I.0 Introduction

The Department of Energy Hydrogen and Fuel Cells Program (the Program) conducts comprehensive efforts 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), including activities in the offices of Energy Efficiency and Renewable Energy (EERE), Science (SC), Nuclear Energy (NE), and Fossil Energy (FE), and it is aligned with DOE's strategic vision and goals–its efforts will help to secure U.S. leadership in clean energy technologies and advance U.S. economic competitiveness and scientific innovation.

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 the 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 hydrogen and fuel cell technologies by integrating basic and applied research, technology development and demonstration, and other supporting activities.

In Fiscal Year (FY) 2011, Congress appropriated approximately $150 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 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/program_plans.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.

PROGRAM PROGRESS AND ACCOMPLISHMENTS

Fuel Cells

The Fuel Cells sub-program continued to make progress toward meeting targets through advancements achieved in both catalysis and membrane R&D. Technological advances in several component areas led to significant improvements in performance and durability, with reduced cost. In FY 2011, the catalyst utilization in polymer electrolyte membrane (PEM) automotive fuel cell systems improved from 2.8 kW/g in 2008 to 5.6 kW/g in 2011 (as measured in units of kW per gram of platinum group metal).[2] This exceeds the Program's 5.5 kW/g target set for FY 2011and has contributed to reducing the high-volume manufacturing cost of fuel cells. This cost is currently projected to be $49/kW (assuming manufacturing volumes of 500,000 units/year), which represents a more than 30% cost reduction since FY 2008.[3]

[1] This includes $98 million for the Fuel Cell Technologies Program within the Office of Energy Efficiency and Renewable Energy, $38 million for hydrogen and fuel cell–related research in the Basic Energy Sciences program within the Office of Science, $12 million for hydrogen production R&D in the Office of Fossil Energy and $2.8 million for hydrogen production R&D in the Office of Nuclear Energy.

[2] See Report V.D.1., "Advanced Cathode Catalysts and Supports for PEM Fuel Cells," in the Fuel Cells chapter of this volume.

[3] DOE Hydrogen and Fuel Cells Program Record #11012, http://hydrogen.energy.gov/pdfs/11012_fuel_cell_system_cost.pdf.

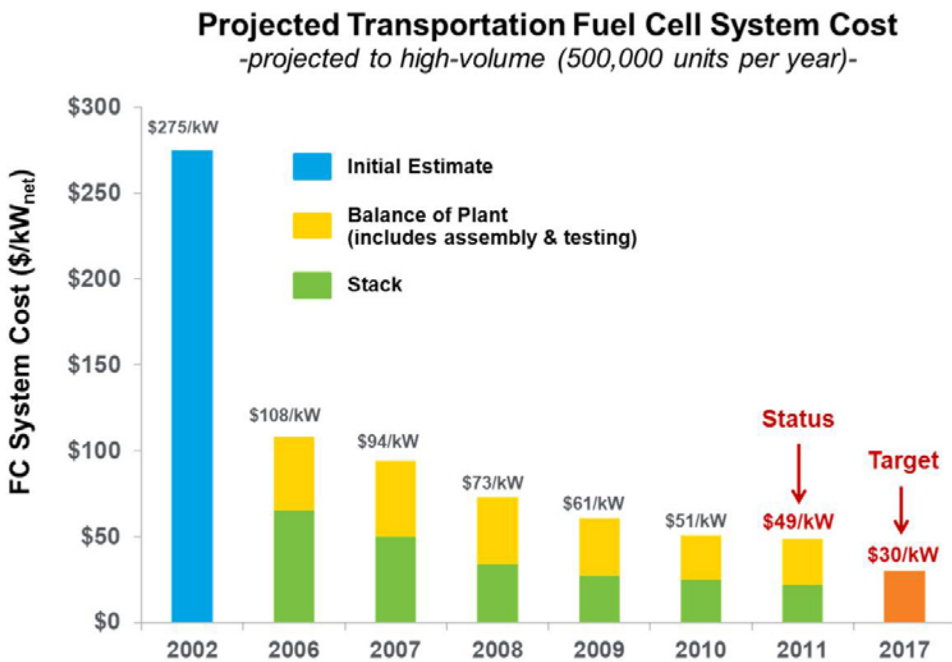


FIGURE 1. Current Modeled Cost of an 80-kW Automotive Fuel Cell System Based on Projection to High-Volume Manufacturing (500,000 Units/Year)[4]

FY 2011 also saw the development of a perfluoroimide acid membrane, for higher-temperature operation (120°C) that meets most DOE targets, including most membrane resistance targets. Progress over the last year enabled a 40% reduction in membrane resistance at 120°C and 40 kPa water vapor, with an additional 13% reduction still required to meet the 2017 DOE target of 0.02 ohm cm^2.[5] Efforts in FY 2011 also led to the development of solid-oxide fuel cell (SOFC) systems for remote power and micro-combined heat and power applications with increased durability, enabling more than 12,000 hours of operation of an SOFC system.[6] This advance represents a significant step toward production of an SOFC system for widespread commercialization and builds on the performance improvements demonstrated in FY 2010.

Hydrogen Production

The FY 2011 Hydrogen Production sub-program continued to focus on developing technologies that enable the long-term viability of hydrogen as an energy carrier for a diverse range of end-use applications, including stationary power, backup power, specialty vehicles, transportation, and portable power. In FY 2011, the sub-program continued to make progress in several key areas, including autothermal reforming of bio-derived liquids, electrolysis, photoelectrochemical (PEC) hydrogen production, and biological hydrogen production.

