
I.0 Introduction

The 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 Department of Energy (DOE or the Department), incorporating activities in the offices of Energy Efficiency and Renewable Energy (EERE), Science (SC), Nuclear Energy, and Fossil Energy (FE), and it is aligned with DOE's strategic vision and goals. The Program's efforts will help boost the competitiveness of U.S. manufacturing, reduce our dependence on foreign oil, and create jobs for American workers.

With emphasis on applications that will most effectively strengthen our nation's energy security and improve our stewardship of the environment, 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) 2012, Congress appropriated approximately \$136 million for the DOE Hydrogen and Fuel Cells Program.¹ The Program is organized into distinct sub-programs focused on specific 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—EERE's *Fuel Cell Technologies Program 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. Highlights of the Program's accomplishments are summarized below. More detail can be found in the sub-program chapters of this report.

PROGRESS AND ACCOMPLISHMENTS, BY SUB-PROGRAM

Fuel Cells

The Fuel Cells sub-program continued to reduce the projected high-volume manufacturing cost of automotive fuel cells, which in 2012 was estimated to be \$47/kW. This represents a reduction of 36% since 2008 and more than 80% since 2002. The 36% reduction since 2008 stems in part from a reduction in platinum group metal (PGM) loading and an increase in cell power density, allowing the design of smaller and less expensive stacks. Newly developed de-alloyed PtNi and PtCo catalysts exceeded the 2017 mass activity target of 0.44 A/mg_{PGM} with 0.46 A/mg_{PGM} for PtCo and 0.52 A/mg_{PGM} for PtNi. The PtCo catalyst also meets durability targets and the PtNi catalyst has demonstrated high-performance operation in MEAs.

Modified catalysts with highly active and durable oxygen evolution met all performance milestones in 2012. By enhancing oxygen evolution capability, these catalysts suppress excursions to high voltage, and thus mitigate corrosion that would occur during startup, shutdown, and fuel starvation conditions. Additionally, a humidifier containing a novel composite membrane and including an integrated module design is projected to meet the cost target of \$100 (for a humidifier in an automotive fuel cell system) when manufactured at high volumes.

¹This includes \$101 million for the Fuel Cell Technologies Program within the Office of Energy Efficiency and Renewable Energy and \$35 million for hydrogen and fuel cell-related research in the Basic Energy Sciences program within the Office of Science.

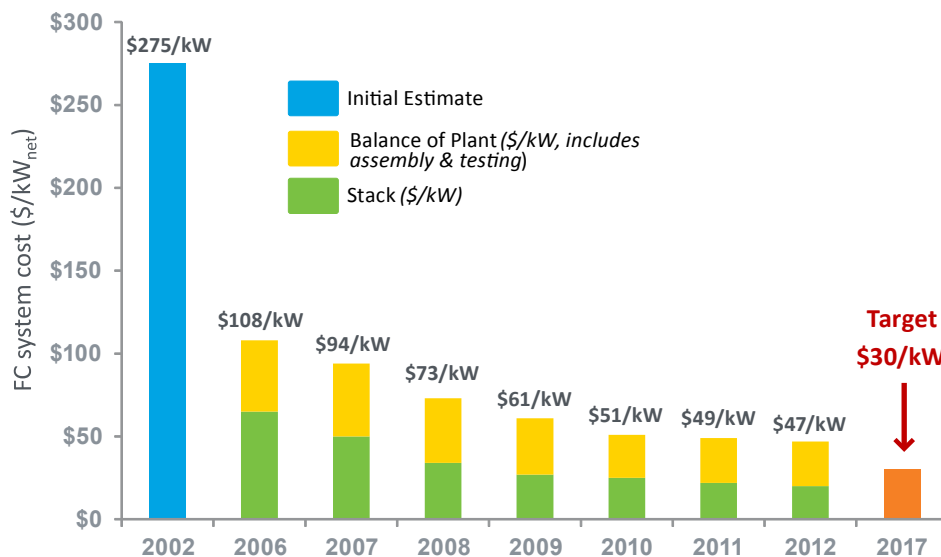


FIGURE 1. Current modeled cost of an 80-kW automotive fuel cell system, based on projections to high-volume manufacturing (500,000 units/year).²

Hydrogen Production

In FY 2012, 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, including stationary power, backup power, specialty vehicles, transportation, and portable power. Progress continued in several key areas, including biomass gasification, reforming of bio-derived liquids, electrolysis, solar-thermochemical hydrogen production, photoelectrochemical (PEC) hydrogen production, and biological hydrogen production. Key examples of progress include:

- Developed an electrolyzer system that incorporates low-cost stack components into a high-efficiency hydrogen production system; this system completed over 100 hours of field testing at the National Renewable Energy Laboratory (NREL) test facility for renewable integration, verifying improvements brought about through sub-program investments. (Giner Inc. and NREL)
- Demonstrated extended durability in high-efficiency III-V crystalline systems for PEC hydrogen production from a baseline of about 20 hours up to more than 100 hours, achieved through innovative theory-inspired surface ion nitride treatments of the crystalline surfaces for passivation against corrosion; the enhanced stability was demonstrated under operating conditions consistent with solar-to-hydrogen conversion efficiencies exceeding 10%. (NREL)
- Achieved improved hydrogen fermentation rates by optimizing reactor design and operating conditions, resulting in a two-fold increase in hydrogen production through higher cellulose feedstock loading. This will serve as the foundation for future efforts to scale-up hydrogen fermentation systems. (NREL)

²DOE Hydrogen and Fuel Cells Program Record #12020, http://hydrogen.energy.gov/pdfs/12020_fuel_cell_system_cost_2012.pdf.

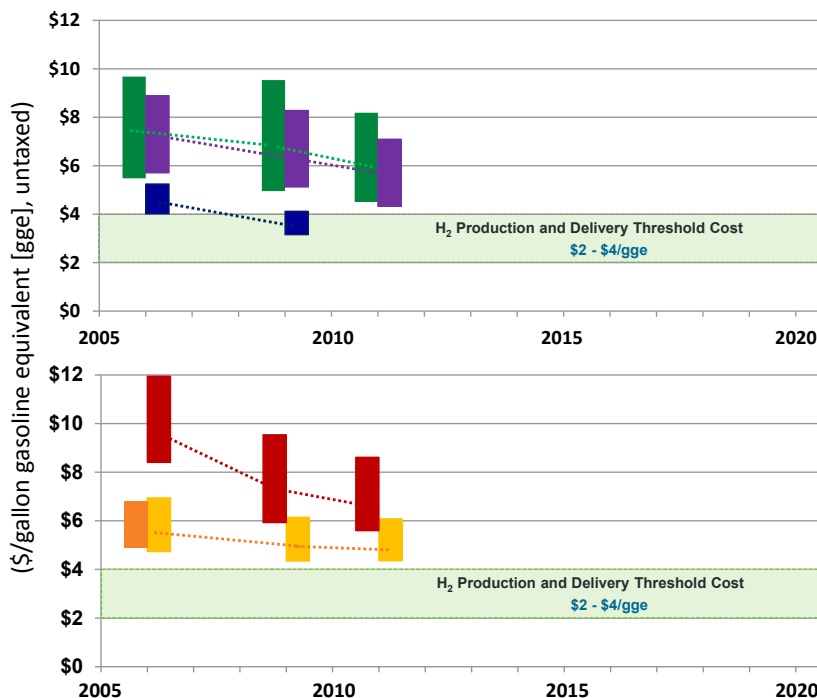
Projected High-Volume Cost of Hydrogen Production¹ (Delivered²)—Status

