of attention is paid to safety and risk mitigation.

Systems Analysis

The Systems Analysis sub-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 2015.

The Hydrogen Financial Analysis Scenario Tool (H2FAST) was developed to provide in-depth financial analysis of hydrogen refueling stations and is available in two formats: an interactive online tool and a downloadable Microsoft Excel spreadsheet. The spreadsheet version of H2FAST offers basic and advanced user interface modes for modeling individual stations or groups of up to ten stations. It provides users with detailed annual financial projections in the form of income statements, cash flow statements, and balance sheets; graphical presentation of financial performance parameters for 65 common metrics; life-cycle cost breakdown for each analysis scenario; and common ratio analysis results such as debt/equity position, return on equity, and debt service coverage ratio. The online H2FAST tool can be used to explore the impact of basic financial performance metrics by varying up to 20 user inputs as illustrated in Figure 8. The tool was thoroughly peer reviewed and issued to the public.[9] The sub-program also evaluated the

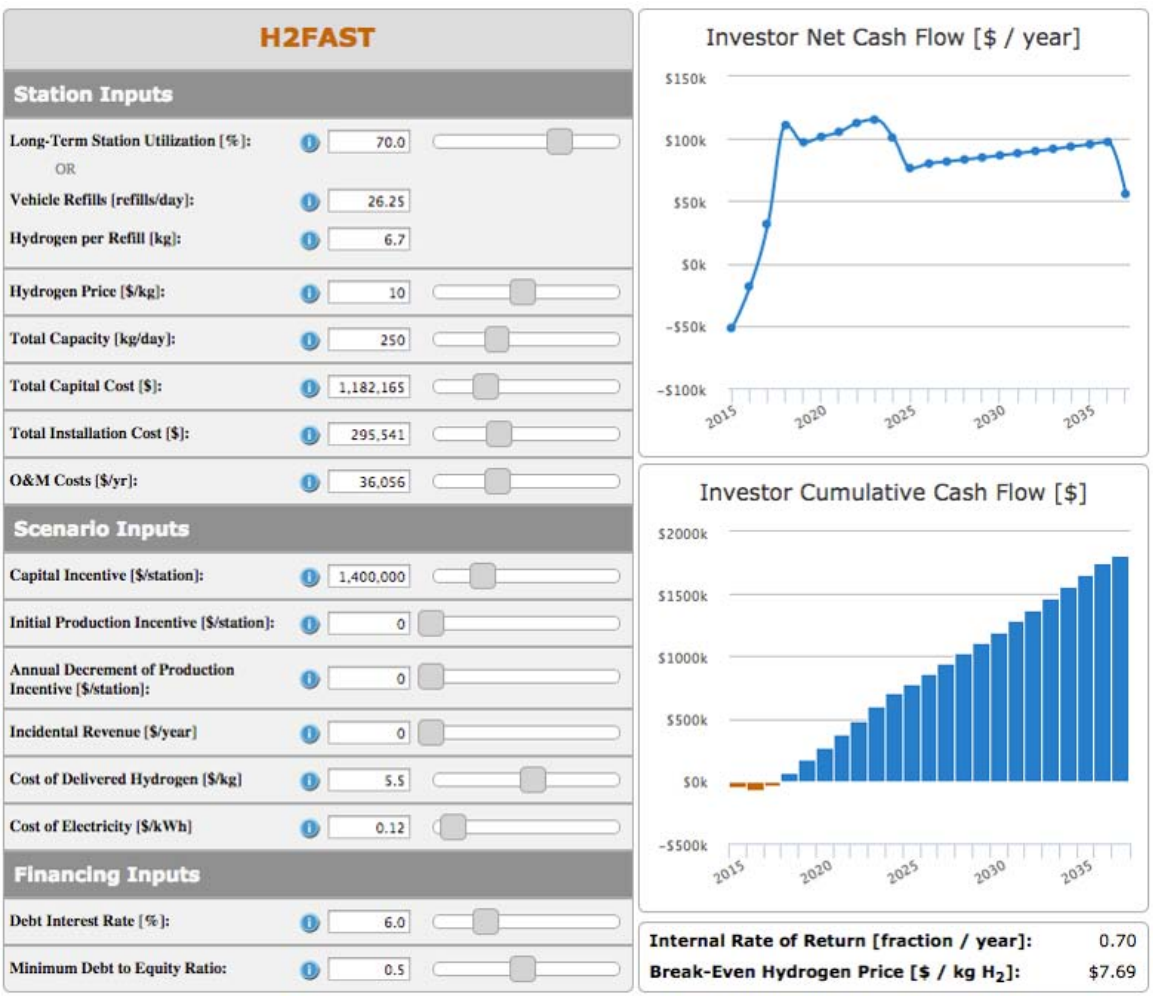


FIGURE 8. H2FAST model input screen

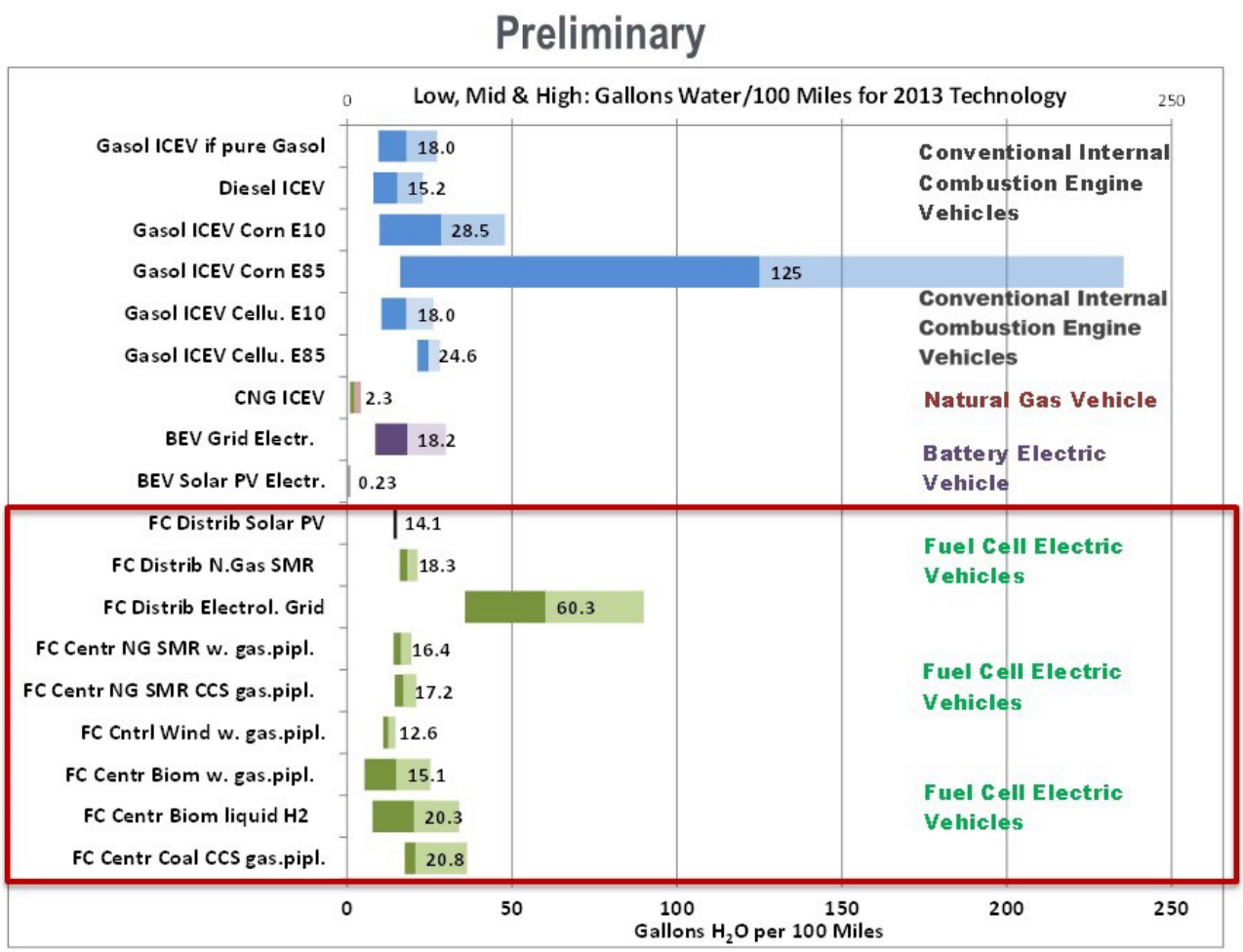
[9] http://www.nrel.gov/hydrogen/h2fast/

