# I. INTRODUCTION

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The U.S. Department of Energy's Hydrogen and Fuel Cells Program (the Program) conducts comprehensive efforts across a range of technical and non-technical areas to enable the widespread commercialization of hydrogen and fuel cell technologies in diverse sectors of the economy. The Program is coordinated across the U.S. Department of Energy (DOE or the Department), incorporating activities in the offices of Energy Efficiency and Renewable Energy (EERE) led through the Fuel Cell Technologies Office (FCTO), Science (SC), Nuclear Energy (NE), and Fossil Energy (FE). 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 pollution, the Program engages in research, development, and demonstration (RD&D) of critical improvements in hydrogen and fuel cell technologies, as well as diverse activities to overcome economic and institutional obstacles to commercialization. The Program addresses the full range of challenges facing the development and deployment of the technologies by integrating basic and applied research, technology development and demonstration, and other supporting activities.

In Fiscal Year (FY) 2014, Congress appropriated approximately $120 million for the DOE Hydrogen and Fuel Cells Program. The Program is organized into distinct areas of RD&D, as well as other activities to address non-technical challenges. More detailed discussions of Program activities and plans can be found in the Hydrogen and Fuel Cells Program Plan, as well as in the plans of the program offices—FCTO's Multi-Year RD&D Plan; FE's Hydrogen from Coal RD&D Plan; and SC's Basic Research Needs for the Hydrogen Economy. All of these documents are available at www.hydrogen.energy.gov/roadmaps_vision.html.

In the past year, the Program made substantial progress toward its goals and objectives. In addition to summarizing examples of key technical accomplishments, this report highlights major programmatic accomplishments such as the launch of a new project called Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) that leverages the capabilities of the national laboratories in direct support of H2USA, a public private partnership formed in 2013 to overcome the barriers of hydrogen infrastructure.

## PROGRESS AND ACCOMPLISHMENTS BY PROGRAM

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 2014 Annual Merit Review and Peer Evaluation Report, which can be found at http://www.hydrogen.energy.gov/annual_review14_report.html.

### Fuel Cells

The Fuel Cell sub-program's goal is to advance fuel cell technologies primarily for transportation, as well as early markets such as stationary and portable applications, to make them competitive in the marketplace in terms of cost, durability, and performance, while ensuring maximum environmental and energy-security benefits. Cost reductions and improvements in durability continue to be the key challenges facing fuel cell technologies.

The sub-program tracks cost of automotive fuel cells on an annual basis through system design and cost analysis projects at Argonne National Laboratory (ANL) and Strategic Analysis, Inc. The 2014 cost status for 80-kW automotive fuel cell systems was determined to be $55 kW. The cost model used the same core technology as used in 2013, resulting in a final cost that was within one dollar of the 2013 cost. Recent technological advancements are planned for inclusion in the 2015 cost model.

A major achievement in 2014 was synthesis of platinum nickel alloy nanoframe catalysts that showed a more than 30 times increase in activity compared to conventional platinum on carbon catalysts. Scientists initially created Pt-Ni crystalline polyhedra particles that were left under ambient conditions in a solvent exposed to air for two weeks. Surprising changes in the structure and composition were noted—the particles had spontaneously dealloyed into a more Pt-rich alloy and transformed into hollow nanoframe structures. Recognizing the potential relevance of these new structures for catalysis, the researchers teamed up with electrochemical experts. They optimized the synthesis process,

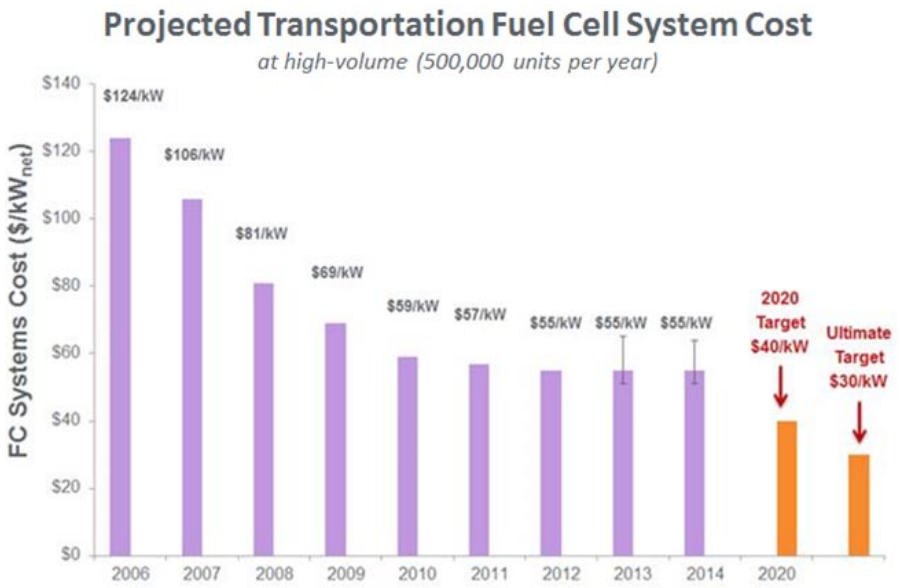


**FIGURE 1.** Projected transportation fuel cell system cost.

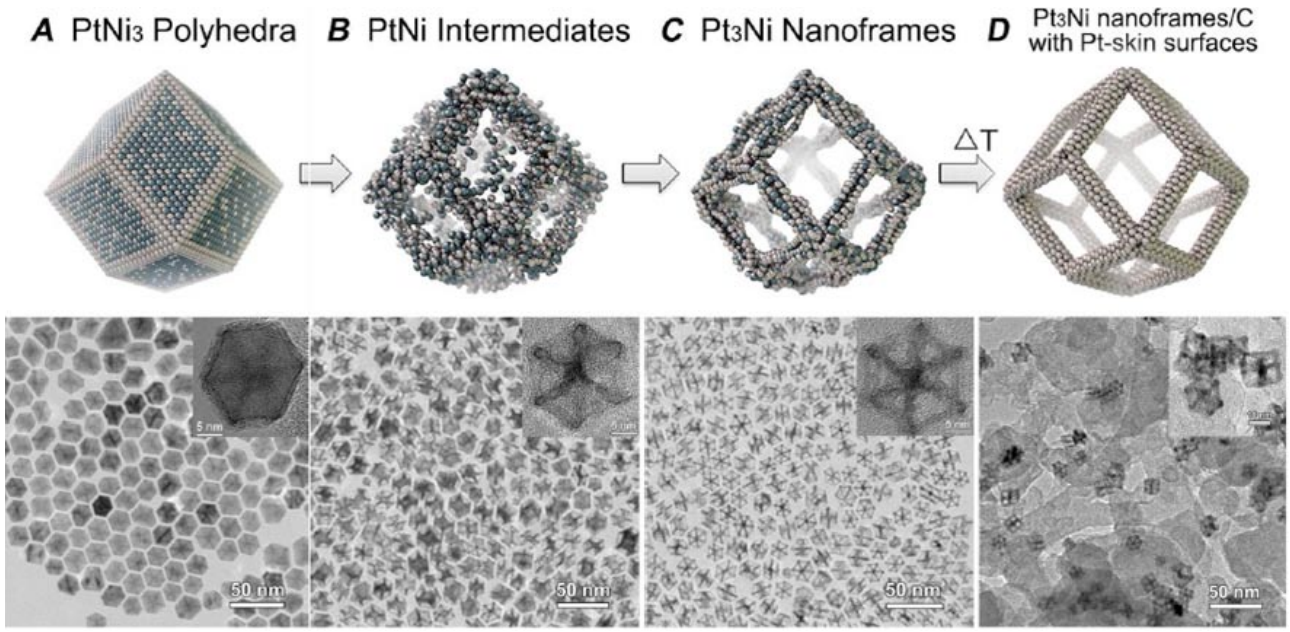


**FIGURE 2.** A new catalyst synthesized in 2014, which consists of a platinum-nickel alloy nanoframe covered by a thin platinum skin, has a performance more than 30 times higher than conventional platinum on carbon catalysts.

resulting in a catalyst that can be prepared in only a few hours with an activity that outstrips all previous fuel cell catalysts in ex situ testing.

Also in 2014, advances in catalyst synthesis and electrode optimization allowed PtCo and PtNi dealloyed catalysts, which have already met DOE targets for mass activity and durability of mass activity, to achieve good durability of high-current performance for the first time. These catalysts achieved the same $H_2$/air fuel cell performance as a 0.4 $mg_{Pt}/cm^2$ electrode, but with only one-fourth the platinum-group metal (PGM) loading. The performance improvements were confirmed in a full-active-area automotive stack. Up to 60,000 cycles between 0.6 and 0.925 V were performed with only 20 mV loss at 1.5 $A/cm^2$.