Distributed Production (near term)

- Electrolysis
Feedstock variability: \$0.03 - \$0.08 per kWh
- Bio-Derived Liquids
Feedstock variability: \$1.00 - \$3.00 per gallon ethanol
- Natural Gas Reforming³
Feedstock variability: \$4.00 - \$10.00 per MMBtu

Central Production (longer term)

- Electrolysis
Feedstock variability: \$0.03 - \$0.08 per kWh
- Biomass Gasification
Feedstock variability: \$40- \$120 per dry short ton
- Nuclear⁴
Feedstock variability: \$0.03 - \$0.08 per kWh



Notes: [1] Cost ranges for each pathway are shown in 2007\$ based on high-volume projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates. [2] Costs include total cost of production and delivery (dispensed, untaxed). Forecourt compression, storage and dispensing added an additional \$1.82 for distributed technologies, \$2.61 was added as the price of delivery for central-production technologies. All delivery costs were based on the Hydrogen Pathways Technical Report (NREL, 2009). [3] Analysis of projected costs for natural gas reforming indicated that the threshold cost can be achieved with current technologies or with incremental improvements made by industry. FCT Program funding of natural gas reforming projects was completed in 2008. [4] High-temp electrolysis activities are ongoing under the Next Generation Nuclear Plant Program.

FIGURE 2. Hydrogen Production Cost Status. Significant progress has already been made in several hydrogen production pathways. The Hydrogen Threshold Cost represents the cost at which hydrogen fuel cell electric vehicles are projected to become competitive on a cost-per-mile basis with competing vehicles (gasoline hybrid-electric vehicles) in 2020.

Hydrogen Delivery

In FY 2012, Hydrogen Delivery sub-program activities continued to focus on reducing the cost and increasing the energy efficiency of hydrogen delivery, to enable the widespread use of hydrogen as an energy carrier. Key examples of progress include:

- Design and construction of a custom-built trailer (shown in Figure 3) capable of holding four 40-foot pressure vessels and an additional 30-foot pressure vessel. This new design has the potential to increase overall capacity by roughly 18%, from about 615 kg in the current U.S. Department of Transportation (DOT)–approved design, to more than 725 kg. (Lincoln Composites)
- Analysis of the cost and power requirements of refueling station compression and pumping technologies, and of the various configurations of high-pressure tube-trailers within DOT-specified weight and size constraints. Two compression options to reduce station capital cost by at least 15% were identified: (1) a high-pressure (900-bar) liquid pump combined with an evaporator to gasify the hydrogen before dispensing (the combined pump/vaporizer cost is less than half the cost of the corresponding gas compressor); and (2) a high-pressure tube trailer that can reduce compression needs at the station, especially in early markets where the utilization of the station compressor would be low. This has the

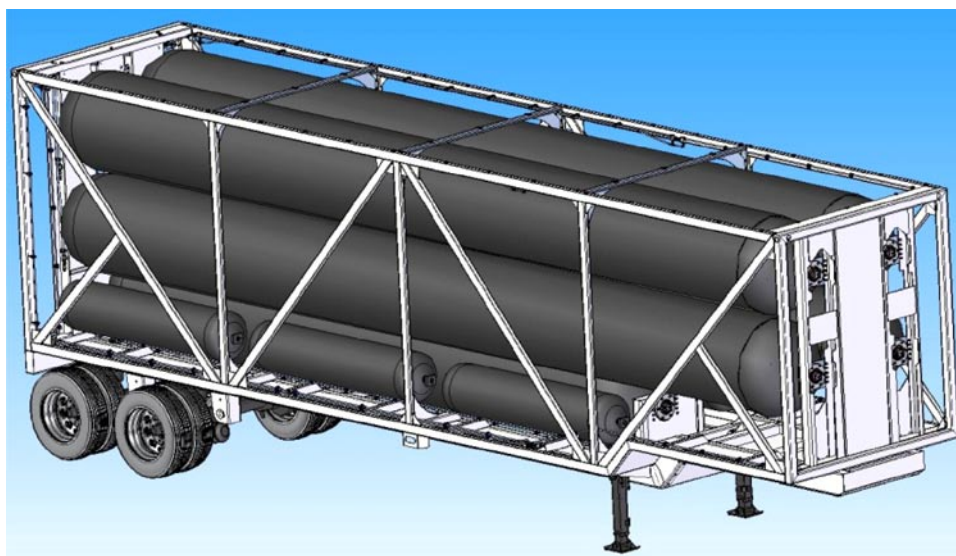


FIGURE 3. Carbon fiber composite tube trailer pressure vessel and International Organization for Standardization container (source: Lincoln Composites).

potential to reduce the impact of station capital cost on overall hydrogen cost by up to 20%, assuming 50% utilization. (Argonne National Laboratory [ANL])

Hydrogen Storage

In FY 2012, the Hydrogen Storage sub-program continued to pursue hydrogen storage materials discovery, including metal hydrides, chemical hydrogen storage, and sorbents, in addition to advanced tank development and total systems engineering to meet DOE onboard hydrogen-storage targets. The sub-program is also initiating efforts for early market fuel cell applications and has developed targets for material handling and portable power applications, which can be found in the *Fuel Cell Technologies Program Multi-Year Research, Development, and Demonstration Plan (MYRD&D Plan)*.