impact of improving fuel cell efficiency and FCEV performance on the cost of fuel cell and hydrogen storage systems, showing the potential to decrease the cost of onboard hydrogen systems by ~80% and fuel cell systems by ~70%.

The JOBS model was used to assess employment and economic impacts of infrastructure development for the early market penetration of fuel cell vehicles in California. The California roadmap projects approximately 100 hydrogen refueling stations will be built between 2016 and 2023. This station development is estimated to create 1,000 to 1,400 jobs and yield an economic impact of $230 million by 2023.

The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model continues to be enhanced for the analysis of greenhouse gas emissions, petroleum use, and water consumption for conventional and renewable hydrogen pathways on a life-cycle basis. The Program expanded the GREET model's life-cycle analysis capabilities in FY 2015 to examine water consumption for hydrogen production and delivery pathways from natural gas, water electrolysis, and other fuels such as gasoline and ethanol (Figure 9). A methodology for allocating water consumption to hydropower generation was also developed.

An early market cost target was developed to guide and prioritize R&D for the Program. The early market hydrogen cost target, a pathway-independent target to guide R&D for production and delivery technologies for hydrogen fuel, is set at $7/gge, untaxed and dispensed at the pump. This target is based on a "top-down" analysis of the cost at which hydrogen fuel for FCEVs is projected to be competitive on a cost per mile basis with gasoline fuel for gasoline ICEVs in the early market timeframe of 2015 to 2020. The target considers a range of vehicle technologies, performance, fuel economy values (for both FCEVs and the competing ICEVs), and the federal and regional incentives



CCS – carbon capture and sequestration; CNG – compressed natural gas; NG – natural gas; PV – photovoltaic; SMR – steam methane reformer

FIGURE 9. Water consumption of hydrogen pathways comparable to conventional fuels

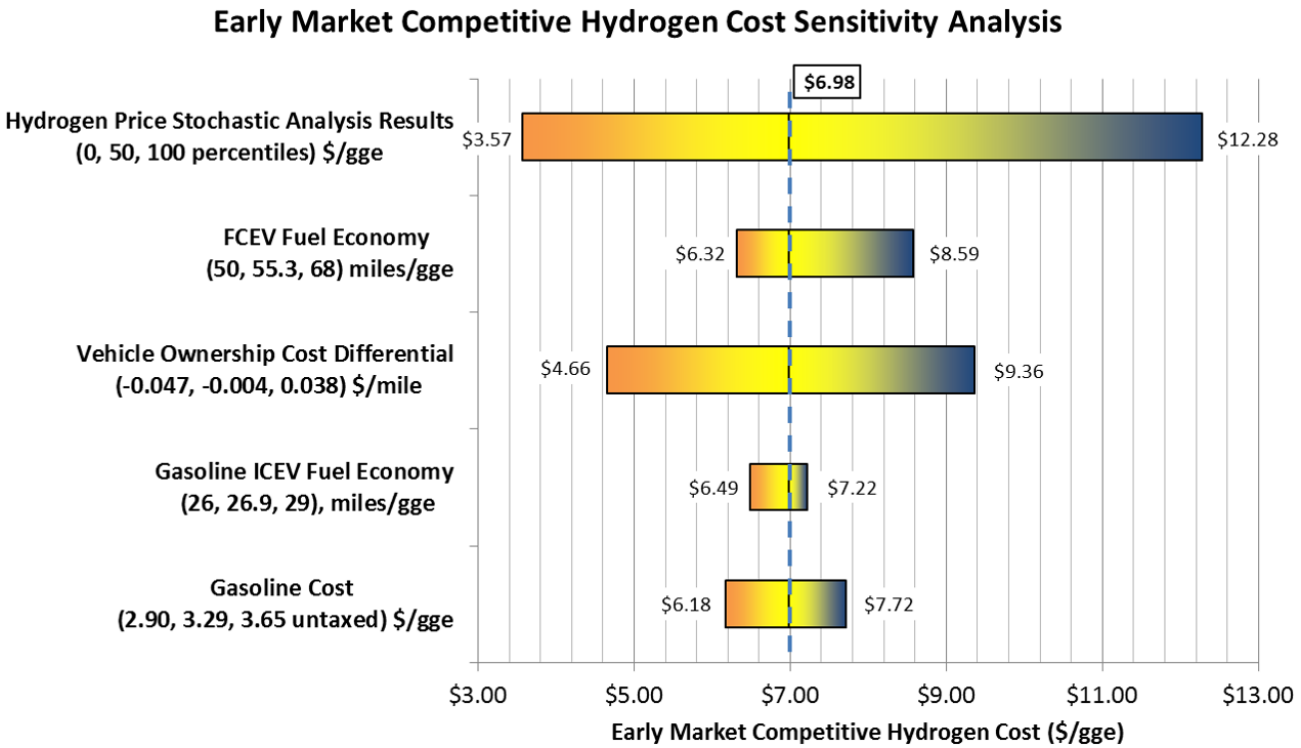


FIGURE 10. Sensitivity of the early market hydrogen cost (untaxed) to gasoline cost, vehicle ownership cost differential, and vehicle fuel economy

currently in place as well as the gasoline market prices in the regions analyzed (Figure 10). A DOE Program Record on this subject was was developed, peer reviewed, and issued.[10]

American Recovery and Reinvestment Act Projects

The American Recovery and Reinvestment Act of 2009 (Recovery Act or ARRA) has been a critical component of the Program's efforts to accelerate the commercialization and deployment of fuel cells in the marketplace. As of October 2015, all of the original twelve projects have been successfully completed, and 100% of the Recovery Act project funds have been invoiced by the projects. A total of 1,330 fuel cell units were deployed—824 fuel cell backup power systems for cellular communication towers, 504 fuel cell lift trucks, and 2 stationary power systems—surpassing the original deployment goal of up to 1,000 fuel cells. The National Fuel Cell Technology Evaluation Center (NFCTEC) at NREL has established data reporting protocols with Composite Data Products (CDPs) and Detailed Data Products showing progress to date. The CDPs are available on the NREL NFCTEC website.

Successful DOE deployments of fuel cells (including deployments from ARRA funding as well as Market Transformation projects) have led to industry orders of more than 8,300 fuel cell forklifts and more than 5,500 fuel cell backup power systems, with no additional DOE funding.[11] In addition, a study by ANL[12] found that DOE's ARRA investments led to the creation or retention of over 1,400 direct, indirect, and induced job-years for U.S. workers.