Protocols and best practices for rotating disk electrode (RDE) catalyst testing also were prepared. Initial screening of fuel cell catalyst activity is typically performed ex situ using RDE. These experiments are performed with little standardization between laboratories, leading to large discrepancies in reported activity values for the same catalysts and undermining the validity and usefulness of RDE data. Improvements in technique that allowed for higher and more reproducible activity have been reported recently, but have not yet been widely adopted. Therefore, FCTO issued a request for information on RDE best practices, discussed the issue at meetings of the catalysis and durability working groups, and supported a collaborative effort between researchers at ANL and the National Renewable Energy Laboratory (NREL) to use the resulting input to develop protocols and best practices for RDE testing. This effort established a standard protocol and test methodology for measurement of electrochemical area (ECA), oxygen reduction reaction (ORR) activity, and durability, and evaluated three electrocatalysts using identical protocols and electrode preparation in three laboratories. Comparison of the results verified the reproducibility of measured ECA, ORR activity, durability between the labs, demonstrating the validity of the newly issued protocols.

Improvements in membrane electrode assemblies (MEAs) containing PtNi nano-structured thin film catalysts have enabled performance improvement at high current densities, resulting in catalyst specific power levels at 0.69 V as high as 6.3 $kW/g_{PGM}$ at 150 $kPa_{abs}$, meeting the 2014 milestone and on track to meet the 2020 target of 8.0 $kW/g_{PGM}$. When compared to catalyst specific power measured at 0.69 V in previous years, this year's results mark a 25% and a 6% improvement since 2012 and 2013, respectively. During voltage cycling accelerated stress tests, these catalysts lose 66% of their initial activity over the course of 30,000 cycles, falling short of the targeted 40% degradation level. MEAs with earlier generation catalysts met the durability target, but fell short of the catalyst specific power target. Further R&D work is under way to meet both targets with the same MEA.

### Hydrogen Production

In FY 2014, 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 (PEC), biological, and solar-thermochemical hydrogen production.

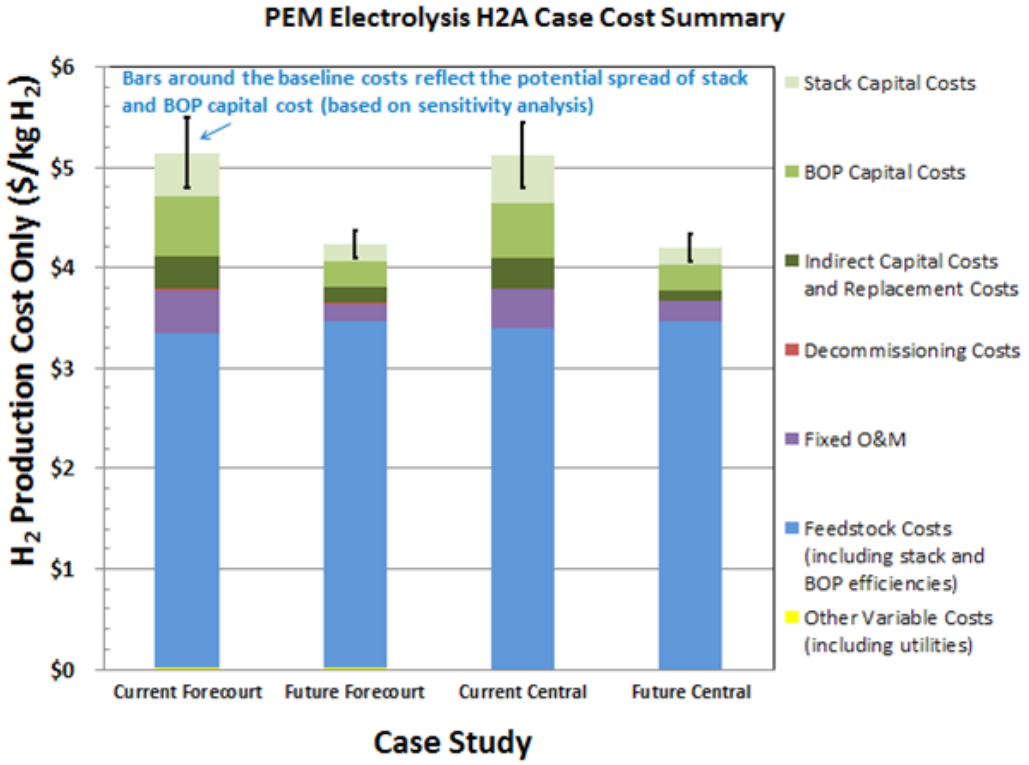


Figure 3. PEM electrolysis hydrogen production cost contributions (2007$/kg) for four case studies, showing of projected high volume untaxed costs ranging from ~$4 to $5.80/kg, broken down in terms of the major cost contributing factors.

In FY 2014, the major emphasis of the electrolysis activities were cost reduction and efficiency improvement through leveraging fuel cell catalyst development. Building off of work done by the Advanced Research Projects Agency – Energy (ARPA-E), a lead-ruthenium pyrochlore alkaline electrolysis membrane catalyst was synthesized and shown to have a mass activity 2,000 times greater than the nickel-cobalt baseline. In addition, an improved drying technique was developed with the potential to reduce drying losses in electrolyzers to less than 3.5% (compared with 11-8% in commercial systems) while operating on a variable (wind or solar) stack power profile. Testing is in progress to verify that the new drying technique meets SAE International J2719 specifications for water content (<5 ppm).

In the area of PEC hydrogen production, semiconductor tandem devices were shown to have more than 300 hours of stability at ~15 $mA/cm^2$ in III-V, showing a significant improvement over the previous year's 115 hours at 10 $mA/cm^2$. This result represents an important step toward demonstration of stabilized solar-to-hydrogen conversion efficiencies >20% using PEC devices.

In the area of biological hydrogen production, a larger, more scalable microbial reverse-electrodialysis cell design demonstrated a 0.9 L/L-reactor/day hydrogen production rate, a 12.5% increase over the 2013 demonstrated rate, using a salinity gradient instead of grid electricity.

Efforts in solar-thermochemical hydrogen characterized the performance of water splitting by novel, non-volatile metal-oxide based reaction materials and developed new reactor concepts to optimize efficiency of the reaction cycles. A thermodynamic model was developed for novel perovskite reaction materials that predicts the optimal operating temperature, $O_2$ pressure, and heat recovery effectiveness required for a solar to hydrogen conversion efficiency >20%; and derived performance criteria and thermodynamic properties for an "ideal" non-stoichiometric oxide reaction material were also developed.

The H2A v3 Production Model was applied to the PEM Electrolysis production pathway to analyze hydrogen costs ($/kg H2) and cost sensitivities. The case studies calculated a levelized cost of hydrogen production ranging from $4-5/kg for both distributed and central electrolyis; and identified the primary cost drivers as: (1) electricity cost; (2) electrolyzer electrical efficiency; and (3) electrolyzer capital cost.[1]

In June 2014, FCTO announced almost $13 million for six new research and development projects to address critical challenges and barriers for hydrogen production technology development, and specifically the long-term goal of hydrogen production at <$2/kg hydrogen. Selected projects are located in Connecticut, Washington, Colorado, Hawaii, and California.[2]

### 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 2014, the Hydrogen Delivery sub-program saw significant progress in RD&D activities. For example, a fueling strategy to improve station capacities during peak hours was developed. This strategy involves the use of a cascade of tubes in the tube trailers, wherein hydrogen gas is consolidated into one tube during peak fueling times. The high-pressure tube is then used directly for vehicle fueling while the compressor is used to either pressurize the gas in the other tubes or replenish buffer storage. This technique reduces on-site compression requirements, enabling a 10 kg/hr compressor to serve a 450 kg/day station, three times the capacity of 150 kg/day it could otherwise serve. This resulted in a 14% cost reduction for tube trailer delivery from $3.30/gasoline gallon equivalent (gge) to $2.85/gge delivered and dispensed for 700-bar refueling.

Other highlights include the Second International Workshop on Hydrogen Infrastructure and Transportation. This workshop, organized by Germany's National Organization of Hydrogen and Fuel Cell Technologies (NOW), Japan's National Energy and Industrial Technology Development Organization (NEDO), and DOE was held in June of 2014 and hosted by Toyota at the Toyota Motor Sales Corporate Accessory Center in Torrance, California. This workshop included members of industry and government from Japan, Germany, the European Union, Scandinavia, and the United States. Participants identified the major challenges and RD&D needs of hydrogen fueling protocols, metering, hydrogen fuel quality, and forecourt hardware. Additional detail will be available in the workshop proceedings when they are published later in calendar year 2014.

In June 2014, FCTO announced more than $7 million for five new awards, three selected from the FY 2014 Hydrogen Delivery Funding Opportunity Announcement (FOA) and two from Small Business Innovation Research

[1] DOE Hydrogen and Fuel Cells Program Record #14004 Hydrogen Cost from PEM Electrolysis is available at http://hydrogen.energy.gov/pdfs/14004_h2_production_cost_pem_electrolysis.pdf

[2] http://energy.gov/eere/articles/energy-department-invests-20-million-advance-hydrogen-production-and-delivery

(SBIR), for projects on compression, storage, and dispensing technologies. Selected projects are located in Texas, Massachusetts, Tennessee, and Virginia.[3]

### Hydrogen Storage

In FY 2014, the Hydrogen Storage sub-program continued its focus on development of lower cost precursors for low-cost, high-strength carbon fibers to lower the cost of high-pressure compressed hydrogen systems, system engineering for transportation applications and advanced material R &D efforts, including for metal hydrides, chemical hydrogen storage materials, and hydrogen sorbents.