Accomplishments in novel hydrogen storage materials development included:

- Validating hydrogen excess uptake in a metal organic framework material synthesized by Northwestern University (NU-100)—the validated excess capacity of ~8 wt% at 50 bar and 77 K for the NU-100 metal organic framework is among the highest confirmed to date. (NREL)
- Achieving a 30% improvement in hydrogen wt% uptake when normalized to surface area through boron incorporation into porous carbon. (University of Missouri)

The Hydrogen Storage Engineering Center of Excellence partners continued to make progress toward successful completion of Phase II, in preparation for Phase III, including:

- Terminating work on metal hydride systems due to low probability of these materials meeting the required properties in the 2017 timeframe and identification of required onboard reversible metal hydride material properties, through use of the integrated Hydrogen Storage SIMulator vehicle model.
- Conducting failure modes and effects analysis for both adsorbent and chemical hydrogen material systems, identifying potential failure modes requiring further consideration.
- Developing an advanced composite pressure vessel for cryo-sorbents with 11% lower weight, 4% greater internal volume, and 10% lower cost (compared with the baseline established during phase I of the Hydrogen Storage Center of Excellence in 2011).

Accomplishments in developing lower-cost compressed hydrogen tanks include:

- Demonstrating carbonized fiber from low-cost textile-grade polyacrylonitrile blended with methyl acrylate comonomer, which meets the 2012 milestone of at least 300 KSI strength and 30 MSI modulus. (Oak Ridge National Laboratory)
- Developing a pressure vessel design to achieve a 20% reduction in carbon fiber requirement. (ANL)

The sub-program also launched the Hydrogen Storage Materials Database (<http://hydrogenmaterialssearch.govtools.us/>), a comprehensive database to collect and disseminate materials data and accelerate advanced hydrogen storage materials R&D. To date, researchers from more than 60 countries have accessed the database, and the tool was presented as part of the President's Materials Genome Initiative.

Manufacturing R&D

In FY 2012, Manufacturing R&D projects continued in the following areas: novel electrode deposition processes for membrane electrode assembly (MEA) fabrication, reduction in the number of assembly steps to produce low-cost MEAs, flow field plate manufacturing variability and its impact on performance, and fabrication technologies for high-pressure composite hydrogen-storage tanks. Key accomplishments include the following:

- In the area of MEA manufacturing, scaling up the microporous layer ink for full-length and full-width roll coating was found to cause severe bubble formation, leading to variable viscosities in the ink. By modifying additives and processes, the problem was solved and the cost of the microporous layer was reduced by 37% compared with the benchmark. This also resulted in a 3x increase in capacity. (BASF)
- Imaged polymer electrolyte membrane thickness and discrete defects (bubbles, scratches, divots) using optical diagnostics on a full scale weblane—detecting defects on the order of ~10–100 μ in membranes at standard web speeds of 30 feet per minute. (NREL)

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 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 architectures; novel fuel cell membranes; innovative synthetic techniques; theory, modeling, and simulation of catalytic pathways, membranes, and fuel cells; and novel characterization techniques.
- Hydrogen Production: Longer-term 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.

Technology Validation

The Technology Validation sub-program demonstrates, tests, and validates hydrogen and fuel cell technologies and uses the results to provide feedback to the Program's R&D activities. The sub-program has been focused on conducting demonstrations that emphasize co-development and integration of hydrogen infrastructure with fuel cell electric vehicles (FCEVs) to permit industry to assess progress toward technology readiness.

In 2012, NREL completed the data collection and analysis portion of the National Fuel Cell Electric Vehicle Learning Demonstration—a government-industry cost-shared project initiated in 2004 with four automobile and energy company teams. A comprehensive final report was published in July 2012. In the course of the project, data were collected on a total of 183 FCEVs and 25 hydrogen fueling stations. FCEVs in the project traveled 3.6 million miles, and 151,000 kg of hydrogen was either produced or dispensed (with some of this hydrogen being used in vehicles outside the Learning Demonstration). Over 500,000 individual vehicle trips were analyzed, and 99 different CDPs were produced to validate the current status of FCEV technology (see Figure 4 for the status of specific performance metrics). FCEVs met or exceeded the 250-mile driving-range goal; fuel cell system efficiencies were demonstrated in the range of 53–59% (at 25% net power), which is close to the DOE target of 60%; and results indicated fuel cell durability in excess of 2,500 hours (>75,000 miles). The final report represents the last of a number of significant and groundbreaking accomplishments by NREL during the project, including the establishment of the HSDC, the methodology of securely aggregating business sensitive performance data into useful public data, and the development of many unique and innovative data products for FCEVs and hydrogen fueling stations.

Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target	2010 – 2011 Results
Fuel Cell Stack Durability			2,000 hours	
Maximum Team Projected Hours to 10% Voltage Degradation	1,807 hours	2,521 hours		--
Average Fuel Cell Durability Projection	821 hours	1,062 hours		1,748 hours
Maximum Hours of Operation by a Single FC Stack to Date	2,375 hours	1,261 hours		1,582 hours
Driving Range			250 miles	
Adjusted Dynamometer (Window Sticker) Range	103-190 miles	196-254 miles		--
Median On-Road Distance Between Fuelings	56 miles	81 miles		98 miles
Fuel Economy (Window Sticker)	42 – 57 mi/kg	43 – 58 mi/kg	no target	--
Fuel Cell Efficiency at ¼ Power	51 – 58%	53 – 59%	60%	--
Fuel Cell Efficiency at Full Power	30 – 54%	42 – 53%	50%	--

FIGURE 4. Summary of key performance metrics for the Learning Demonstration. *Outside of this project, DOE independent panels estimated that producing hydrogen from distributed reforming of natural gas would cost approximately \$2.75–\$3.50/kg H₂ (2006 study) and producing hydrogen from distributed electrolysis would cost approximately \$4.90–\$5.70/kg H₂ (2009 study)—both analyses assume a build-out rate of 500 stations/year, with stations producing 1,500 kg of H₂/day.³*

³ *Distributed Hydrogen Production from Natural Gas: Independent Review*, NREL, October 2006, <http://hydrogen.energy.gov/pdfs/40382.pdf>; and *Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis: Independent Review*, NREL, 2009, <http://hydrogen.energy.gov/pdfs/46676.pdf>.

In addition to its light-duty vehicle demonstrations, since 2010, the sub-program has been collecting and analyzing data from 17 second-generation fuel cell buses. As of August 2012, one of these buses had exceeded 12,000 hours of operation, and efficiencies up to twice as high as those of diesel buses have been demonstrated.

The Fountain Valley Renewable Energy Tri-Generation Station—the world’s first facility capable of co-producing hydrogen, heat, and power—has operated for more than 1,000 hours in power and power-and-hydrogen modes, and over 5 million standard cubic feet of digester gas has been processed to produce more than 5,000 kg of hydrogen and over 1 million kWh of electricity. The system has achieved an overall efficiency of 54% when co-producing hydrogen and power.