OTHER PROGRAM ACTIVITIES AND HIGHLIGHTS FROM FY 2015

Tracking Commercialization

One indicator of the robustness and innovative vitality of an RD&D program is the number of patents granted, as well as the number of technologies commercialized. The Program continued to assess the commercial benefits of

[10]DOE Program Record #14013, http://hydrogen.energy.gov/pdfs/14013_hydrogen_early_market_cost_target.pdf
[11]DOE Program Record #15004, http://www.hydrogen.energy.gov/pdfs/15004_industry_bup_deployments.pdf and DOE Program Record #15003, http://www.hydrogen.energy.gov/pdfs/15003_industry_lift_truck_deployments.pdf
[12]Economic Impact of Fuel Cell Deployment in Forklifts and for Backup Power under the American Recovery and Reinvestment Act, http://energy.gov/eere/fuelcells/downloads/economic-impact-fuel-cell-deployment-forklifts-and-backup-power-under

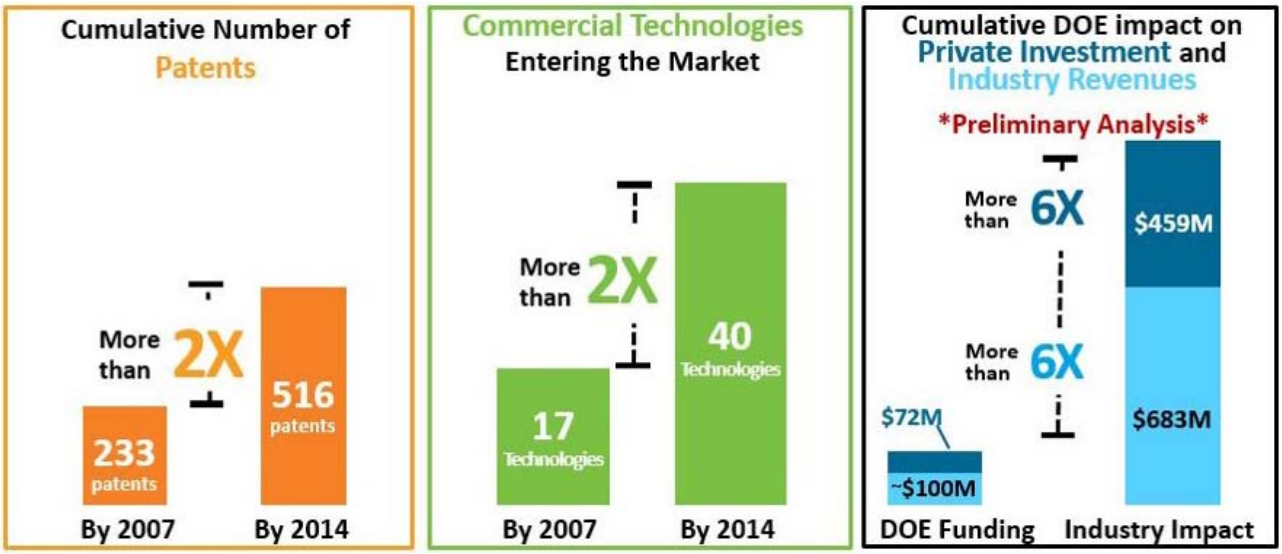


FIGURE 11. RD&D efforts funded by FCTO have resulted in 515 patents, 40 commercial technologies in the market, and 65 technologies that are projected to be commercialized within three to five years (as of October 2014).

funding by tracking the commercial products and technologies developed with the support of FCTO. RD&D efforts funded by FCTO have resulted in 515 patents, 40 commercial technologies in the market, and 65 technologies that are projected to be commercialized within three to five years (as of October 2014, Figure 11).[13]

In addition, the Program's investment of $100 million in specific hydrogen and fuel cell projects led to more than $683 million in revenue, and investments of approximately $72 million in specific projects led to nearly $459 million in additional private investment. These values are periodically updated based on industry input and their feedback on which technologies resulted from DOE support.

Awards and Distinctions

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

- Proton OnSite was presented with the President's "E" Award for Exports by the U.S. Secretary of Commerce, Penny Pritzker, during a ceremony in Washington, D.C.
- Rod Borup of Los Alamos National Laboratory won the 2015 Research Award presented annually by the Energy Technology Division of the Electrochemical Society.
- Drew Higgins, University of Waterloo, was awarded the Grand Prize for the 2014 Dr. Bernard S. Baker Student Researcher Award for Fuel Cell Research.
- Y. F. (John) Khalil of the United Technologies Research Center was awarded the Institution of Chemical Engineers Senior Moulton Medal for best technical and meritorious paper for his research in experimental and theoretical investigations for mitigating $NaAlH_4$ reactivity risks during postulated accident scenarios involving exposure to air or water.
- Lawrence Berkeley National Laboratory's and Argonne National Laboratory's nanoframe catalyst project was a finalist for R&D Magazine's 53rd Annual R&D 100 Awards.
- Proton OnSite was recognized in U.S. Senator Chris Murphy's (D-Conn.) weekly series (August 3, 2015) called "Murphy's Monday Manufacturer."
- Ian M. Robertson of the University of Wisconsin–Madison was awarded the 2014 ASM Edward DeMille Campbell Memorial Lectureship award in recognition of seminal contributions for the understanding of hydrogen embrittlement of metals and alloys.

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

- Adam Weber, Lawrence Berkeley National Laboratory, was selected as a Kavli Fellow of the National Academy of Sciences for 2014.
- Piotr Zelenay received the Fellows Prize for Outstanding Research from Los Alamos National Laboratory. He also received the honorary title of Professor in Chemistry from Poland's President Bronisław Komorowski during a June 23 ceremony at the Presidential Palace in Warsaw.

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 (2014 Fuel Cell Technologies Market Report), the commercialization report (2014 Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Office), and the State of the States: Fuel Cells in America 2014 report—while others are published when studies are complete, projects have ended, or key milestones have been reached. Key examples include the following:

- The ***2014 Fuel Cell Technologies Market Report*** finds that the hydrogen and fuel cell market continues to grow rapidly. According to the report, the industry grew by almost $1 billion in 2014, reaching $2.2 billion in sales—up from $1.3 billion in 2013. In addition, more than 50,000 fuel cells were shipped worldwide in 2014.[14]
- ***States of the States: Fuel Cells in America 2014***, the sixth annual report on state activities, details fuel cell and hydrogen activities and policies in the 50 states and the District of Columbia.[15]
- ***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 515 patents, 40 commercial technologies, and 65 technologies that are expected to reach commercial scale within the next three to five years.[16]
- ***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.[17]
- The ***Hydrogen Fueling Station in Honolulu, Hawaii, Feasibility Analysis*** assesses the technical and economic feasibility of developing a vacant, undeveloped General Services Administration-owned property into an income-producing site equipped with a hydrogen fueling station and a covered 175-stall parking structure with roof-top solar panels.[18]
- The ***Mass Production Cost Estimation of Direct H_2 PEM Fuel Cell Systems for Transportation Applications: 2013 Update*** is the seventh annual update of a comprehensive automotive fuel cell cost analysis conducted by Strategic Analysis, Inc.[19]
- The ***A Total Cost of Ownership Model for Low Temperature PEM Fuel Cells in Combined Heat and Power and Backup Power Applications*** report describes a total cost of ownership model for emerging applications in stationary fuel cell systems.[20]
- The ***Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison*** report identifies the factors impacting the value proposition for fuel cell backup power and presents the estimated annualized cost of ownership for fuel cell backup power systems compared with the incumbent technologies of battery and diesel generator systems.[21]