The Hydrogen Storage sub-program continued carrying out technoeconomic assessments of hydrogen storage technologies. System models were developed and top-down analyses was used to determine thermodynamic properties of sorbent materials needed to meet onboard system and offboard well-to-engine efficiency targets.

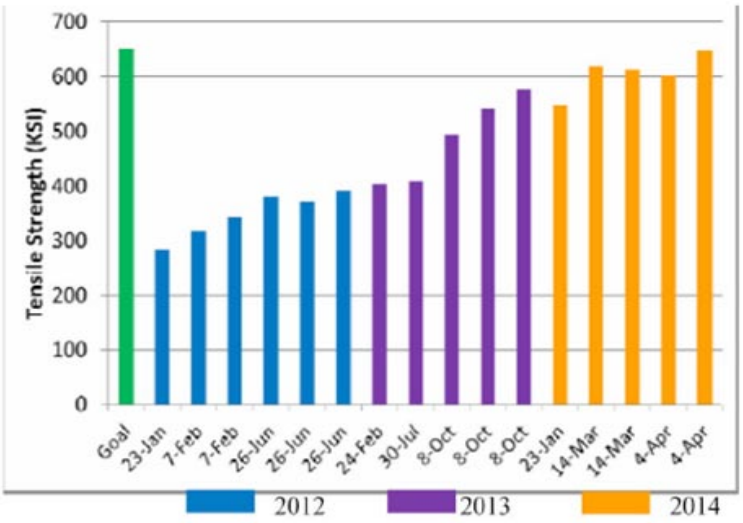


**FIGURE 4.** Tensile strength as a function of time for the F2350 precursor. (ORNL)

In the area of high pressure storage, the sub-program continued to reduce the cost of compressed hydrogen gas storage tanks. Progress included an increase of tensile strength from 405 KSI to 649 KSI, and tensile modulus from 33 MSI to 38 MSI for carbon fibers produced from polyacrylonitrile with methyl acrylate (PAN/MA) precursor fibers manufactured on high-volume, textile lines. FY 2014 analysis also projected a 52% mass reduction and 30% cost reduction in compressed hydrogen storage systems with 5.6 kg hydrogen usable capacity, at 500 bar and ~200 K, operating conditions, compared to baseline 700-bar ambient systems.

Of particular note, the FCTO-supported efforts delivered over 9 kg of MOF-5 to Hydrogen Storage Engineering Center of Excellence (HSECoE) partners for Phase III testing, with scaled-up batch material achieving performance within 10% of lab-scale batch material, and demonstrated 20x improvement in MOF-5 thermal conductivity using an enhanced natural graphite layering approach compared to random loading. Finally, the Hydrogen Storage sub-program established the HSECoE model website page (http://hsecoe.org/models.html) and posted the metal hydride (MH) acceptability envelope, MH finite element model, hydrogen tank mass and cost estimator, and hydrogen vehicle simulation framework models for public availability.

### 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 2014 saw a number of advancements in the manufacturing of fuel cells and hydrogen storage systems, including the assembly of infrared/direct current equipment on an industrial electrode coating line. Data was collected on three coating runs and defects were successfully detected at speed at the drying oven exit.

FCTO spearheaded a cross-cutting workshop, along with other offices within EERE, on quality control/metrology to leverage diagnostic capabilities and identify synergies and opportunities across other technologies. The purpose of the workshop was to convene government, industry, and other stakeholders to discuss the current status of quality control and metrology in manufacturing processes relevant to the EERE offices; note gaps in which current techniques are inadequate or missing; discuss similarities in materials inspection and metrology needs across technologies; and identify opportunities for collaboration across EERE offices to address shared challenges. Additional participating offices included Solar Energy, Vehicle, and Building Technologies and the Advanced Manufacturing Office and the Proceedings are available online.[4]

[3] http://energy.gov/eere/articles/energy-department-invests-20-million-advance-hydrogen-production-and-delivery
[4] http://energy.gov/eere/fuelcells/eere-quality-control-workshop

In May 2014 FCTO released a FOA for up to $2 million focused on *Clean Energy Supply Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cell Technologies*. This funding will support projects that focus on scaling up the production of today's hydrogen and fuel cell components and systems. The topics included outreach to develop strategies and new approaches to facilitate expansion of the domestic supply chain of hydrogen and fuel cell related components in the U.S., and global manufacturing competitive analysis for hydrogen and fuel cell-related technologies.[5]

### Basic Research

The Basic Energy Sciences 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:

- 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 2014, the Program included 20 presentations and posters from Basic Energy Sciences-funded researchers on fundamental science related topics in conjunction with presentations by EERE and ARPA-E funded researchers.

### Technology Validation

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

Six major original equipment manufacturers (OEMs) were awarded $5.5M in FY 2014 to demonstrate advanced light-duty FCEVs, where data will be collected from up to 90 vehicles. The first composite data product will be published on NREL's website in December 2014.

A hydrogen fueling station at California State University in Los Angeles (CSULA) was commissioned in May 2014 and stations in West Sacramento and San Juan Capistrano are expected to be installed and commissioned by the third and fourth quarters of 2014, respectively. Data is being collected from these state-of-the-art fueling facilities to validate technology performance under real-word use. The CSULA project also serves educational purposes, as it provides a "living lab" environment for engineering and technology students.

During FY 2014, data from four fuel cell electric bus (FCEB) demonstrations at three transit agencies were collected and analyzed; AC Transit (Oakland, California), SunLine (Thousand Palms, California), and BC Transit (Whistler, Canada). Fuel cell buses continue to show improved fuel economy (ranging from 1.8 to 2.4 times higher) compared to baseline (diesel and compressed natural gas—CNG) buses in similar service. Fuel economy for the FCEBs ranged from 5.8 mi/diesel gallon equivalent (DGE), up to 7.3 mi/DGE (for an average of 6.8 mi/DGE), approaching the Federal Transit Administration's performance target for FCEB fuel economy of 8 mi/DGE.

[5] http://energy.gov/eere/articles/energy-department-announces-2-million-develop-supply-chain-manufacturing

Early market application of fuel cell technologies includes validating MHE and backup power fuel cell performance through analysis and reporting of real-world operation and value proposition metrics. By the fourth quarter of 2013, more than 850 backup power units were in operation as part of the Technology Validation sub-program efforts. These units were found to be operating with average availability of about 99.5 percent in 23 states. By the fourth quarter of FY 2013, almost 500 MHE fuel cell units were in operation as part of the data collection efforts, filling-up on average in 2.3 minutes, and operating an average of 4.4 hours between fills.

### 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. In FY 2014, 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 the area of hydrogen behavior, risk assessment, and materials compatibility, an initial test matrix was completed to determine the fatigue life of stainless steel 21Cr-6Ni-9Mn in 103 MPa hydrogen gas, satisfying the need to quantitatively evaluate methods published in CSA CHMC1 standard and to generate qualification data for lower-cost stainless steels.

Additionally, the sub-program released a first-of-its kind iPad/iPhone app to enhance utility and integration of the safety knowledge tools with other safety planning resources. As of May 2014, there have been more than 940 downloads of the app.

As hydrogen station deployment ramps up, the siting of hydrogen dispensers at existing stations is gaining interest. The SCS sub-program supported a study showing that 20% of 70 gasoline stations evaluated in California could accommodate hydrogen.[6]

Finally, a major milestone in FY 2014, also supported over several years by the SCS sub-program, and led by industry, was the standardization and publication of two SAE International standards: J2799 Standard for 70 MPa Compressed Hydrogen Surface Vehicle Fuelling Connection Device and Optional Vehicle to Station Communications and J2601 Standard Fueling Protocols for Light-Duty Gaseous Hydrogen Surface Vehicles.

### Education

The Education sub-program facilitates hydrogen and fuel cell demonstrations and supports commercialization by providing technically accurate and objective information to key target audiences both directly and indirectly involved in the use of hydrogen and fuel cells. Funding from prior appropriations supported the sub-program's activities.

In FY 2014 FCTO published more than 80 success stories through news articles, blogs, press releases, and media announcements and conducted more than 15 webinars, averaging more than 150 attendees per webinar. Activities reached at least 3,000 people at key conferences and meetings. The sub-program is also continuing to train middle school and high school teachers based on prior years' funding through "H2 Educate!" reaching a cumulative of 12,000 teachers, in 35 states; 90% of participants have stated that the training resources increased the effectiveness of their lesson plans.

### Market Transformation

To ensure that the benefits of the Program's efforts are realized in the marketplace, in FY 2014 the Market Transformation program continued to facilitate the growth of early markets for fuel cells used in stationary, specialty-vehicle and truck fleet applications. Market Transformation 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. Market Transformation also partners with other federal agencies and stakeholders to deploy fuel cell systems in applications such as marine cargo transport operations.