NREL is demonstrating commercially available low-temperature electrolyzer technologies (proton exchange membrane and alkaline electrolyzers) to evaluate their response to commands to increase and decrease stack power (which enable them to shorten frequency disturbances on an alternating current microgrid). The quick response and precise control offered by variable electrolyzer stack operation have been shown to be superior to the control capabilities of many conventional generators. NREL is demonstrating that electrolyzers can perform repeated high cyclic power variations (20–100% of rated stack power) to model performance with wind and solar power. To date, NREL has completed 7,000 hours of operation to help quantify performance differences between constant and variable stack power operation.

Safety, Codes and Standards

In FY 2012, the Safety, Codes and Standards sub-program continued to support R&D to provide the technical basis for codes and standards development, with projects in a wide range of areas, including fuel specification, separation distances, materials and components compatibility, and hydrogen sensor technologies. The sub-program also continued to promote collaboration among diverse stakeholders in order to harmonize regulations, codes, and standards, and it continued to create and enhance safety knowledge tools for emergency responders and authorities having jurisdiction. Key FY 2012 accomplishments include:

- Publishing the compressed hydrogen materials compatibility (CHMC) testing and data application standard, Canadian Standards Association CHMC 1 Part 1.
- Developing accelerated test methods for measurement of hydrogen-assisted fatigue crack growth; this accelerated test greatly reduces the cost barriers that prevent qualification of new materials for hydrogen service.
- Conducted two fire training classes at the Los Angeles City and County Fire Department, with approximately 300 first responders in attendance; to date, more than 23,000 code officials and first responders have been reached through the sub-program’s efforts.

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 FY 2010 appropriations supported the sub-program’s activities during FY 2012. Key accomplishments in FY 2012 included:

- Initiating a northeast cluster group for collaboration between states and developing roadmaps for seven states in the cluster.
- Organizing an event to “match” suppliers with manufacturers.
- Launching a monthly newsletter that reaches over 7,500 subscribers.
- Continuing to train middle school and high school teachers through “H2 Educate!”, reaching a cumulative total of 9,700 teachers, in 35 states; 90% of participants felt 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 2012 the Market Transformation sub-program continued to facilitate the growth of early markets for fuel cells used in portable, stationary, and specialty-vehicle 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. FY 2012 activities primarily involved continuation of projects initiated with FY 2010 appropriations. The Market Transformation sub-program is currently focused on building upon past successes in material handling equipment (e.g., lift trucks) and emergency backup power applications, which received support from Recovery Act funding. The sub-program is seeking to expand on these successes by exploring other potential and emerging applications for market viability. These Recovery Act projects are highly leveraged, with more than half of project funding provided by partner resources, and they are providing valuable data on the status of the technologies in real-world operation that will be used to validate the benefits and potential needs for further R&D (for more information, see the "American Recovery and Reinvestment Act Projects" section, below). Specific accomplishments by the Market Transformation sub-program in FY 2012 include:

- Demonstrating and validating a fuel cell mobile lighting system that combines high-pressure (5,000-psi) hydrogen storage, efficient lighting, and a 5-kW PEM fuel cell; the mobile lighting system was field tested at industry and government installations and demonstrated at various entertainment industry award events, including the Oscars, the Golden Globe Awards, and the Screen Actors Guild Awards.
- Developing and publishing guidelines for federal facilities managers to procure energy from stationary fuel cell power systems, including the use of innovative financing mechanisms that require little or no capital investment.
- Conducting modeling and simulation for evaluating onboard fuel cell rechargers for battery-electric road vehicles.

Systems Analysis and Integration

The Systems Analysis sub-program supports decision-making by providing a greater understanding of technology gaps, options and risks, and examining the interaction of individual technologies and components and their contributions to the performance of larger systems—e.g., the entire hydrogen fuel system, from production to utilization. The sub-program also analyzes cross-cutting issues, such as the integration of hydrogen and fuel cell systems with the electrical sector and the use of renewable fuels. Particular emphasis is given to assessing stationary fuel cell applications and the implications of various approaches to establishing hydrogen infrastructure. The Systems Analysis sub-program made several significant contributions in FY 2012, including:

- Analyzing infrastructure costs for hydrogen fueling and electric vehicle charging, which showed that the capital intensities of the two infrastructure systems are roughly comparable, on a cents-per-mile basis. (NREL)
- Evaluating potential cost reductions for early market hydrogen fueling stations, utilizing diverse stakeholder input to NREL's cost calculator; results will be published at the end of 2012. (NREL)
- Developing and releasing the JOBS FC model, which enables analysis of the impacts of fuel cell market deployments on employment and revenue generation; the model was used to estimate the impact of American Recovery and Reinvestment Act (ARRA) deployments of fuel cells (this analysis was supplemented with calculations that capture economic impacts from expenditures unique to the ARRA program that are not modeled in JOBS FC)—preliminary results indicate that nearly 700 net jobs were created in 2011 as a result of ARRA funding for fuel cell deployments (Figure 5). (ANL and RCF Economic and Financial Consulting)

Employment Impacts of ARRA Fuel Cell Deployments Including Backup Power Fuel Cells and Fuel Cell–Powered Forklifts

- PRELIMINARY ANALYSIS -

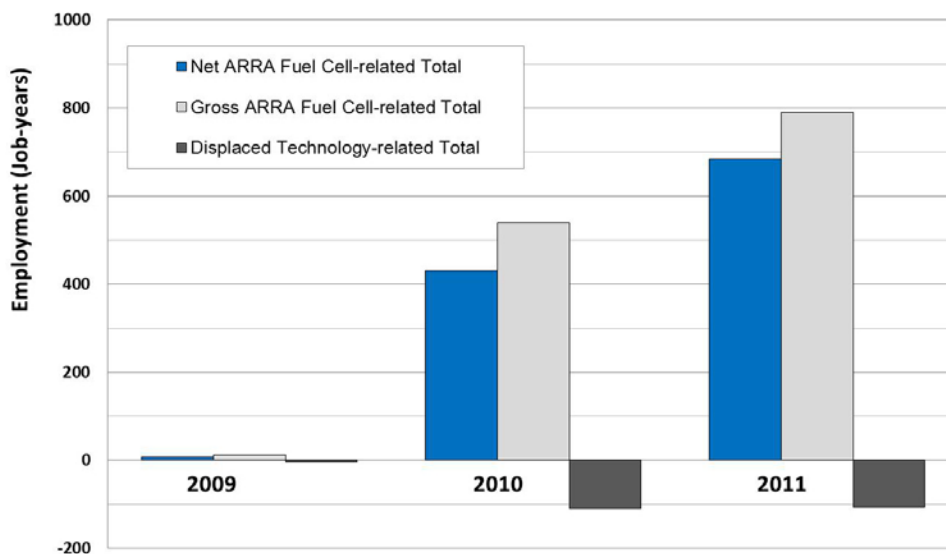


FIGURE 5. Preliminary analysis of employment impacts from ARRA fuel cell deployments, using the JOBS FC model (supplemented with calculations that capture economic impacts from expenditures unique to the ARRA program that are not modeled in JOBS FC) (source: ANL).