[14]2014 Fuel Cell Technologies Market Report, http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_program
[15]State of the States: Fuel Cells in America 2014, http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_state
[16]Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Office, http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways
[17]The Business Case for Fuel Cells, http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_business
[18]Hydrogen Fueling Station in Honolulu, Hawaii Feasibility Analysis, http://energy.gov/eere/fuelcells/downloads/hydrogen-fueling-station-honolulu-hawaii-feasibility-analysis
[19]Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2013 Update, http://energy.gov/eere/fuelcells/downloads/mass-production-cost-estimation-direct-h2-pem-fuel-cell-systems
[20]A Total Cost of Ownership Model for Low Temperature PEM Fuel Cells in Combined Heat and Power and Backup Power Applications, http://energy.gov/eere/fuelcells/downloads/total-cost-ownership-model-low-temperature-pem-fuel-cells-combined-heat-and
[21]Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison, http://energy.gov/eere/fuelcells/downloads/backup-power-cost-ownership-analysis-and-incumbent-technology-comparison

- The ***Economic Impacts Associated with Commercializing Fuel Cell Electric Vehicles in California: An Analysis of the California Road Map Using the JOBS H2 Model*** summarizes an analysis of the economic impacts associated with commercializing FCEVs in California.[22]

Workshops and Events

In FY 2015, the Program organized a number of workshops and events valuable to both stakeholders and to the DOE, including those below:

- The ***Transitioning the Transportation Sector: Exploring the Intersection of Hydrogen Fuel Cell and Natural Gas Vehicles*** report includes the proceedings from a September 2014 workshop that considered common opportunities and challenges in expanding the use of hydrogen and natural gas as transportation fuels.
- On Tuesday, November 11, 2014, FCTO hosted several ***Tech-to-Market events at the Fuel Cell Seminar and Energy Exposition*** in Los Angeles, California, to foster increased collaboration between national labs and industry. Events included a plenary presentation by Deputy Assistant Secretary for Transportation Reuben Sarkar, a panel discussion aimed to demystify the process of working with the national labs, presentations highlighting national labs' unique capabilities, and a poster session.
- On January 27–28, 2015, FCTO held the ***DOE Materials-Based Hydrogen Storage Summit: Defining Pathways to Onboard Automotive Applications*** workshop. The objectives of this meeting were to (1) present and discuss recent results from DOE's hydrogen storage system modeling efforts and their implications for hydrogen storage materials development efforts and (2) gather input from various stakeholders to identify hydrogen storage materials development pathways and areas of research needed.
- On March 18–19, 2015, FCTO held the ***Hydrogen, Hydrocarbons, and Bioproduct Precursors from Wastewaters Workshop*** and gathered 30 experts from academia, government, and industry to share information and identify the current status and potential RD&D possibilities for production of hydrogen and higher hydrocarbons (containing four or more carbon molecules) from wastewaters using biological, biochemical, and other techniques.
- On June 22, 2015, EERE hosted ***Sustainable Transportation Day*** at the Energy Department's headquarters in Washington, D.C. Together, the Bioenergy, Fuel Cell, and Vehicle Technologies Offices showcased how EERE's strategic investments in sustainable transportation technologies are improving vehicle efficiency and advancing the use of alternative fuel vehicles. The event was kicked off by remarks from Deputy Assistant Secretary for Transportation Reuben Sarkar.
- On October 8, 2015, FCTO celebrated the first ***National Hydrogen and Fuel Cell Day***. The day included announcements and events all over the country, a DOE blog authored by Principal Deputy Assistant Secretary David Friedman, and a press release announcing FCTO's office-wide Funding Opportunity Announcement selections.
- On October 12 and 13, 2015, FCTO hosted several ***Tech-to-Market events at the Electrochemical Energy Summit 2015*** in Phoenix, Arizona, including a plenary presentation by Under Secretary for Science and Energy Lynn Orr, a panel discussion aimed to demystify the process of working with the national labs, and a poster session highlighting the national labs' unique capabilities and opportunities in fuel cells and electrochemical systems.

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.

- **$21.5 million** was awarded to ten projects to advance fuel cell and hydrogen technologies and enable early adoption of fuel cell applications such as light-duty FCEVs. Selected projects are located in Oregon, Minnesota, Michigan, Colorado, Illinois, Massachusetts, New York, and California.
- **$10 million** in incubator funding was awarded to eleven projects to support innovations in fuel cell and hydrogen fuel technologies. The intent of the incubator FOA, implemented across EERE, was to spur innovation in higher-risk and high-impact areas slightly outside each program's roadmap. Selected projects are located in Connecticut, Georgia, Illinois, Massachusetts, California, Delaware, New Mexico, Colorado, and Virginia.

[22]The Economic Impacts Associated with Commercializing Fuel Cell Electric Vehicles in California: An Analysis of the California Road Map Using the JOBS H2 Model, http://energy.gov/eere/fuelcells/downloads/economic-impacts-associated-commercializing-fuel-cell-electric-vehicles

- **$4.6 million** was awarded to four projects to develop advanced hydrogen storage materials that have potential to enable longer driving ranges and help make fuel cell systems competitive for different platforms and sizes of vehicles. The projects are located in Iowa, California, Texas, and Michigan.
- **$2 million** was awarded to two projects for clean energy supply chain and manufacturing competitiveness analysis for hydrogen and fuel cell technologies. Selected projects are located in Ohio and Virginia.

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

- **2015 SBIR/STTR Phase I** Release 1 award winners included three projects focusing on non-platinum catalysts for fuel cells and detection of contaminants in hydrogen. Selected projects are located in Connecticut, New Mexico, and Ohio.
- **2015 SBIR/STTR Phase I** Release 2 award winners included projects that will evaluate opportunities for fuel cell-battery electric hybrid trucks and develop a real-time, in-line optical detector for the measurement of fuel cell membrane thickness. Award winners are located in California and Florida.
- **2015 SBIR/STTR Phase II** Release 1 award winners included three Office of Science-funded projects focusing on hydrogen production from electrolysis and hydrogen systems supporting FCEVs. Selected projects are in Massachusetts and South Carolina.
- **2015 SBIR/STTR Phase II** Release 2 award winners included projects focused on fuel cell durability, performance, and efficiency, with the ultimate goal of lowering costs. The projects are located in Massachusetts and South Carolina.
- **2016 SBIR/STTR Phase I** Release 1 topics included hydrogen production from organic waste streams and fuel cell membranes, funded through the Office of Science. Applications were due October 19, 2015.

The Program also coordinated with other offices, and the following FOA from FY 2015 is relevant.

- **$20 million** was awarded through the Small Business Voucher Pilot, a public-private partnership that will connect clean energy innovators across the country with the top-notch scientists, engineers, and world-class facilities at our national laboratories. Five national laboratories were competitively selected to lead the $20 million pilot, including Oak Ridge National Laboratory ($5.6 million), National Renewable Energy Laboratory ($4.9 million), Lawrence Berkeley National Laboratory ($4.2 million), Sandia National Laboratories ($2.8 million), and Pacific Northwest National Laboratory ($2.7 million). Small businesses will be competing to receive "vouchers" allowing them to work with a national lab of their choice to accelerate progress in key areas.