Current key objectives of the Market Transformation program are to build on past successes in MHE (e.g., lift trucks or forklifts) and emergency backup power applications by exploring other emerging applications for market viability. FY 2014 accomplishments included designing a commercial viable fuel cell-powered airport ground support baggage tractors, developing fuel cell-powered electric medium-duty hybrid trucks for parcel delivery applications,

[6] http://energy.sandia.gov/wp/wp-content/gallery/uploads/SAND_2014-3416-SCS-Metrics-Development_distribution.pdf

completing the design development of fuel cell auxiliary power systems for refrigerated trucks, and completing the design for a maritime auxiliary power system. These projects are highly leveraged, with an average of more than half of the projects' funds being provided by DOE's partners.

Affordable hydrogen in accessible locations is another key goal; Market Transformation is supporting this by a landfill-gas-to-hydrogen project at a working manufacturing facility and using curtailed renewable power to electrolyze water on another project.

A potential new activity that could be initiated subject to Congressional appropriations is the design and deployment of fuel cell battery-powered hybrid light-duty vehicles for parcel delivery or passenger transportation applications.

### 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. Analysis conducted in FY 2014 included socio-economic impacts such as increased employment from early market infrastructure development, life-cycle analysis of various vehicle platforms including FCEVs with EERE's Bio-Energy Technologies and Vehicle Technologies Offices, hydrogen use for energy storage, fuel cell system cost impact to improve fuel cell efficiency, life cycle impacts of water use of hydrogen production pathways, identification of early markets for fuel cells, and options to reduce infrastructure cost through the application of tri-generation fuel cell systems.

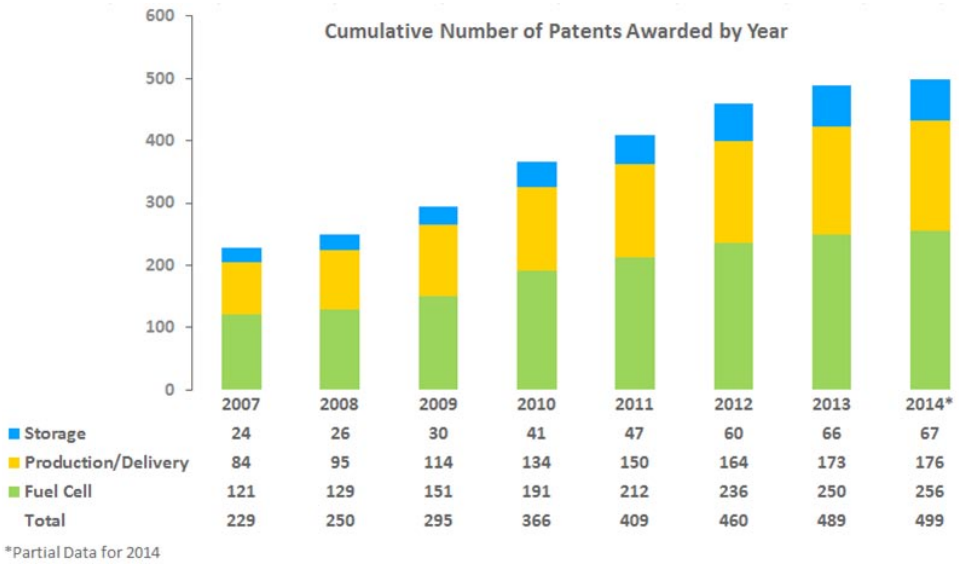


**FIGURE 5.** Number of issued patents as a result of FCTO funding. (PNNL)

The commercial benefits of FCTO were analyzed by tracking the commercial products and technologies, and patents developed from R&D funding. The benefits of DOE funded projects continue to grow. FY 2014 tracking showed 499 cumulative patents issued as a result of FCTO funding. In addition, 45 FCTO-funded were in the market and 65 were identified to be commercialized within three to five years.[7]

In FY 2014, the GREET (Greenhouse gases, Regulated Emissions and Energy use in Transportation) model's life cycle analysis capabilities were enhanced to include water consumption for hydrogen production and delivery pathways from natural gas, water electrolysis, and other fuels such as gasoline and ethanol. The analysis includes the water use assessment of pathway components including feedstocks such as natural gas and crude oil and energy use such as electricity, and biofeedstocks such as corn and cellulosic sources. Converting these conventional and new feedstocks to fuels require additional water consumption. The results of the analysis shown in the figure below show that water

[7] http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways

for irrigation, cooling water for electricity generation, and evaporation associated with hydropower generation has the greatest impact on life cycle water consumption of E85 (85% ethanol, 15% gasoline) fuel, hydrogen fuel cell, and electric vehicles.

The impact of different fuel cell targets on the vehicle energy consumption and cost were also studied using the Autonomie model and compared to conventional gasoline internal combustion powertrains. In addition, the impact of fuel cell system improvements on the potential on-board storage requirements and cost were analyzed. The findings of the study indicate the fuel economy of the FCEV could be improved by 10-14% by increasing the fuel cell peak efficiency from 60 to 68%. When the FCEV improvements are compared to conventional vehicle, the FCEV fuel economy was found to be 4 times higher (139 mpg unadjusted) than the 2013 conventional vehicle in the 2030 timeframe.

### 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 2014, all of the original twelve projects have been successfully completed, and over 96% 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 system 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. NREL's National Fuel Cell Technology Evaluation Center (NFCTEC) has established data reporting protocols and Composite Data Products (CDPs) and Detailed Data Products showing progress to date have been prepared. The CDPs are available on the NREL NFCTEC website.[8]

Notable accomplishments in FY 2014 included design and construction of a 250-W propane-fueled, portable solid oxide fuel cell (SOFC) units successfully operated over 4 days (on a single 20-lb propane bottle) to power television cameras at NASCAR events; and successful backup operation of three propane-fueled, 5-kW, GenSys fuel cells to provide lighting to a building during a 30 minute, simulated outage at Ft Irwin, California.

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 7,500 fuel cell forklifts and more than 4,000 fuel cell backup power systems, with no additional DOE funding.[9,10]

## OTHER PROGRAM ACTIVITIES AND HIGHLIGHTS FROM FY 2014

### 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 funding by tracking the commercial products and technologies developed with the support of FCTO. R&D efforts funded by FCTO have resulted in 499 patents, 45 commercial technologies in the market, and 65 technologies that are projected to be commercialized within three to five years (as of October 2014).[11]

In addition, EERE's investment of $95 million in specific hydrogen and fuel cell projects led to more than $400 million in revenue and investments of approximately $70 million in specific projects led to a nearly $390 million in additional private investment.

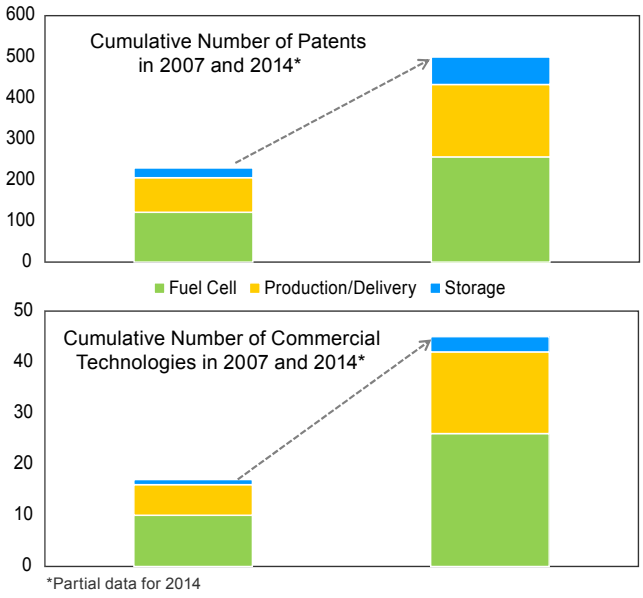


**FIGURE 6.** Patents and commercial products as a result of FCTO funding.

[8] http://www.nrel.gov/hydrogen/facilities_nfctec.html
[9] http://hydrogen.energy.gov/pdfs/14009_industry_bup_deployments.pdf
[10] http://hydrogen.energy.gov/pdfs/14010_industry_lift_truck_deployments.pdf
[11] http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways

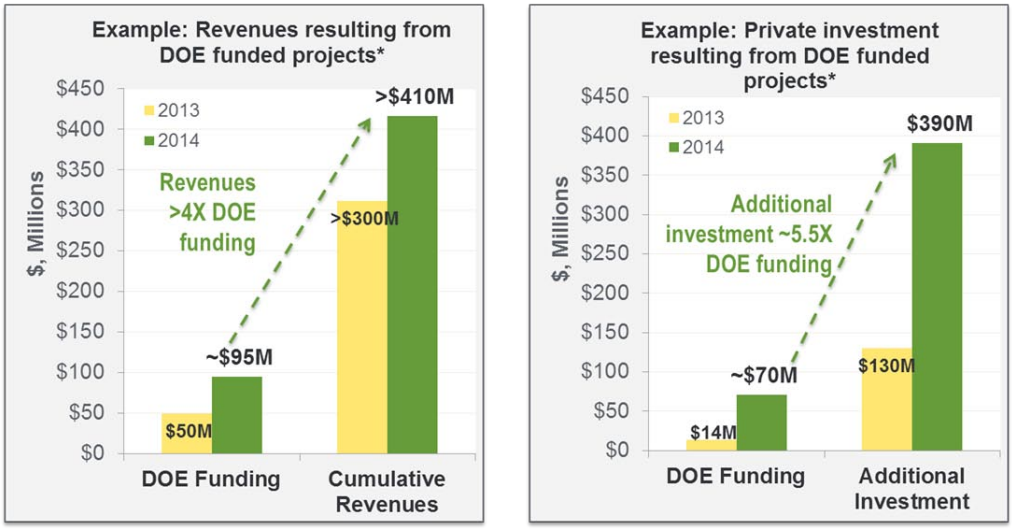


**FIGURE 7.** Revenues and private investment as a result of specific FCTO funding of projects.

### Awards & Distinctions

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

- Dr. Adam Weber of the Energy Department's Lawrence Berkeley National Laboratory was honored with a Presidential Early Career Awards for Scientists and Engineers (PECASE), the federal government's highest honor for science and engineering professionals in the early stages of their careers. This follows last year's PECASE award to FCTO-funded Professor Tom Jaramillo of Stanford University and makes the only two PECASE awards within all of EERE. Dr. Weber also received the 2014 Charles W. Tobias Young Investigator Award.
- Dr. Maria Ghirardi was named to NREL's Research Fellows Council, the laboratory's top advisory council comprised of internationally recognized NREL scientists and engineers.
- The Women Chemists Committee of the American Chemical Society selected Katherine Ayers of Proton OnSite to be a recipient of the 2014 Women Chemists Committee Rising Star award.
- Northeastern chemistry professor Sanjeev Mukerjee was named a Fellow of The Electrochemical Society.
- James Miller and Riccardo Scarcelli of ANL's Energy Systems division are 2014 recipients of the prestigious McFarland Award from SAE International.
- The ACS Division of Inorganic Chemistry announced Jeffrey Long, University of California, Berkeley, as the winner of the second Inorganic Chemistry Lectureship Award.
- Dr. Piotr Zelenay of Los Alamos National Laboratory (LANL) was named a Fellow of The Electrochemical Society.
- Thomson Reuters has included University of South Carolina professor Branko N. Popov as one of the 2014 World's Most Influential Scientific Minds and one of our nation's most highly cited researchers from 2002 to 2014.
- Jennifer Kurtz and Keith Wipke from NREL and Daniel Dedrick from Sandia National Laboratories (SNL) have won prestigious Federal Lab Consortia 2014 Far West Regional Awards.

### Key Reports/ 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 (2013 Fuel Cell Technologies Market Report), the commercialization report (2013 Pathways to Commercial Success: Technologies and Products Supported by FCTO), 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 ***Hydrogen Production Expert Panel (HPEP)***, a Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) subcommittee, published major findings from their May 10–12, 2012 workshop which was launched with opening remarks by the previous Energy Secretary. Tasked with providing recommendations to enable the widespread production of affordable, low-carbon hydrogen, HPEP collected input from experts from industry, academia, and national laboratories during the workshop and developed recommendations based on that input. http://www.hydrogen.energy.gov/advisory_htac.html#reports
- The ***2013 Fuel Cell Technologies Market Report*** finds that there is continued growth in fuel cell commercial deployments, including MHE such as forklifts as well as combined heat and power systems and backup and auxiliary power units. Nationally, U.S. fuel cell shipments grew from 1,000 units in 2008 to nearly 5,000 units in 2013, while domestic manufacturing increased by more than 60% from 2012 to 2013. http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_program
- ***States of the States: Fuel Cells in America 2013***, the fifth annual report on state activities, details fuel cell and hydrogen activities and policies in the 50 states and the District of Columbia. http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_state
- ***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 450 patents, 40 commercial technologies, and 65 technologies that are expected to reach commercial scale within the next three to five years, and issue more than 450 U.S. patents. http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways
- 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. http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_business
- ***Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs*** detail the findings of an independent review of hydrogen compression, storage, and dispensing for pipeline delivery of hydrogen and forecourt hydrogen production. http://www.hydrogen.energy.gov/peer_reviews.html
- ***Twenty new fact sheets*** on the models and tools used for system analysis of hydrogen and fuel cells were published. The models and tools summarized in the fact sheets are used by FCTO's System Analysis sub-program to perform hydrogen/fuel cell-related calculations, evaluations, and environmental assessments. This template was subsequently used by EERE's Vehicle Technologies Office (VTO) to document VTO-sponsored models and tools as well. http://energy.gov/eere/fuelcells/downloads/analysis-models-and-tools-systems-analysis-hydrogen-and-fuel-cells
- An inter-agency and inter-office report titled ***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. http://energy.gov/eere/fuelcells/downloads/hydrogen-fueling-station-honolulu-hawaii-feasibility-analysis

### Workshops and Proceedings

- On November 4, 2013, FCTO held its first ***Early Market Fuel Cell Showcase and Project Review*** in New York City at the New York Times building. This event was held for potential investors, business partners, and other stakeholders through presentations and a poster session in an effort to facilitate industry and investor awareness of these emerging and innovative technology areas. Attendees included Steve Chalk, Deputy Assistant Secretary of Renewable Energy; Congressman Paul Tonko (D-NY); and Richard Kauffman, Chairman of Energy and Finance for New York State.
- On April 15, 2014, FCTO held its ***Clean Energy Technology Showcase Review*** featuring fuel cells, flow batteries, and related energy efficiency technologies at Stanford University. Reviewers provided feedback to FCTO as well as Advanced Manufacturing Office (AMO) and ARPA-E on the projects presented. The event was launched by the Office of Energy Efficiency and Renewable Energy's Assistant Secretary Dr. David Danielson.
- The ***proceedings from the Biological Hydrogen Production Workshop*** that took place September 23–24, 2013, were released in November. The objective of the Biological Hydrogen Production Workshop was to share

information and identify issues, barriers, and R&D needs for biological hydrogen production to enable hydrogen production that meets cost goals. http://energy.gov/eere/fuelcells/biological-hydrogen-production-workshop

- The ***EERE Quality Control Workshop proceedings*** detail the activities of a workshop held December 9 and 10, 2013 and convened government, industry, and other stakeholders to discuss the current status of quality control and metrology in manufacturing processes relevant to the EERE offices. http://energy.gov/eere/fuelcells/articles/eere-quality-control-workshop-proceedings-released
- The ***2014 Hydrogen Transmission and Distribution Workshop proceedings*** and final summary report provide details on a workshop held February 25–26, 2014 that brought together experts from the industrial gas and energy industries, national laboratories, academia, and the National Institute of Standards and Technology to discuss and share information on the RD&D needs and challenges for low-cost, effective hydrogen transmission and distribution from centralized production facilities to the point of use. http://energy.gov/eere/fuelcells/downloads/hydrogen-transmission-and-distribution-workshop
- The ***2014 Electrolytic Hydrogen Production Workshop proceedings and final summary report*** shares information compiled during a workshop held on February 27–28, 2014 on the RD&D needs for enabling low-cost, effective hydrogen production from all types of water electrolysis systems, both centralized and forecourt. http://energy.gov/eere/fuelcells/downloads/electrolytic-hydrogen-production-workshop

### New FOAs and Awards

- **$7 million** for four projects that will help bring cost-effective, advanced hydrogen and fuel cell technologies online faster through early market applications such as delivery vans. Selected projects are located in Georgia, Kansas, Pennsylvania, and Tennessee.
- **$3 million** to advance U.S. competitiveness in molten carbonate technology. The selected project is located in Connecticut.
- **$7 million** was awarded for six projects to develop lightweight, compact, and inexpensive advanced hydrogen storage systems that will enable longer driving ranges and help make fuel cell systems competitive for different platforms and sizes of vehicles. Selected projects are located in California and North Carolina.
- **$20 million** was awarded for 10 new research and development projects to advance hydrogen production and delivery technologies. Selected projects are located in Connecticut, Washington, Colorado, Hawaii, California, Texas, Massachusetts, Tennessee, and Virginia.
- **National Science Foundation (NSF)** funding, through the first ever Memorandum of Understanding between FCTO and NSF, to address discovery and development of advanced materials systems and chemical processes for direct photochemical and/or thermochemical water splitting for application in the solar production of hydrogen fuel. Four projects were announced in September 2014.
- **$2 million** to develop supply chain manufacturing competitiveness analysis for hydrogen and fuel cell technologies. This FOA closed on June 30, 2014.
- **$4.6 million** in incubator funding to identify potentially impactful technologies that are not already addressed in FCTO's strategic plan or project portfolio. Full responses were due September 3, 2014.

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

- Fuel cell project selected through a new **EERE SBIR Technology Transfer Opportunity topic** that moves existing inventions developed at DOE's national laboratories to the marketplace and accelerates the pace of commercialization. This was the first ever SBIR in EERE and provided national laboratory patents for small businesses to commercialize. The selected project is located in Massachusetts.
- **SBIR/Small Business Technology Transfer (STTR) Phase II** Release 1 Award Winners included two hydrogen and fuel cell projects. Topics include "optimizing the cost and performance of composite cylinders for hydrogen storage using a graded construction" and "novel structured metal bipolar plates for low cost manufacturing."
- **SBIR/STTR Phase I** Release 2 Technical Topics Announced for FY 2014, include prototype fuel cell-battery electric hybrid trucks for waste transportation and novel membranes and non-platinum group metal catalysts for direct methanol as well as hydrogen fuel cells.