- Modifying the GREET model to enable greenhouse gas emissions to be evaluated on a well-to-wheels basis for hydrogen produced from natural gas extracted by hydraulic fracturing. (ANL)
- Conducting a natural gas workshop, involving multiple stakeholders, to gain valuable insight for potential synergies with hydrogen (a summary report and proceedings are available online at www.hydrogenandfuelcells.energy.gov/wkshp_nat_gas_h2_infrastructure.html)

American Recovery and Reinvestment Act Projects

The American Recovery and Reinvestment Act (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. With approximately \$41.9 million from the Recovery Act and \$54 million in cost-share funding from industry participants—for a total of nearly \$96 million—these efforts have deployed more than 1,100 fuel cells, primarily in backup power and forklift applications, exceeding the original ARRA target of 1,000 units. As of the end of October 2012, over 90% of Recovery Act funds had been spent, and more than 1 million hours of operation had been achieved.

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 3,600 fuel cell forklifts and more than 1,400 fuel cell backup power systems, with no additional DOE funding. For example, as a result of deployments of fuel cell lift trucks at the Sysco food distribution center in West Houston, Texas, Sysco is planning to deploy 900 or more fuel cells at seven sites over the next 24 months. Success in these early markets is helping to pave the way for longer term success of fuel cells in larger markets, such as transportation. Additional information about the Program's Recovery Act projects can be found in a newly published fact sheet (www.hydrogenandfuelcells.energy.gov/pdfs/fct_recovery_act_highlights.pdf).

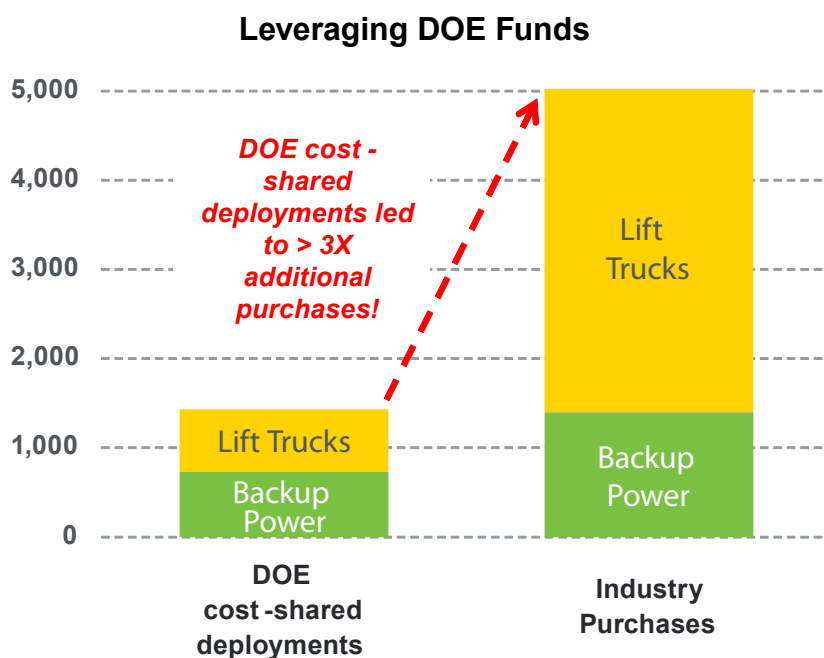


FIGURE 6. Early market deployments of approximately 1,400 fuel cells have led to more than 5,000 additional purchases by major companies (including Coca-Cola, Sprint, Sysco, FedEx, and others) *with no additional DOE funding*.

OTHER PROGRAM ACTIVITIES AND HIGHLIGHTS FROM FY 2012

Tracking Commercialization

One indicator of the robustness and innovative vitality of an RD&D program is the number of patents applied for and granted, and the number of technologies commercialized. The Program continued to assess the commercial benefits of Program funding by tracking the commercial products and technologies developed with the support of the EERE Fuel Cell Technologies Program (FCT Program). R&D efforts funded by the FCT Program have resulted in 363 patents and 36 hydrogen and fuel cell technologies entering the market.⁴ (See Figures 7 and 8.)

Awards & Distinctions

- Dr. Thomas Jaramillo from Stanford University was honored with a **Presidential Early Career Award for Scientists and Engineers (PECASE)** for his innovations in solar hydrogen production and for excellence in mentoring at the university level. Dr. Jaramillo was one of only 96 researchers across the nation honored with this award, which is the highest honor bestowed by the U.S. Government on science and engineering professionals in the early stages of their careers. To date, this was the first and only PECASE award presented to a researcher funded by DOE's Office of Energy Efficiency and Renewable Energy.
- Researchers at Brookhaven National Laboratory won an **R&D 100 Award** for work funded by the FCT Program on platinum monolayer electrocatalysts for fuel cell cathodes. The award was one of only 100 given out this year by *R&D Magazine* for the most outstanding technology developments with promising commercial potential.

⁴ *Pathways to Commercial Success: Technologies and Products Supported by The Fuel Cell Technologies Program*, Pacific Northwest National Laboratory, September 2012, www.hydrogenandfuelcells.energy.gov/pdfs/pathways_2012.pdf.

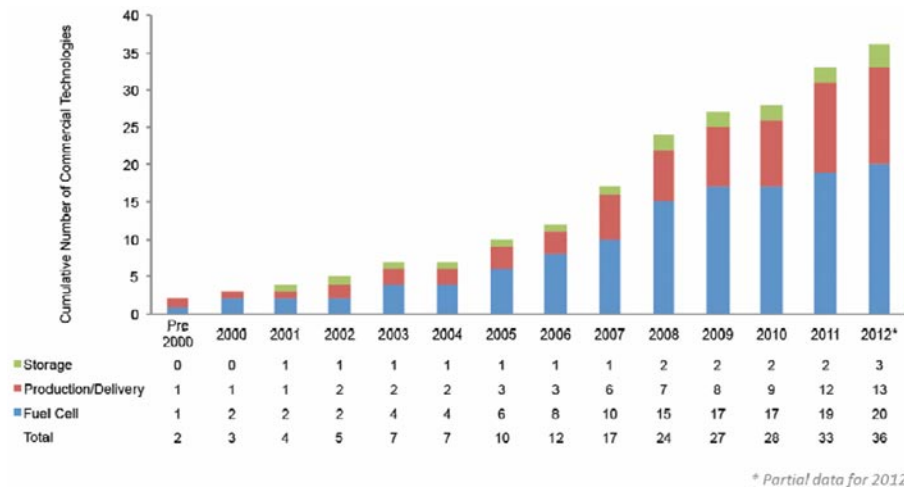


FIGURE 7. Cumulative number of commercial products on the market as a result of funding by the DOE Fuel Cell Technologies Program (source: Pacific Northwest National Laboratory).