Requests for Information (RFIs)

The Program uses RFIs to solicit feedback from the stakeholder community in an open and transparent process that serves to inform the Program and develop future plans. Key examples included collecting feedback on the following topics:

- Hydrogen production and hydrogen delivery RD&D activities aimed at developing technologies that can ultimately produce and deliver low-cost hydrogen. (October 2014)
- Gas clean-up for fuel cell applications. (June 2015)

Webinars and Blogs

The Program held a number of webinars throughout the year (Table 2). These are archived on the Program's website, providing valuable information to the entire stakeholder community.[23]

The Program also published multiple blogs focused on hydrogen and fuel cell activities (Table 3).

[23]http://energy.gov/ eere/fuelcells/2014-webinar-archives

TABLE 2. Program Webinars Offered to Stakeholders in FY 2015

Date	Title	Summary
September 11, 2014	Introduction to SAE Hydrogen Fueling Standardization	This webinar provided an overview of the SAE Standards J2601 and J2799 and how they are applied to hydrogen fueling for FCEVs. Validated in the lab and proven in the field over the last decade, the SAE J2601 hydrogen fueling protocol standard, coupled with the SAE J2799 FCEV communications standard, provide the basis for hydrogen fueling in the first generation of infrastructure worldwide.
October 21, 2014	Opportunities for Wide Bandgap Semiconductor Power Electronics for Hydrogen and Fuel Cell Applications	This webinar featured representatives of Cree Inc., who provided an overview and roadmap of silicon carbide (SiC) power electronic technology and highlighted opportunities for product development responsive to the market pull of the hydrogen and fuel cell technology applications.
November 6, 2014	2014 and 2015 Hydrogen Student Design Contests	This webinar covered the results of the 2014 Hydrogen Student Design Contest and introduced the theme for the 2015 contest. The teams from Washington State University and Humboldt State University presented their winning designs. The 2014 contest teams were challenged to design a hydrogen fueling module that fulfills the requirements of low cost, easy permitting, low maintenance, mass production, and transportability in order to create a model for a reliable, convenient, and reasonably priced refueling experience for all hydrogen fuel cell vehicle customers.
November 18, 2014	An Overview of the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) Project	This webinar reviewed the objectives, approach, and structure of H2FIRST and provided a progress update on active and proposed technical tasks. The H2FIRST project focuses on technical tasks in support of H2USA to ensure that fuel cell vehicle customers have a positive fueling experience similar to conventional gasoline/diesel stations as vehicles are introduced (2015–2017) and we transition to advanced fueling technology beyond 2017. Led by the National Renewable Energy Laboratory and Sandia National Laboratories, the project leverages core capabilities at the national laboratories to address the technology challenges related to hydrogen refueling stations.
December 2, 2014	Materials Genome Initiative	DOE supports the use of the Materials Genome Initiative (MGI) tools and methodologies to accelerate the discovery and development of materials in the clean energy technologies space. The approach centers on coordinating research efforts in theory, synthesis, characterization, and information management, and uses the latest combinatorial and high-throughput techniques in both computation and experimentation. This webinar described current directions in the evolution of the clean energy MGI and showcased several exciting DOE projects, mainly in the Fuel Cell Technologies Office, that have been early adopters of MGI methods.
January 13, 2015	Highly Efficient Solar Thermochemical Reaction Systems	This webinar focused on DOE's investments in micro- and meso-channel reactors and heat exchangers, which have led to the development of a highly compact reaction system that efficiently converts concentrated solar energy into chemical energy. The webinar described the evolving status of the technology with a focus on near-term, anticipated applications that include fuel cells, combustion gas turbines, and the production of various chemical products.
March 10, 2015	2nd International Hydrogen Infrastructure Challenges Webinar	This webinar summarized the second international information exchange on the hydrogen refueling infrastructure challenges and potential solutions to support the successful global commercialization of hydrogen FCEVs. The information exchange took place in May 2014 at Toyota's Torrance, California, facility as a follow-up to the previous June 2013 workshop in Berlin, Germany. Participants included topical experts from Germany, Japan, the United States, Scandinavia, and the European Commission. The webinar focused on the station requirements necessary to meet the latest SAE J2601 protocol and the development of alternative fueling protocols; maintaining and measuring purity to the SAE J2619 fuel quality standard; the availability and accuracy of meters for hydrogen dispensing for 700 bar onboard fueling; and the current status of key hardware for 700 bar refueling.
March 10, 2015	Overview of Funding Opportunity Announcement DE-FOA-000224: Hydrogen and Fuel Cell Technologies Research, Development, and Demonstrations	This webinar outlined information regarding Funding Opportunity Announcement DE-FOA-0001224: Hydrogen and Fuel Cell Technologies Research, Development, and Demonstrations. This FOA covers a broad spectrum of the FCTO portfolio with areas of interest ranging from research and development to demonstration and deployment projects.
March 24, 2015	National Hydrogen Safety Training Resource for Emergency Responders	This webinar discussed the launch of a new, free, online national hydrogen safety training resource for emergency responders. Developed by the Pacific Northwest National Laboratory and the California Fuel Cell Partnership, the resource provides a single repository of credible and reliable information related to hydrogen and fuel cells that is current and accurate and eliminates duplicative efforts among various training programs.
May 12, 2015	Overview of Station Analysis Tools Developed in Support of H2USA	This webinar provided a basic introduction to two new models—HRSAM and H2FAST—developed by ANL and NREL, respectively. The tools were designed to address key technical and financial barriers to hydrogen fueling infrastructure deployment. HRSAM will help to assess the impact of station design on the economics and incorporates a station's capital and operating costs based on key design variables such as station capacity and mode of hydrogen delivery. To complement HRSAM, H2FAST provides in-depth financial analysis, including cash flow and return on investments for hydrogen fueling stations, based on key financial inputs such as station capital cost, operating cost, and financing mechanisms.

TABLE 2. Program Webinars Offered to Stakeholders in FY 2015 (Continued)

Date	Title	Summary
May 14, 2015	H2 Refuel H-Prize Technical Data Collection Requirements	This webinar provided testing specifications and plans for FCTO's $1 million H2 Refuel H-Prize competition, a two-year competition administered by the Hydrogen Education Foundation that challenges America's engineers and entrepreneurs to develop systems for small-scale hydrogen fueling. The testing specification documents are intended to inform potential contestants about the type of data that will need to be provided and how to ensure that it is compatible with the data collection system. For more information on the H2 Refuel H-Prize competition, visit hydrogenprize.org.
June 25, 2015	H2 Refuel H-Prize Overview and Q&A	This webinar focused on the $1 million H2 Refuel 2014–2016 H-Prize competition, which challenges America's innovators to deploy an on-site hydrogen generation system, using electricity or natural gas, that can be used in homes, community centers, retail sites, or similar locations to fuel hydrogen vehicles. The entry that meets all the requirements and scores the highest on the technical and cost criteria will win $1 million. The H-Prize is administered by the Hydrogen Education Foundation and sponsored by the U.S. Department of Energy.
August 6, 2015	H2 Refuel H-Prize Safety Guidance	This webinar included a discussion on safety planning and what information should be included in the safety plan document for FCTO's $1 million H2 Refuel H-Prize competition. As part of the design submission for finalist selection, contestants must include a safety plan and a hazard analysis. There also was a general discussion on codes and standards and the need for local fire/building approval requirements. Members of the Hydrogen Safety Panel led the discussion and answered questions.
August 11, 2015	Analysis Using Fuel Cell Material Handling Equipment (MHE) for Shaving Peak Building Energy	This webinar explored the synergy between a facility's use of hydrogen fuel cell forklifts and its reduction of electric grid time-of-use energy charges. Electric fuel cell forklifts use electricity generated from hydrogen fuel and can be used for either mobility or to offset grid charges associated with peak facility demands. The analyzed scenarios focused on how different buildings can benefit from offsetting their peak energy demands by connecting fuel cells to their internal power systems. The webinar included a techno-economic analysis as well as competitive analysis for the alternative peak-shaving apparatus.