- **2015 SBIR/STTR Phase I** Release 1 FOA includes hydrogen and fuel cell topics. Applications are due October 14, 2014. Topics include "non-platinum group metal catalysts for fuel cells" and "understanding of material behavior for detection of hydrogen contaminants."

The Program also coordinated with other offices and the following FOAs from FY 2014 were relevant.

- **$70 million** in AMO funding to a new Advanced Composite Manufacturing Institute to target continuous or discontinuous carbon and glass fiber composites. This FOA closed on June 24, 2014.
- **$33 million** in ARPA-E funding for intermediate-temperature fuel cell systems for distributed generation.[12]
- **$15 million** in FE funding for improved reliability of solid oxide fuel cell systems**.** This FOA closed on March 31, 2014.
- **$6.4 million** in FE funding for R&D support of the solid oxide fuel cell core technology program. This FOA closed on March 31, 2014.

### Requests for Information (RFIs)

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

- Strategies for a robust market introduction of hydrogen supply, infrastructure, and FCEVs.The input received will augment financing strategies that DOE analyzes for public deployment of infrastructure for supporting FCEV introduction in U.S. markets. Such financing strategies should maximize financing, for example, with debt and equity, while minimizing public incentives. (January 31, 2014)
- Biological hydrogen production R&D pathways, barriers, issues and opportunities for development of technologies that can ultimately produce low cost hydrogen that meets DOE goals. (February 28, 2014)
- Existing and potential hydrogen contamination detectors and related factors such as performance characteristics, system integration requirements, costs, deployment guidance, and R&D needs. (May 19, 2014)
- Technical and economic feasibility of commercializing fuel cell range extenders as onboard power generators for all-electric vehicles in the United States market. (August 7, 2014)

[12] http://arpa-e.energy.gov/?q=arpa-e-news-item/arpa-e-announces-30-million-distributed-generation-technologies

The Program also held a number of webinars throughout the year.[13]

| DATE | TITLE | DESCRIPTION |
|---|---|---|
| September 11, 2014 | Introduction to SAE Hydrogen Fueling Standardization | This webinar provided an overview of the SAE International 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. |
| August 19, 2014 | Increasing Renewable Energy with Hydrogen Storage and Fuel Cell Technologies | This webinar featured representatives from NREL discussing a unique opportunity for the integration of multiple sectors including transportation, industrial, heating fuel, and electric sectors on hydrogen. This presentation looked at the architecture of hydrogen storage systems and economic competitiveness for those systems when compared with conventional systems. |
| July 29, 2014 | Supporting a Hawaii Hydrogen Economy | During this webinar the Hawaii Natural Energy Institute (HNEI) discussed the status of current and planned hydrogen projects in Hawaii. HNEI has worked to reduce Hawaii's dependence on fossil fuels and increase energy security, serving as the implementing organization for several large-scale public-private partnerships to develop, deploy, and demonstrate renewable energy systems. |
| June 24, 2014 | Hydrogen Fueling for Current and Anticipated Fuel Cell Electric Vehicles | This webinar featured representatives from the California Energy Commission who discussed their recently announced Notice of Proposed Award for 28 hydrogen fueling stations, the evaluation criteria, and the variety of competitions. In addition, representatives from ANL discussed a new tool for estimating the economic impacts of hydrogen infrastructure for early market fuel cell electric vehicles. The tool, titled JOBS and economic impacts of Hydrogen (JOBS H2), estimates the jobs, earnings, and economic output created by deploying hydrogen fueling stations. |
| May 27, 2014 | NREL's Fuel Cell Contaminant Database | This webinar focused on the NREL's online data tool for fuel cell system-derived contaminants. NREL has led a multi-year project studying the effect of system-derived contaminants on the performance and durability of polymer electrolyte membrane fuel cells. The webinar provided an overview of data obtained during the project and a tutorial on how to use the Web-based data tool to access project results. |
| April 17, 2014 | Fuel Cells at NASCAR | This webinar focused on fuel cell use at NASCAR Green. Presentations by NASCAR and Acumentrics described the use of SOFC generators for use in powering broadcast cameras for NASCAR. Recently, Acumentrics Corporation completed a field test program with NASCAR to replace small portable gasoline generators with SOFC units operational on commercial propane. |
| March 11, 2014 | National Fuel Cell Technology Evaluation Center (NFCTEC) | This webinar focused on the NFCTEC, which is dedicated to the independent analysis of advanced hydrogen and fuel cell technologies at the Energy Department's Energy Systems Integration Facility located at the NREL in Golden, Colorado. The presentation by NREL highlighted the efforts of NFCTEC to accelerate the commercialization of fuel cell technologies through analysis of technologies operating under real-world conditions and comparison to technical targets. |
| February 11, 2014 | Additive Manufacturing for Fuel Cells | This webinar focused on additive manufacturing to stimulate discussion in the hydrogen and fuel cell community on the application of additive manufacturing to prototyping and production. Presentations by Eaton and Nuvera highlight Eaton's experience using additive manufacturing for prototype development and recent developments in additive manufacturing for full scale production being employed at Nuvera. |
| January 16, 2014 | Energy 101: Fuel Cells Discussion | This Google+ Hangout discussion focused on audience questions about fuel cells. Several experts answered questions and discussed fuel cells in front of a live online audience. Expert panelists included Dr. Sunita Satyapal, Director of the Energy Department's Fuel Cell Technologies Office; Daniel Dedrick, Manager of Hydrogen and Combustion Technologies at SNL; Anthony Eggert, Executive Director of the UC Davis Policy Institute for Energy, Environment and the Economy; and Charlie Freese, Executive Director of Global Fuel Cell Activities at General Motors. |
| January 14, 2014 | 2014 Hydrogen Student Design Contest | This webinar focused on the winning entries of the 2013 Hydrogen Student Design Contest from the University of Kyushu and University of Birmingham. This year, teams were challenged to develop hydrogen fueling infrastructure plans for the Northeast and mid-Atlantic for the 2013-2025 timeframe. During the webinar the theme for the 2014 contest—Designing a Drop-in Fueling Station—was also discussed. |
| December 16, 2013 | International Hydrogen Infrastructure Challenges Workshop Summary – NOW, NEDO, and DOE | This webinar summarized the international information exchange on the hydrogen refueling infrastructure challenges and potential solutions to support the successful global commercialization of hydrogen fuel cell electric vehicles. The information exchange took place in June 2013 at the German Ministry of Transport, in Berlin. |
| November 19, 2013 | Micro-structural Mitigation Strategies for PEM Fuel Cells | This webinar highlighted micro-structural mitigation strategies for polymer electrolyte membrane (PEM) fuel cells focusing on morphological simulations and experimental approaches. Presented by Ballard Power Systems, the webinar highlighted an open-source fuel cell simulation package funded by EERE that allows users to simulate both the performance and durability of a PEM fuel cell membrane electrode assembly. In this webinar, the details of the model were discussed with a focus on the theory, background, and validation/results of the simulation package. |

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

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

| DATE | TITLE | SUMMARY |
|---|---|---|
| September 30, 2014 | And the Oscar for Sustainable Mobile Lighting Goes to…. Lighting Up Operations with Hydrogen and Fuel Cell Technology[1] | An Energy Department-supported project is addressing these problems by designing, building, and testing a mobile lighting tower powered by hydrogen fuel cell technology, which is quiet and emits nothing but water while generating electricity. |
| September 26, 2014 | Hyundai Tucson Fuel Cell Electric Vehicle visits Department of Energy[2] | From researchers to project managers to technical experts, there are dozens of EERE staff dedicated to supporting the research, development, and deployment of fuel cells. |
| September 11, 2014 | Highlighting Hydrogen: Hawaii's Success with Fuel Cell Electric Vehicles Offers Opportunity Nationwide[3] | Engineers from the Energy Department's Idaho National Laboratory and NREL identified a new way to launch economically viable hydrogen fueling stations for FCEVs in Honolulu, Hawaii, based on a report titled "Hydrogen Fueling Station in Honolulu, Hawaii." The report's findings could also have a broad national impact, accelerating the pace of America's growing clean energy economy. |
| May 13, 2014 | Research Leads to Improved Fuel Yields from Smaller Antenna Algae[4] | A study funded by the Energy Department could lead to big improvements in alternative fuel production. Researchers at the University of California, Berkeley have discovered that if particular genes are missing in certain strains of algae, the algae can produce more hydrogen and other fuel from full sunlight than the ordinary algae. |
| April 29, 2014 | Small Catalyst Finding Could Lead to Big Breakthrough for Fuel Cell Deployment[5] | Researchers at the Energy Department's national labs have developed a new catalyst that could make fuel cells cost-competitive with other power generators. |
| March 28, 2014 | Interested in Hydrogen and Fuel Cell Technologies? Help Shape the H2Refuel H-Prize Competition[6] | The Energy Department recently posted a blog about the H-Prize H2 Refuel Competition, which involves designing a small-scale hydrogen refueler system for homes, community centers, or businesses. |
| February 24, 2014 | NASCAR Green Gets First Place in Daytona 500[7] | A story about how fuel cell generators were used at the Daytona 500 is currently posted on the Energy Department's blog. |
| February 4, 2014 | Nebraska Company Expands to Meet Demand for Hydrogen Fuel[8] | Hexagon Lincoln develops carbon fiber composite fuel tanks that help deliver hydrogen to fleets throughout the country. The company has more than doubled its workforce to accommodate growing demand for the tanks. |
| January 28, 2014 | You Asked, We're Answering Your Fuel Cell Questions[9] | The Energy Department posted a blog with answers to some of the fuel cell questions that didn't get covered during the Energy 101 Google+ Hangout on January 16. |
| January 9, 2014 | Help Design the Hydrogen Fueling Station of Tomorrow[10] | As the hydrogen industry expands, refueling infrastructure needs to be developed to keep fuel cell electric vehicles powered and moving on America's roadways. University students can play a big role in this through the Hydrogen Education Foundation's Hydrogen Student Design Contest, supported by the Energy Department. |
| December 20, 2013 | Your Holidays … Brought to You by Fuel Cells[11] | A story about how fuel cells are helping bring the holidays to you is currently posted on the Energy Department's Blog. |