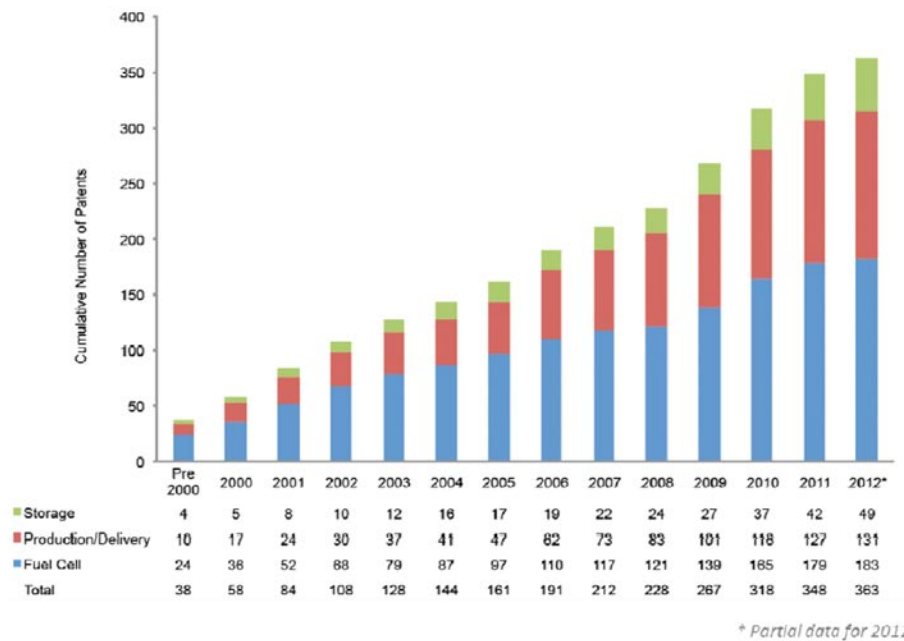


FIGURE 8. Cumulative number of patents awarded as a result of funding by the DOE Fuel Cell Technologies Program (source: Pacific Northwest National Laboratory).

- Dr. Vijay Ramani, a principal investigator for the FCT Program with the Illinois Institute of Technology, and Dr. Adam Weber, the program manager for Lawrence Berkeley National Laboratory’s hydrogen and fuel cell activities, were among the recipients of the **2012 Supramaniam Srinivasan Young Investigator Award** from the Electrochemical Society. Dr. Ramani and his team are currently researching the synthesis of multi-functional electrolyte and electrode materials for polymer based electrochemical systems; Dr. Weber has conducted research for the FCT Program in the areas of fuel cells, electrochemistry, energy storage, and the manufacturing of hydrogen and fuel cell technologies.
- Dr. Fernando Garzon, a long time principal investigator supported by the FCT Program (most recently working on ultra-low platinum group metal catalysts), was elected **President of the Electrochemical Society (ECS)**.

- Lawrence Livermore National Laboratory received a **Pollution Prevention Award** from the National Nuclear Security Administration for their demonstration of hydrogen-powered vehicles, which was supported by the FCT Program.
- Sandia National Laboratories received the Federal Laboratory Consortium's **Excellence in Technical Transfer Award** for their fuel cell mobile lighting project, which demonstrated the ability to meet the needs for portable, indoor lighting that can be operated safely and continuously without ventilation.
- Dr. Radoslav Adzic, an inventor of an innovative nanocatalyst for fuel cell electric vehicles, was named the **2012 Inventor of the Year** by the New York Intellectual Property Law Association for work he and his team did that will effectively reduce the cost required to produce hydrogen fuel cells.

Key Reports/Publications

Every year, the Hydrogen and Fuel Cells 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*, the commercialization report (*Pathways to Commercial Success*), and the *State of the States* report—while others are published when studies are complete, projects have ended, or key milestones have been reached.

- The *2011 Fuel Cell Technologies Market Report* indicates that commercial markets for fuel cell technologies expanded significantly over the previous year and forecasts continued growth through 2012, especially in the material-handling industry, www.hydrogenandfuelcells.energy.gov/pdfs/2011_market_report.pdf. (Breakthrough Technologies Institute, Inc.)
- *Pathways to Commercial Success*, the Program's annual commercialization report, indicates that FCT Program funding has resulted in 363 patents and 35 hydrogen and fuel cell technologies entering the market, www.hydrogenandfuelcells.energy.gov/pdfs/pathways_2012.pdf. (Pacific Northwest National Laboratory)
- *State of the States: Fuel Cells in America 2012*, the third annual report on state activities, details fuel cell and hydrogen activities and policies in the 50 states and the District of Columbia, www.hydrogenandfuelcells.energy.gov/pdfs/state_of_the_states_2012.pdf. (Fuel Cells 2000)
- *Business Case for Fuel Cells 2011* 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, www.hydrogenandfuelcells.energy.gov/pdfs/business_case_fuel_cells_2011.pdf. (Fuel Cells 2000)
- The *National Fuel Cell Electric Vehicle Learning Demonstration Final Report* documents the results of a technology validation project that collected data from more than 180 fuel cell electric vehicle, which made more than 500,000 trips, traveled 3.6 million miles, and completed more than 33,000 fill-ups at hydrogen fueling stations across the country, www.nrel.gov/hydrogen/pdfs/54860.pdf. (NREL)
- *Fuel Quality Issues in Stationary Fuel Cell Systems* assesses impurities encountered in stationary fuel cell systems, the effects of those impurities on fuel cells, and the effectiveness and cost of impurity removal strategies, www.hydrogenandfuelcells.energy.gov/pdfs/fuel_quality_stationary_fuel_cells.pdf. (ANL)
- *Procuring Fuel Cells for Stationary Power: A Guide for Federal Facility Decision Makers* offers step-by-step guidance on implementing a fuel cell stationary power project, www.hydrogenandfuelcells.energy.gov/pdfs/fed_facility_guide_fc_chp.pdf. (Oak Ridge National Laboratory)
- *Executive Summaries for the Hydrogen Storage Materials Centers of Excellence*, summarizes activities performed, accomplishments, and recommendations from each of the centers, which operated from 2005–2010 to develop advanced hydrogen storage materials in the areas of chemical hydrogen storage

materials, hydrogen sorbents, and reversible metal hydrides, www.hydrogenandfuelcells.energy.gov/pdfs/executive_summaries_h2_storage_coes.pdf. (Specific final reports for each Center of Excellence are also available, at www.hydrogenandfuelcells.energy.gov/hydrogen_publications.html#h2_storage.)