TABLE 3. EERE Blog Posts in FY 2015 Focusing on Hydrogen and Fuel Cell Activities

Date	Title	Summary
December 29, 2014	H2 Refuel H-Prize Aims to Make Fueling Hydrogen Powered Vehicles Easier than Ever[24]	The H2 Refuel H-Prize is challenging America's innovators to develop systems that make it easier and convenient to fuel hydrogen powered vehicles.
January 9, 2015	Fuel Cell Technologies Office Reaches Major Patent Milestone[25]	Fuel cells are an emerging technology that can provide heat and electricity to buildings and power for vehicles while emitting nothing but water. The Energy Department's Fuel Cell Technologies Office (FCTO) within the Office of Energy Efficiency and Renewable Energy supports research and development (R&D) that improves the performance and lowers the cost of these systems. The office recently reached a major milestone, with 500 patents resulting from FCTO-supported R&D.
January 27, 2015	Washington Auto Show Spotlight: How Fuel Cell Electric Vehicles Work[26]	Fuel cell electric vehicles (FCEVs) are quickly becoming a commercially viable sustainable transportation option for Americans. Unlike gasoline-powered cars, these cutting-edge vehicles are fueled by hydrogen and emit only water. The latest and greatest FCEVs are on display this week at the Washington Auto Show. Learn more about how FCEVs work and what the Energy Department is doing to make them even more energy efficient and cost effective.
April 10, 2015	EERE Energy Impacts: You Can Now Drive a Fuel Cell Electric Vehicle[27]	Fuel cell electric vehicles (FCEVs) are now commercially available, so car buyers have the option to drive these vehicles that run on hydrogen gas rather than gasoline and emit only water from the tailpipe. FCEVs have the potential to significantly reduce our nation's dependence on foreign oil and lower harmful emissions that contribute to climate change—just one of EERE's Energy Impacts.
April 21, 2015	H2USA Accomplishments Push Hydrogen Infrastructure Forward[28]	The U.S. Department of Energy (DOE) has announced new tools developed in support of H2USA focused on hydrogen fueling infrastructure analysis. H2USA is a public-private partnership founded in 2013 by DOE, along with automakers and other stakeholders, to address the key challenges of hydrogen infrastructure. H2USA's mission is to promote the introduction and widespread adoption of FCEVs across America.
June 5, 2015	Annual Merit Review Evaluates Impact of Sustainable Transportation Projects[29]	This week from June 8 to 12, the Vehicle Technologies Office and Hydrogen and Fuel Cells Program are simultaneously holding their Annual Merit Review and Peer Evaluation Meeting in Washington, D.C., where hundreds of Energy Department-funded projects will be put to the test.
June 10, 2015	World's First Fuel Cell Cargo Trucks Deployed at U.S. Airport[30]	A ribbon-cutting ceremony held at Memphis International Airport on April 9, 2015, marked the start of a two-year demonstration of the world's first zero-emissions, hydrogen fuel cell powered ground support equipment.
June 24, 2015	Sustainable Transportation Day Drives Innovation Forward[31]	On June 22, the Office of Energy Efficiency and Renewable Energy (EERE) hosted Sustainable Transportation Day at the Energy Department's headquarters in Washington, D.C. Together, the Bioenergy, Fuel Cell, and Vehicle Technologies Offices showcased how EERE's strategic investments in sustainable transportation technologies are improving vehicle efficiency and advancing the use of alternative fuel vehicles.
August 25, 2015	Garbage In, Power Out: South Carolina BMW Plant Demonstrates Landfill Gas to Hydrogen Fuel[32]	In a first-of-its-kind demonstration, the Energy Department, BMW, and project partners Ameresco, Gas Technology Institute, and the South Carolina Research Authority powered some of the facility's fuel cell forklifts with hydrogen produced on-site from biomethane gas at a nearby landfill.
October 8, 2015	Stacked for Success: Celebrating National Hydrogen and Fuel Cell Day[33]	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.
December 10, 2015	First Commercially Available Fuel Cell Electric Vehicles Hit the Street[34]	Fuel cell electric vehicles are now widely available in the United States. These passenger vehicles have the driving range, ease of refueling, and performance of today's gasoline-powered cars while emitting nothing but water.

[24] http://energy.gov/eere/articles/h2-refuel-h-prize-aims-make-fueling-hydrogen-powered-vehicles-easier-ever
[25] http://energy.gov/eere/articles/fuel-cell-technologies-office-reaches-major-patent-milestone
[26] http://energy.gov/eere/articles/washington-auto-show-spotlight-how-fuel-cell-electric-vehicles-work
[27] http://energy.gov/eere/articles/eere-energy-impacts-you-can-now-drive-fuel-cell-electric-vehicle
[28] http://energy.gov/eere/articles/h2usa-accomplishments-push-hydrogen-infrastructure-forward
[29] http://energy.gov/eere/articles/annual-merit-review-evaluates-impact-sustainable-transportation-projects
[30] http://energy.gov/eere/articles/worlds-first-fuel-cell-cargo-trucks-deployed-us-airport
[31] http://energy.gov/eere/articles/sustainable-transportation-day-drives-innovation-forward
[32] http://energy.gov/articles/garbage-power-out-south-carolina-bmw-plant-demonstrates-landfill-gas-hydrogen-fuel
[33] http://energy.gov/eere/articles/stacked-success-celebrating-national-hydrogen-and-fuel-cell-day
[34] http://energy.gov/eere/articles/first-commercially-available-fuel-cell-electric-vehicles-hit-street

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 17 member countries (Australia, Austria, Brazil, Canada, China, France, Germany, Iceland, India, Italy, Japan, Norway, the Republic of Korea, the Russian Federation, South Africa, the United Kingdom, and the United States) and the European Commission. 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 during the past year, and the Chair of IPHE transitioned from Japan to France. The U.S. continues its strong role as a Vice Chair. In FY 2015, the IPHE Steering Committee met in Rome, Italy (December 2014), and in Wuhan, China (May 2015), to share progress and plans related to hydrogen and fuel cells. IPHE related workshop topics in FY 2015 included education, smart cities, and fuel cell backup power.[35]

International Energy Agency

The United States is also involved in international collaboration on hydrogen and fuel cell R&D through the International Energy Agency (IEA) implementing agreements and is a member of both the Advanced Fuel Cells Implementing Agreement and the Hydrogen Implementing Agreement. These agreements 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 IEA tasks and activities. During FY 2015, the United States, along with other representatives of the Hydrogen and Fuel Cell Technology Roadmap steering committee, supported the IEA in preparation of the first IEA Technology Roadmap on Hydrogen and Fuel Cells, published in the summer of 2015.

EXTERNAL COORDINATION, INPUT, AND ASSESSMENTS

H2USA Partnership

To help address the challenge of hydrogen infrastructure, in 2013 DOE co-launched H2USA, a public-private partnership focused on the widespread commercial adoption of FCEVs. H2USA currently consists of 45 participants, including the state of California, as well as developers, car companies, and hydrogen providers. The number of partners has increased more than four-fold since its launch.

In April 2014, the Program announced two new tools developed in support of H2USA to help address technical and financial barriers to hydrogen fueling infrastructure deployment. The Hydrogen Refueling Station Analysis Model will help to assess the impact of station design on station economics. The model optimizes station component size to meet demand while minimizing cost. It estimates capital and operating cost based on design variables such as station capacity and mode of hydrogen delivery. The Hydrogen Financial Analysis Scenario Tool provides in-depth financial analysis, including cash flow and return on investments for hydrogen fueling stations, based on financial inputs such as station capital cost, operating cost, and financing mechanisms.