[1] http://energy.gov/eere/articles/and-oscar-sustainable-mobile-lighting-goes-lighting-operations-hydrogen-and-fuel-cell
[2] http://energy.gov/eere/articles/hyundai-tucson-fuel-cell-electric-vehicle-visits-department-energy
[3] http://energy.gov/eere/articles/highlighting-hydrogen-hawaii-s-success-fuel-cell-electric-vehicles-offers-opportunity
[4] http://energy.gov/eere/articles/research-leads-improved-fuel-yields-smaller-antenna-algae
[5] http://energy.gov/articles/small-catalyst-finding-could-lead-big-breakthrough-fuel-cell-deployment
[6] http://energy.gov/eere/fuelcells/articles/interested-hydrogen-and-fuel-cell-technologies-help-shape-h2-refuel-h-prize
[7] http://energy.gov/eere/fuelcells/articles/nascar-green-gets-first-place-daytona-500
[8] http://energy.gov/eere/articles/nebraska-company-expands-meet-demand-hydrogen-fuel
[9] http://energy.gov/eere/fuelcells/articles/you-asked-were-answering-your-fuel-cell-questions
[10] http://energy.gov/eere/fuelcells/articles/help-design-hydrogen-fueling-station-tomorrow-0
[11] http://energy.gov/eere/fuelcells/articles/your-holidaysbrought-you-fuel-cells

## 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. The IPHE is a forum for governments to work together to advance worldwide progress in hydrogen and

fuel cell technologies. IPHE also offers a mechanism for international R&D managers, researchers, and policymakers to share program strategies. IPHE members embarked upon a second 10-year term in November 2013. The Chair of the IPHE is currently Japan, with the United States and Germany serving as Vice Chairs.[14]

In FY 2014, IPHE members met in Fukuoka, Japan (November 2013) and in Oslo, Norway (May 2014) to share progress and plans related to hydrogen and to discuss plans for the IPHE Secretariat. IPHE-related workshop topics in FY 2014 included energy storage and hydrogen infrastructure.

### 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; the United States is a member of both the Advanced Fuel Cells Implementing Agreement (AFCIA) and the Hydrogen Implementing Agreement (HIA). These agreements provide a mechanism for member countries to share the results of R&D and analysis activities. The AFCIA is in a unique position to provide an overview of the status of fuel cell technology, deployment, and the opportunities and barriers faced within the member countries. The AFCIA has several annexes: Molten Carbonate Fuel Cells, Polymer Electrolyte Fuel Cells, Solid Oxide Fuel Cells, Fuel Cells for Stationary Applications, Fuel Cells for Transportation, Fuel Cells for Portable Power, and Systems Analysis. Participating countries include Australia, Austria, Belgium, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Mexico, Sweden, Switzerland, and the United States. The IEA HIA is focused on RD&D and analysis of hydrogen technologies. Tasks include Hydrogen Safety, Renewable Hydrogen, Fundamental and Applied Hydrogen Storage Materials Development, Small-Scale Reformers for On-site Hydrogen Supply, Large Scale Hydrogen Delivery Infrastructure, Distributed and Community Hydrogen for Remote Communities, and Global Hydrogen Systems Analysis. Members of the HIA include Australia, Denmark, the European Commission, Finland, France, Germany, Greece, Italy, Japan, Korea, Lithuania, New Zealand, Norway, Spain, Sweden, Switzerland, Turkey, Taiwan, and the United States. Additional sponsor members include Shell, Germany's National Organisation Hydrogen and Fuel Cell Technology, and Hy-SAFE Technology. The United States is a strong contributor to numerous IEA tasks and activities. During FY 2014 the United States hosted a workshop to solicit input to IEA's Roadmap activities related to hydrogen and fuel cells.

## EXTERNAL COORDINATION, INPUT, AND ASSESSMENTS

### H2USA Partnership

While hydrogen infrastructure remains a key challenge to the widespread adoption of FCEVS, states like California continue to show their commitment to this clean energy technology. A series of major announcements in 2014 shows increased momentum in overcoming obstacles.

On May 1, Governor Brown of California signed on to join H2USA, a public-private partnership led by the Energy Department and industry partners. H2USA was launched in May 2013 to address the challenge of hydrogen infrastructure, bringing together Federal agencies, state agencies, hydrogen providers, energy companies, technology developers, national labs, academia, and other trade associations or non-profit organizations. The partnership provides a platform for the United States similar to the public-private partnerships in other countries focused on hydrogen, particularly Germany, Japan and the UK. H2USA has more than tripled its partners in the last year and currently consists of 37 participants.

On April 30, the Energy Department announced the launch of a new project leveraging the capabilities of its national laboratories in direct support of H2USA. The project is led by NREL and SNL and will tackle the technical challenges related to hydrogen fueling infrastructure. The Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project is designed to reduce the cost and time of fueling station construction, increase station availability, and improve reliability by creating opportunities for industry partners to pool knowledge and resources to overcome hurdles. The project was established by FCTO, drawing on existing and emerging core capabilities at the national labs.

### 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

[14] http://www.iphe.net/

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 2014. In June 2014, HTAC released its sixth annual report, which summarizes hydrogen and fuel cell technology, domestic and international progress in RD&D projects, commercialization activities, and policy initiatives.[15]

Currently, the Committee has two established subcommittees, both started in late 2013. The Advanced Manufacturing Subcommittee is conducting 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. 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 both subcommittees will prepare written reports detailing their accomplishments and findings to the full Committee during FY 2015.

### 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) 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 also worked with EPA to further refine the interpretation of a qualified renewable fuel under their Renewable Fuel Standard Program, resulting in the acceptance of biogas derived hydrogen for transportation within the program. In addition, the Office developed an interagency federal fleet strategy that provides a strategic, coordinated set of agency roles to help ensure a successful rollout of FCEVs to early markets. Finally, further collaboration with the Department of Agriculture and the Department of Defense to identify locations for future hydrogen stations is also helping support the early FCEV and hydrogen fuel infrastructure market.

### 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 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 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 Office is an active participant in CEMI activities, leveraging opportunities for hydrogen and fuel cell manufacturing. In FY 2014, AMO released a request for information on Clean Energy Manufacturing Topics for a new National Network of Manufacturing Innovation Institute. Topics included materials discovery, next gen electric machines, high value-add roll-to-roll manufacturing, and manufacturing with biomaterials.

On September 17, 2014, as part of the American Energy and Manufacturing Competitiveness (AEMC) Partnership, CEMI, and the Council of Competitiveness co-hosted the Second Annual AEMC Summit. The Summit brought together perspectives from industry, government, academia, national laboratories, labor, and policy organizations

[15] http://www.hydrogen.energy.gov/advisory_htac.html

dedicated to the competitiveness of U.S. clean energy products and increasing U.S. energy productivity across the board. Also in FY 2014, CEMI held a regional summit in San Francisco, and two dialogue events in Santa Clara and in Berkeley, California.

### FY 2014 Annual Merit Review and Peer Evaluation

The Program's AMR took place June 16-20 in Washington, DC, and provided an opportunity for the Program to obtain expert peer reviews of the projects it supports and to report its accomplishments and progress. For the sixth 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 FY. 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 100 experts peer-reviewed 100 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 at www.hydrogen.energy.gov/annual_review14_report.html. The 2015 Annual Merit Review and Peer Evaluation Meeting will be held June 8–12, in Arlington, Virginia.

### Funds Saved through Active Project Management

The AMR is a key part of the Program's comprehensive approach toward active management of its projects. Termination of underperforming projects—identified through the AMR as well as through other Go/No-Go decisions (with criteria defined in the project scope of work)—helped the Program redirect $3.0 million in funding in FY 2014, $7.6 million in FY 2013, and over $35 million over the past five years.