- ***Recommended Best Practices for the Characterization of Storage Properties of Hydrogen Storage Materials*** provides an introduction to and an overview of the recommended best practices for making measurements of the hydrogen storage properties of materials, www.hydrogenandfuelcells.energy.gov/pdfs/best_practices_hydrogen_storage.pdf. (H2 Technology Consulting)
- ***2011 Hydrogen and Fuel Cell Manufacturing R&D Workshop Report*** summarizes the results of a workshop that brought together key industry, university, and government representatives to discuss the critical issues facing aspects of manufacturing of hydrogen and fuel cell products, www.hydrogenandfuelcells.energy.gov/pdfs/mfg2011_wkshp_report.pdf. (NREL)
- ***Flow Cells for Energy Storage: Workshop Summary Report*** documents the results of a workshop held to understand the applied R&D needs and the grand challenges for the use of flow cells as energy storage devices, www.hydrogenandfuelcells.energy.gov/pdfs/flow_cells_2012_workshop_report.pdf. (Lawrence Berkeley National Laboratory)
- ***Summary Report: Natural Gas and Hydrogen Infrastructure Opportunities Workshop*** documents the results of a workshop that convened industry and other stakeholders to discuss current status and state-of-the-art technologies for natural gas and hydrogen infrastructure; identify key challenges preventing or delaying widespread deployment of natural gas and hydrogen infrastructure; identify synergies between natural gas and hydrogen fuels; and determine roles and opportunities for both government and industry stakeholders, www.transportation.anl.gov/pdfs/AF/812.PDF. (ANL)
- Proceedings from the ***Biogas and Fuel Cells Workshop*** include the agenda and all presentations from workshop, which focused on discussions of biogas and waste-to-energy technologies for fuel cell applications. The overall objective was to identify opportunities for coupling renewable biomethane with highly efficient fuel cells to produce electricity; heat; combined heat and power; or combined heat, hydrogen and power for stationary or motive applications, www.hydrogenandfuelcells.energy.gov/wkshp_biogas_fuel_cells.html.

New Financial Assistance Awards and Funding Opportunities

- **\$5 Million awarded to two projects to reduce the cost of advanced fuel cells.** These three-year projects will lower the cost of advanced fuel cell systems by developing and engineering cost-effective, durable, and highly efficient fuel cell components.
- **\$2.4 million (not yet awarded) for five projects to collect and analyze performance data for hydrogen fueling stations and advanced refueling components.** Projects located in California, Illinois, and Connecticut will track the performance and technical progress of innovative refueling systems at planned or existing hydrogen fueling stations to find ways to lower costs and improve operation.
- **\$6 Million funding opportunity announced for FCEV data collection.** This funding opportunity announcement (FOA) closed in June, and award negotiations are underway. The projects selected for funding will collect data from next-generation FCEVs as they are operated in real-world conditions, to identify ways to lower costs and improve fuel cell durability and overall vehicle performance.
- **\$2.5 million funding opportunity announced to deploy fuel cell-powered baggage vehicles at U.S. airports.** This FOA closed in July, and award negotiations are underway. These efforts will focus on demonstrating first-generation fuel cell-powered baggage towing tractors operating under real-world conditions, and collect and analyze data to test their performance and cost-effectiveness.
- **FOA for Small-Business Innovation Research (SBIR) includes opportunities for research in fuel cell catalysts.** Topic 10 C of the SBIR FOA is “Innovative Approaches Toward Discovery and/or Development

of Ultra-Low- and Non-PGM Catalysts for PEMFCs and Non-PGM Catalysts for AFCs.” The deadline for receipt of Phase I “letters of intent” was in September 2012.

- **Request for proposals (RFP) issued for deployment of fuel cell-based auxiliary power units for refrigerated trucks.** DOE’s Pacific Northwest National Laboratory issued an RFP for the analysis and demonstration of fuel cell-based auxiliary power units, or APUs, for refrigerated trucks. The project aims to accelerate market deployment of fuel cell-based APUs. The RFP closed in November 2012. This work will be supported by prior-year FCT Program funds made available through down-selections or no-go decisions.

Requests for Information (RFI)

- **Hydrogen Storage for Material Handling and Portable Power Applications** gathered feedback from stakeholders regarding the proposed performance, durability, and cost targets for hydrogen storage sub-systems designed for material handling and portable power fuel cell applications. This RFI closed in June 2012.
- **Fuel Cells for Material Handling and Backup Power Applications** collected feedback from stakeholders regarding the proposed performance, durability, and cost targets for fuel cells designed for backup power and material handling applications. This RFI closed in June 2012.
- **Commercial Readiness of Hydrogen and Fuel Cell Technologies** collected information from stakeholders regarding transportation electrification using fuel cells, specifically onboard refrigeration auxiliary power for heavy duty road vehicles, fuel cell rechargers for battery electric vehicles used for transporting cargo or passengers, and technology deployment opportunities for other on- or off-road transportation markets. This RFI closed in March 2012.
- **High-Accuracy Meters for Hydrogen Fueling Equipment** gathered feedback from stakeholders regarding the current and near-term status and availability of high-accuracy meters that can perform under hydrogen fueling conditions and meet measurement accuracy requirements. This RFI closed in September 2012.

INTERNATIONAL ACTIVITIES

International Partnership for Hydrogen and Fuel Cells in the Economy

The United States is a founding member of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE),⁵ which includes 17 member countries (Australia, Brazil, Canada, China, France, Germany, Iceland, India, Italy, Japan, New Zealand, 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. In FY 2012, the 17th Steering Committee Meeting was held in South Africa on May 3 and 4. An IPHE Workshop titled “Hydrogen—A Competitive Energy Storage Medium to enable the large scale integration of renewable energies” was held November 15 and 16 in Seville, Spain, following the 18th Steering Committee Meeting, also in Seville, on November 14.

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)⁶ and the Hydrogen Implementing Agreement

⁵ <http://www.iphe.net/>

⁶ www.ieafuelcell.com

(HIA).⁷ These agreements provide a mechanism for member countries to share the results of research, development, and analysis activities. The AFCIA currently includes seven 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. The participating countries are Australia, Austria, Belgium, Denmark, Finland, France, Germany, Italy, Japan, Korea, Mexico, Sweden, Switzerland, and the United States. The IEA HIA is focused on RD&D and analysis of hydrogen technologies. It includes 11 tasks: Hydrogen Safety, Biohydrogen, Fundamental and Applied Hydrogen Storage Materials Development, Small-Scale Reformers for On-site Hydrogen Supply, Wind Energy and Hydrogen Integration, High-Temperature Production of Hydrogen, Advanced Materials for Hydrogen from Water Photolysis, Near-Market Routes to Hydrogen by Co-Gasification with Biomass, Large Scale Hydrogen Delivery Infrastructure, Distributed and Community Hydrogen for Remote Communities, and Global Hydrogen Systems Analysis. The United States participates in all of these tasks. Members of the HIA include: Australia, Denmark, the European Commission, Finland, France, Germany, Greece, Iceland, Italy, Japan, Korea, Lithuania, New Zealand, Norway, Spain, Sweden, Switzerland, Turkey, Taiwan, United Nations Industrial Development Organization-International Center for Hydrogen Energy Technologies, and the United States.