In direct support of H2USA, DOE launched the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project in 2014 to leverage capabilities at the national laboratories to address the technology challenges related to hydrogen refueling stations. Jointly led by Sandia National Laboratories and NREL, H2FIRST is a strong example of DOE's efforts to bring national lab capabilities and facilities together to address immediate and mid-term challenges faced by the industry.

H2FIRST recently released two critical reports. The Reference Station Design report[36] details engineering models and economic analyses of five hydrogen refueling station templates that can meet near-term market needs. The Hydrogen Contaminant Detection report[37] describes the current commercial state-of-the-art technologies in contamination detection. These tools and reports will identify and accelerate near-term solutions that will help industry address the challenges of hydrogen infrastructure.

[35] http://www.iphe.net/
[36] H2FIRST Reference Station Design Task, http://www.nrel.gov/docs/fy15osti/64107.pdf
[37] H2FIRST Hydrogen Contaminant Detector Task, http://www.nrel.gov/docs/fy15osti/64063.pdf

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 and to provide recommendations regarding DOE's programs, plans, and activities, as well as on the safety, economic, and environmental issues related to hydrogen and fuel cells. 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 2015. In May 2015, HTAC released its seventh annual report, which summarizes hydrogen and fuel cell technology, domestic and international progress in RD&D projects, commercialization activities, and policy initiatives.

Currently, the Committee has two established subcommittees, both started in 2013. The Advanced Manufacturing Subcommittee conducted an assessment of the state of manufacturing techniques that are, or could be, used to benefit commercialization in the fuel cell and hydrogen generation industries. Their written report, "Advanced Manufacturing Status and Opportunities to Accelerate Growth in Fuel Cell and Hydrogen Products," was submitted to the Secretary of Energy in January 2015. The Retail Infrastructure Subcommittee will track the progress of the worldwide rollout of FCEVs and examine the evolving business case for retail hydrogen fueling stations, including the effects of technology advancement and government policy. It is anticipated that this subcommittee will prepare a written report detailing its accomplishments and findings to the full Committee in FY 2016.

Federal Inter-Agency Coordination

The Hydrogen and Fuel Cell Interagency Task Force (ITF), mandated by the Energy Policy Act of 2005, includes senior representatives from federal agencies supporting hydrogen and fuel cell activities, with the DOE/EERE serving as chair. The Hydrogen and Fuel Cell Interagency Working Group (IWG), also chaired by DOE, supports the initiatives and actions passed down by the ITF. The IWG meets monthly to share expertise and information about ongoing programs and results, to coordinate the activities of federal entities involved in hydrogen and fuel cell RD&D, and to ensure efficient use of taxpayer resources. A key example of interagency collaboration included work with the Environmental Protection Agency's (EPA's) Diesel Emission Reduction Act program to broaden program rules to allow fuel cell alternatives. DOE worked with EPA to show how fuel cell applications can replace diesel power trains. DOE and the Department of Transportation's Maritime Administration commissioned an operational testing project for an auxiliary maritime power system that can provide power for ocean vessels both pier-side and onboard. Finally, further collaboration with the Federal Aviation Administration and the Department of Defense to identify locations for future hydrogen stations is also helping support the early FCEV and hydrogen fuel infrastructure markets.

The National Academies

The National Research Council (NRC) of the National Academies provides ongoing technical and programmatic reviews and input to the Hydrogen and Fuel Cells Program. The NRC has conducted independent reviews of both the Program and the R&D activities of the United States Driving Research and Innovation for Vehicle efficiency and Energy sustainability (U.S. DRIVE) partnership. Formerly known as the FreedomCAR and Fuel Partnership, the U.S. DRIVE partnership advances an extensive portfolio of advanced automotive and energy infrastructure technologies, including batteries and electric drive components, advanced combustion engines, lightweight materials, and hydrogen and fuel cell technologies. Plans were developed for future reviews.

Clean Energy Manufacturing Initiative

The Clean Energy Manufacturing Initiative (CEMI) is a strategic integration and commitment of manufacturing efforts across EERE's clean energy technology offices and DOE's Advanced Manufacturing Office (AMO), focusing on American competitiveness in clean energy manufacturing. The objectives are to increase U.S. competitiveness in the production of clean energy products by strategically investing in technologies that leverage American advantages and overcome disadvantages, and increase U.S. manufacturing competitiveness by strategically investing in technologies and practices to enable U.S. manufacturers to increase their competitiveness through energy efficiency, combined heat and power, and taking advantage of low-cost domestic energy sources.

The DOE announced selections from a recent FOA, including a project to develop innovative, low-cost processes for manufacturing fiber reinforced composite pipe that eliminates O-ring failure and is capable of carrying hydrogen at 100 bar, is durable for 50 years, and has a reasonable leak rate. The project should lead to installed fiber reinforced

plastic costs that are equivalent to or lower than the cost of installing a natural gas pipeline of the same size and be scalable to high-volume manufacturing.

At the American Energy and Manufacturing Competitiveness Summit held in Washington, D.C., in September 2015, DOE's Assistant Secretary for Energy Efficiency and Renewable Energy, David Danielson, announced the Clean Energy Manufacturing Analysis Center (CEMAC) at NREL. CEMAC will harness NREL's analytical and modeling capabilities to provide detailed data on all aspects of manufacturing (material and labor costs, interest rates, trade flows, tariffs, etc.) so that companies can select the most favorable place to initiate their next manufacturing plans. In FY 2015, FCTO's Manufacturing R&D sub-program expanded its global competitiveness analysis project on hydrogen and fuel cells with the Great Lakes WIND Network to include activities with CEMAC.

The Program also supported CEMI's technologist in residence pilot initiative for personnel exchange to help national laboratories identify issues in industrial manufacturing processes while industry will learn about the capabilities and facilities of the national labs. The result of the initiative will be a long-term plan for the team to increase collaborative R&D.

As discussed earlier under FOAs, the FCTO is involved in EERE's Small Business Voucher pilot to increase access of small businesses to the expertise and infrastructure of DOE's national labs; small businesses will apply for and use vouchers to work with the labs to tackle industry-wide problems.

FY 2015 Annual Merit Review and Peer Evaluation (AMR)

The Program's AMR took place June 8–12, 2015, in Arlington, Virginia, and provided an opportunity for the Program to obtain expert peer reviews of the projects it supports and to report its accomplishments and progress. Under Secretary Franklin "Lynn" Orr kicked off the meeting, and former Senator Byron Dorgan (ND-D) gave the keynote plenary presentation. For the seventh 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 370 experts peer-reviewed 120 of the Program's projects—conducting a total of more than 600 individual project reviews, with an average of more than six reviewers per project. The report summarizing the results and comments from these reviews is available.[38] The 2016 Annual Merit Review and Peer Evaluation Meeting will be held June 6–10, in Washington, D.C.

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 go/no-go decisions (with criteria defined in the project scope of work)—helped the Program redirect $0.6 million in funding in FY 2015, $3.0 million in funding in FY 2014, and over $32 million over the past five years.

DOE Cross-Cutting Activities

Hydrogen Energy Storage (HES)/Grid Integration: HES 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 portfolio. FCTO is contributing significant funding to the Grid Modernization program (a cross-cutting effort involving various offices within EERE and the DOE Office of Electricity Delivery and Energy Reliability) with an objective to help set the nation on a cost-effective path to an integrated, secure, and reliable grid that is flexible enough to provide an array of emerging services while remaining affordable to consumers. Activities were described under the Technology Validation sub-program.