### DOE Cross-Cutting Activities

Grid Integration: 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. With the appropriate secure communication technology, electrolyzers can participate in energy markets to help balance the variability of these renewable energy sources by modulating the production of hydrogen to reduce or increase overall energy consumption within the electric grid. Further benefits include the ability of stationary fuel cells to effectively contribute to a grid market by increasing their visibility and controllability. Changing fuel cell generation from a variable source to a controllable source increases there value to the grid and makes stationary fuel cell systems more economical, especially in small-scale (e.g. residential applications) where electricity and heat demand is highly variable. EERE is working to address some of these issues through a new cross-cutting initiative focused on integrating clean energy technologies into the energy system in a safe, reliable, and cost effective manner at a relevant scale to support the nation's goals of 80% clean electricity by 2035 and reducing oil imports by 33% by 2025. All of the participating technologies offices, including FCTO, are determining the high impact RD&D necessary to enable the integration of energy efficiency and renewable energy technologies into the energy system at a scale necessary to realize this vision.

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 the storage systems. The PAN precursor fibers used to produce high-strength carbon fiber accounts 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. Two projects have made significant advancements in this past year on demonstrating potential of lower cost precursors. One project is projected to have a 25% reduction in high-strength carbon fiber costs through use of a melt-spinning process to produce PAN fibers versus the conventional wet-spinning process. A second project has demonstrated that PAN fibers co-monomered with MA and produced in high volume on traditional high-volume textile-based manufacturing lines can be converted into high-strength carbon fiber. Cost modeling has estimated an approximate 17% reduction in the carbon fiber cost.

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. 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. In support of this cross-cutting initiative, the Program has initiated cross-office and cross-agency R&D collaborations for innovative applications of WBG products. Numerous applications of hydrogen and fuel cell technologies could benefit from the development of next-generation WBG power electronics, including fuel cell-powered MHE and FCEVs in the transportation section; and large scale grid integration of fuel cells and electrolyzers in the stationary power sector. The Program is working with leading innovators in the WBG electronics industry to explore opportunities for product development responsive to the market pull of the hydrogen and fuel cell technology applications.

Materials Genome Initiative for Clean Energy: 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 represents one of the leading pilot efforts at DOE in the cross-cutting Materials Genome Initiative (MGI) for Clean Energy. Consistent with the White House Office of Science and Technology Policy's Materials Genome Initiative strategic plan and with Advanced Manufacturing Partnership 2.0 recommendations, MGI for Clean Energy has become a core pillar of the Advanced Materials Manufacturing focus in the DOE Clean Energy Manufacturing Initiative. One important thrust of the FCTO pilot effort is the in situ development and optimization of alternative low-cost, high-performance non-PGM catalysts integrated into membrane electrode assemblies for PEM fuel cells and electrolyzers. Another activity is the combinatorial discovery and development of low-cost compound oxides (such as perovskites) for solar-thermochemical and photoelectrochemical hydrogen production technologies. The MGI-related efforts at FCTO, which have been kick-started by roundtable meetings of experts, RFIs and workshops, are expected to continue through FY 2015 and beyond.

## IN CLOSING …

The need for clean, sustainable energy, combined with the need to reduce emissions, has 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.

In 2013, worldwide fuel cell industry sales surpassed $1 billion for the first time, reaching $1.3 billion. In 2013 there was an approximately 30% increase in fuel cell systems shipments worldwide, continuing to achieve a consistent 30% annual market growth rate over the last few years. There were more than 35,000 fuel cell units shipped worldwide in 2013, making a total of 170 MW, nearly a 20% increase over 2012. This includes 80 MW shipped by the United States alone. Independent analyses have shown global markets could mature over the next 10–20 years, producing revenues of $14–$31 billion per year for stationary power, $11 billion per year for portable power, and $18–$97 billion per year for transportation. The global hydrogen market is also robust with over 55 Mtons produced in 2011 and over 70 Mtons projected in 2016, a >30% increase.

Another indicator of the robustness and innovative vitality of a thriving market is the number of patents granted, and the number of technologies commercialized. The number of patents in clean energy technologies continues to grow. The U.S. produced 44% of fuel cell patents followed by Japan with 33% from 2002 to 2012.[16] EERE-funded R&D has resulted in 499 patents, 45 commercial technologies, and 65 technologies that are projected to be commercialized within three to five years.[17] In addition, EERE's investment of $95 million in specific hydrogen and fuel cell projects led to more than $410 million in revenue and investments of approximately $70 million in specific projects led to a nearly $390 million in additional private investment.

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

At this year's Daytona 500, four fuel cell generators powered some of the broadcast cameras around the track, demonstrating how the technology could help NASCAR save money on fuel costs. As part of the FCTO-supported project, two 250-watt SOFCs were used to power some of the remote broadcast cameras and two 1-kilowatt SOFCs will be used to power lights in pit row.

[16] Clean Energy Patent Growth Index http://www.cepgi.com/2014/07/the-clean-energy-patent-growth-index-cepgi-published-quarterly-by-the-cleantech-groupat-heslin-rothenberg-farley.html

[17] http://energy.gov/eere/fuelcells/market-analysis-reports#mkt_pathways

Hexagon Lincoln, of Lincoln, Nebraska, more than doubled its workforce and added a fourth shift for 24-hour/7-days-a-week operation to accommodate growing demand for its carbon fiber composite tanks. With FCTO support, Hexagon developed a new trailer that uses high-strength composite vessels to carry more than 720 kg of hydrogen, thus transporting 2.5 times more compressed hydrogen gas than traditional steel tube trailers. With the increase in demand for their products for use on cars, trucks, and buses, and as large capacity tube trailers for delivering hydrogen and natural gas, the company has expanded annual sales from $33 million to $88 million and more than doubled their employees from 119 to 269 since 2010.

FCTO also completed a demonstration of landfill gas (LFG) as a source of renewable hydrogen production, using BMW's assembly plant in South Carolina as the host site. This project represents a first-of-its-kind LFG-to-hydrogen production project in the nation and is expected to serve as a model for future adoption of renewable biogas as a feedstock for hydrogen production. The hydrogen produced by this project could be used to power BMW's 300+ MHE fleet, the largest in the world to date.

While hydrogen infrastructure remains a key challenge to the widespread adoption of FCEVs, states like California continue to show their commitment. A series of major announcements in 2014 shows increased momentum in overcoming obstacles. For example, on April 30, the DOE announced the launch of a new project leveraging the capabilities of its national laboratories in direct support of H2USA. The project is led by NREL and SNL and will tackle the technical challenges related to hydrogen fueling infrastructure. The H2FIRST project is designed to reduce the cost and time of fueling station construction, increase station availability, and improve reliability by creating opportunities for industry partners to pool knowledge and resources to overcome hurdles.

FY 2014 brought with it a focus on technology transfer aligned with Assistant Secretary David Danielson's National Lab impact initiative. During the year, FCTO held two very successful financial forums that introduced DOE's early market projects to potential investors, business partners, and other stakeholders through presentations and a poster session in an effort to facilitate industry and investor awareness of these emerging and innovative technology areas.

EERE also recently announced the selection of small businesses for new SBIR awards that total nearly $6.3 million. Among the selections is a first-of-its-kind award under a new EERE SBIR technology-to-market topic that moves existing inventions developed at DOE's national laboratories to the marketplace and accelerates the pace of commercialization. Newton, Massachusetts-based Giner Inc. will use technology patented by LANL along with the company's well-established dimensionally-stabilized membrane technology to develop advanced, high-performance, and durable PEM electrode assemblies for fuel cell and electrolysis applications.

EERE cross-cutting activities proved successful as well. DOE researchers won 31 of the 100 awards given out this year by *R&D Magazine* for the most outstanding technology developments with promising commercial potential. PNNL was recognized for the Solar Thermochemical Advanced Reactor System, or STARS, that converts natural gas and sunlight into a more energy-rich fuel (syngas), which power plants can burn to make electricity. Initial funding was provided by FCTO to develop compact micro-meso-channel reactors and heat exchangers for the production of hydrogen from hydrocarbon fuels for use in automotive fuel cells. EERE's Solar Energy Technologies Office then supported an initial on-sun demonstration of the STARS concept—an evolution of the micro- and meso-channel concept—plus improvements that have achieved nearly 70% solar-to-chemical energy conversion. The group is now advancing the technology toward a commercial power generation application.

At the Washington Auto Show in January, Secretary Moniz highlighted the Energy Department's role in developing the next generation of fuel-efficient and electric vehicles and visited some of the latest vehicles that have benefitted from Energy Department R&D. Featured FCEVs included Hyundai's Tucson Fuel Cell that became available in Spring 2014, and a Toyota fuel cell vehicle that will be available in 2015.

In addition to the technical progress, education and outreach are critical and FCTO efforts have reached more than 30,000 code officials and first responders, 12,000 teachers, and more than 10,000 stakeholders per month through its monthly newsletter.[18] DOE also actively participated in the Senate and House Hydrogen and Fuel Cell Caucus events in FY 2014, including a ride and drive at which Deputy Secretary Poneman drove an FCEV. This event was followed by an EERE blog posting.[19]

This is a critical time for fuel cells and hydrogen. The DOE Hydrogen and Fuel Cell Program will continue to work in close collaboration with key stakeholders, and will continue its strong commitment to effective stewardship of

[18] http://energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

[19] http://energy.gov/eere/articles/hyundai-tucson-fuel-cell-electric-vehicle-visits-department-energy

tax payer 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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