EXTERNAL COORDINATION, INPUT, AND ASSESSMENT

Hydrogen and Fuel Cell 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 three times in FY 2012—twice in person and once via webinar. In March 2012, HTAC released its fourth annual report, which summarizes hydrogen and fuel cell technology domestic and international progress in RD&D projects, commercialization activities, and policy initiatives. A major HTAC activity in FY 2012 was the Hydrogen Production Expert Panel Workshop, which was conducted by a new HTAC subcommittee. The workshop was held in May 2012, with opening remarks provided by Secretary of Energy Steven Chu. The panel was charged with providing recommendations to DOE regarding both policy and investments in R&D to enable the widespread production of affordable, low-carbon hydrogen—taking into consideration relevant market and business forces, technology barriers, and policy barriers, as well as the impact of safety codes and standards. A report from the workshop is expected to be published in early 2013. More information about HTAC, including the latest annual report, is available at: http://www.hydrogen.energy.gov/advisory_htac.html.

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. Recently, efforts by the ITF have focused on facilitating federal deployment of hydrogen and fuel cells in emerging technology applications such as stationary power and specialty vehicles. The Hydrogen and Fuel Cell Interagency Working Group, co-chaired by DOE and the White House Office of Science and Technology Policy, continues to meet 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. In January 2012, the Task Force and the Working Group

⁷ www.ieahia.org

released their *Interagency Action Plan*, www.hydrogen.gov/interagency_action_plan.html. Examples of successful inter-agency coordination include:

- Announcement in January that 16 GM Equinox FCEVs would be deployed in Hawaii, as a result of collaboration between DOE, the Department of Defense (DOD), NREL, the University of Hawaii, and the University of California at Irvine. Data collected from the FCEVs will be used for early market evaluation.
- DOD-DOE collaboration to deploy fuel cells for emergency backup power. DOE and DOD are collaborating on a project to install and operate 18 fuel cell backup power systems at eight defense installations across the country. The departments are testing how the fuel cells perform in real-world conditions, identifying improvements manufacturers can make to enhance the value proposition, and highlighting the benefits of fuel cells for emergency backup power applications.

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 Program⁸ and the R&D activities of the U.S. DRIVE Partnership.⁹ Formerly known as the FreedomCAR and Fuel Partnership, the U.S. DRIVE (Driving Research and Innovation for Vehicle efficiency and Energy sustainability) partnership works on 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. In FY 2012, a new review of U.S. DRIVE was initiated and FCT Program representatives presented recent activities to the NRC.

FY 2012 Annual Merit Review and Peer Evaluation

The Program's Annual Merit Review (AMR) took place May 14-18, 2012, providing an opportunity for the Program to obtain expert peer reviews of the projects it supports and to report its accomplishments and progress. For the fourth time, this meeting was held in conjunction with the annual review of DOE's Vehicle Technologies Program. 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, more than 1,800 participants attended, and the Hydrogen and Fuel Cells Program had 163 oral presentations and 65 poster presentations. More than 200 experts peer-reviewed 145 of the Program's projects—conducting a total of over 900 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_review12_report.html. In 2013, the AMR will be held May 13–17 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 \$6.8 million in funding in FY 2012, \$13.8 million in FY 2011, and nearly \$30 million over the past four years.

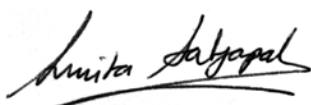
⁸ *The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs*, National Research Council and National Academy of Engineering, National Academies Press, 2004.

⁹ *Review of the Research Program of the FreedomCAR and Fuel Partnership: First Report*, National Research Council, National Academies Press, 2005, http://www.nap.edu/catalog.php?record_id=11406; *Review of the Research Program of the FreedomCAR and Fuel Partnership: Second Report*, National Research Council, National Academies Press, 2008, http://www.nap.edu/catalog.php?record_id=12113; *Review of the Research Program of the FreedomCAR and Fuel Partnership: Third Report*, National Research Council, National Academies Press, 2010, www.nap.edu/catalog.php?record_id=12939.

IN CLOSING...

The Program will continue to pursue a broad portfolio of RD&D activities for fuel cell applications across multiple sectors. Efforts will span the full spectrum of technology readiness, including: early market applications that are already viable or are expected to become viable in the next few years, such as forklifts, backup power, and portable power applications; mid-term markets that are expected to emerge in the 2012-2015 timeframe, such as residential combined heat and power systems, auxiliary power units, fleet vehicles, and buses; and longer-term markets that are expected to emerge in the 2015-2020 timeframe, including light-duty passenger vehicles and other transportation applications. The Program will also continue to pursue activities to enable commercialization and stimulate the markets for hydrogen and fuel cells as they achieve technology readiness. Supporting these markets will not only help to achieve the economic, environmental, and energy security benefits that fuel cells provide in those specific applications, but it will complement the Program's longer-term R&D efforts by helping to increase current sales and manufacturing volumes, providing essential cost reductions—through economies of scale—for many of the same technologies that will be used in longer-term applications. Supporting earlier markets can also reduce many non-technological barriers to the deployment of hydrogen and fuel cell technologies and lay the groundwork for the larger infrastructure and supply base that will be needed for fuel cell electric vehicles. Communication and outreach remain critical to all these efforts, and the Program actively pursues opportunities to publicize its activities and progress, releasing more than 70 news items in FY 2012, including DOE press releases, progress alerts, success stories, and blogs.

Finally, in 2012 several individual sub-program chapters of the updated *Fuel Cell Technologies Program Multi-Year Research, Development, and Demonstration Plan (MYRD&D Plan)* were published, and they are currently available online (www.hydrogenandfuelcells.energy.gov/mypp/index.html). These updated chapters include a number of revised technical targets. Final updates of the remaining chapters are expected to be complete early in 2013. The *MYRD&D Plan* describes the planned research, development, and demonstration activities for hydrogen and fuel cell technologies. It was first published in 2005, and elements of it have been revised periodically to reflect progress in the technologies and revisions to developmental timelines and targets.



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