Carbon Fiber: Carbon fiber composites are expected to play an important role across many clean energy technologies, such as in high-efficiency, longer wind turbine blades; lighter-weight, higher-fuel-economy vehicles; and high-pressure gaseous fuel storage systems. EERE's cross-cutting carbon fiber initiative aims to lower the cost of carbon fiber for clean energy applications through higher-energy-efficiency manufacture, higher piece production throughput, lower-cost raw materials, and increased recyclability. For high-pressure gaseous fuel storage systems, such as for hydrogen and compressed natural gas, high-strength carbon fiber is required and is a major contributor to cost of

[38] www.hydrogen.energy.gov/annual_review15_report.html

the storage systems. The polyacrylonitrile (PAN) precursor fibers used to produce high-strength carbon fiber account for over 50% of the final carbon fiber costs. An approach FCTO has taken to lower the cost of carbon fibers has been to focus on alternative, lower-cost PAN precursors. In FY 2015, Strategic Analysis Inc. updated the cost projections for 700 bar compressed hydrogen storage systems. The updated analysis projects a system cost of $14.69/kWh, an overall cost reduction of approximately $2/kWh from the baseline cost of $16.76/kWh established in FY 2013. The analysis reflects recent technology advancements to reduce cost of carbon fiber precursor and resin, and through balance of plant components integration. The analysis also includes changes in the tank design to better reflect commercially manufactured pressure vessels, which result in increased projected costs.

Wide Bandgap Semiconductors for Clean Energy Initiative: Wide bandgap (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 AMO, 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 PowerAmerica partnership, a 2014 addition to DOE's National Network for Manufacturing Innovation (NNMI) focused on accelerated development of next-generation WBG semiconductor products. FCTO has 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 MHE 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 PowerAmerica and with leading innovators in the WBG electronics industry to explore opportunities for product development responsive to the market pull of these hydrogen and fuel cell technology applications.

Energy Materials Network: 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 Presidential Materials Genome Initiative (MGI) launched in 2011. In FY 2015, several DOE offices identified complementary MGI-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 will form the Energy Materials Network (EMN), a resource network with capabilities in materials design, synthesis, characterization, manufacturing, and digital data management and informatics. One important thrust of the FCTO pilot effort in EMN is the accelerated development and optimization of alternative low-cost, high-performance, PGM-free catalysts integrated into membrane electrode assemblies for PEM fuel cells and electrolyzers. The EMN-related efforts at FCTO, which have already included roundtable meetings of experts, RFIs and workshops, are expected to continue through FY 2016 and beyond.

IN CLOSING …

The need for clean, sustainable energy and the need to reduce emissions have come together to form a global imperative—one that demands new technologies and new approaches for the way we produce and use energy. Widespread use of hydrogen and fuel cells can play a substantial role in a portfolio of clean energy technologies that will overcome key energy challenges. In addition, growing interest and investment among leading world economies, such as Germany, Japan, and South Korea, underscores the global market potential for these technologies.

The Program's latest Fuel Cell Technologies Market Report[39] shows that the fuel cell industry continues to grow at an unprecedented rate, totaling more than $2.2 billion in sales in 2014. Globally, fuel cell shipments increased by around 37% over 2013, and the number of megawatts (MWs) shipped grew by about 7%. More than 50,000 fuel cells, totaling over 180 MW, were shipped worldwide in 2014. This continues to uphold the consistent 30% annual market growth rate over the last few years. EERE-funded R&D has resulted in 515 patents, 40 commercial technologies, and 65 technologies that are projected to be commercialized within three to five years.[40]

With so much FCTO-supported activity in the last year, only a few highlights are summarized below.

In January, Energy Secretary Moniz gave plenary remarks at the 2015 Washington Auto Show and toured a number of FCEV original equipment manufacturer displays. A slideshow featuring highlights from Secretary Moniz's tour of the 2015 Washington Auto Show was posted on the Energy Department's blog. Featured fuel cell vehicles

[39]Fuel Cell Technologies Market Report, http://energy.gov/eere/fuelcells/downloads/2014-fuel-cell-technologies-market-report
[40]Pathways to Commercial Success, http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways

included Toyota's Mirai, Hyundai's Tucson fuel cell vehicle, and the Honda FCV concept car.[41] Soon after the tour, Secretary Moniz test drove the Mirai, which was filmed and posted online.[42]

In February the Program launched a new, free, online national hydrogen safety training resource for emergency responders. The resource provides a single repository of credible and reliable information related to hydrogen and fuel cells that is current and accurate and eliminates duplicative efforts among various training programs. To date, the resource has been downloaded more than 300 times by people from 35 states and six continents. It has also been translated into Japanese.[43]

In August, the industry celebrated 50 years of fuel cells in space. On August 21, 1965, the National Aeronautics and Space Administration launched the Gemini 5, the first manned spacecraft to use fuel cells. Using fuel cells to power onboard electronics allowed the United States to break the world's spaceflight endurance record by traveling for eight days. Fuel cells were then used on all subsequent American manned space missions through the Gemini, Apollo, and Space Shuttle programs.

This year the program has had a strong focus on tech-to-market activities and encouraging industry to work with national labs to bring technology to the real world faster. On November 11, 2014, at the Fuel Cell Seminar and Energy Exposition in Los Angeles, California, and again on October 12, 2015, at the Electrochemical Energy Summit in Phoenix, Arizona, the Program hosted several events to foster increased collaboration between national labs and industry. The events included keynote addresses from Deputy Assistant Secretary for Transportation Reuben Sarkar and Under Secretary for Science and Energy Franklin "Lynn" Orr, respectively. Both events also included panel discussions that worked to demystify the process of working with national labs and the mechanisms put in place to put labs to work on industry problems. These panels were followed by presentations and poster sessions that highlighted the capabilities of the national labs.

On Thursday, October 8, 2015, the industry celebrated the first National Hydrogen and Fuel Cell Day. The day was marked by events across the country, including a National Renewable Energy Laboratory hydrogen station ribbon cutting and announcements from multiple national laboratories and industry partners. Aptly chosen for the atomic weight of hydrogen (1.008), National Hydrogen and Fuel Cell Day was recognized by the U.S. Senate.[44]

The most notable development of the year was the launch of commercially available FCEVs. The Department of Energy's fuel cell program began in the 1970s after the first oil embargo, when a group of researchers met at Los Alamos National Laboratory. Eventually, national lab researchers developed breakthrough methods of fabricating fuel cell electrodes that spurred worldwide research and development on PEM fuel cells. Forty years later, we see the impact of those early pioneers as car makers around the world develop fuel cell cars. In November 2014, Hyundai started leasing its Tucson FCEV, and in October 2015, Toyota announced FCEVs for sale, right on track with DOE's original plans for R&D resulting in commercial decisions being made in the 2015 timeframe. Several other companies also plan to release FCEVs very soon, including Honda, GM, Daimler, and BMW.[45]

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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[41] http://energy.gov/eere/articles/washington-auto-show-spotlight-how-fuel-cell-electric-vehicles-work

[42] http://energy.gov/eere/fuelcells/test-driving-toyota-mirai

[43] https://h2tools.org/fr/nt/

[44] http://energy.gov/eere/articles/stacked-success-celebrating-national-hydrogen-and-fuel-cell-day

[45] http://energy.gov/eere/articles/first-commercially-available-fuel-cell-electric-vehicles-hit-street