In the area of bio-derived liquids, increases in process efficiency from 47% to 62% and increases in yield from 7.4 g to 10.1 g hydrogen per 100 g bio-oil were achieved for bench-scale tests of catalytic steam reforming of pyrolysis oil as a result of improvements in catalyst performance through the use of a 0.5% Pt/Al_2O_3 BASF catalyst.[7] Progress in the area of electrolysis included demonstration of a PEM electrolyzer incorporating advanced low-cost membrane electrode assemblies (MEAs) with chemically etched supports.[8] Due to improvements in MEAs and flow fields and reductions in catalyst loading, the projected capital cost of electrolyzer stacks was reduced to less than $400/kW, representing a cost reduction of more than 10% relative

[4] DOE Hydrogen and Fuel Cells Program Record #11012, http://hydrogen.energy.gov/pdfs/11012_fuel_cell_system_cost.pdf.

[5] See Report V.C.1, "Membranes and MEAs for Dry, Hot Operating Conditions," in the Fuel Cells chapter of this volume.

[6] "V.L.1. Development of a Low Cost 3-10kW Tubular SOFC Power System," in the Fuel Cells chapter of this volume.

[7] See Report II.A.2, "Distributed Bio-Oil Reforming," in the Hydrogen Production chapter of this volume.

[8] See Report II.E.1, "PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane," in the Hydrogen Production chapter of this volume.

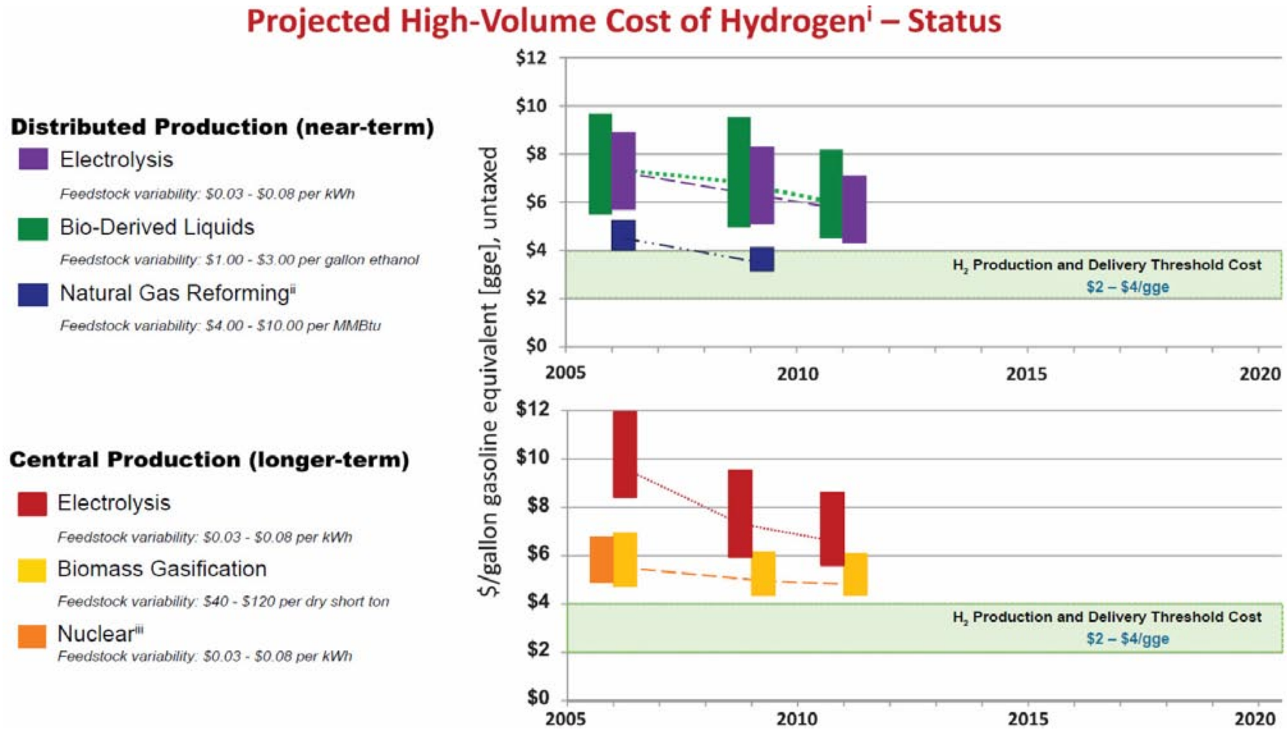


FIGURE 2. Hydrogen Production and Delivery Cost Status. Significant progress has already been made in several hydrogen production pathways. The Hydrogen Threshold Cost represents the cost at which hydrogen fuel cell electric vehicles are projected to become competitive on a cost-per-mile basis with competing vehicles (gasoline hybrid-electric vehicles) in 2020. Notes: (i) Costs shown include all delivery and dispensing costs, but do not include taxes. A cost of $1.80 for forecourt compression, storage, and dispensing is included for distributed technologies, and $2.60 is included as the total cost of delivery (including transportation, compression, storage, and dispensing) for centralized technologies. All delivery costs are based on the Hydrogen Pathways Technical Report (NREL, 2009). Projections of distributed costs assume station capacities of 1,500 kg/day, with 500 stations built per year. Projections of centralized production costs assume capacities of ≥50,000 kg/day. Cost ranges for each pathway are shown in 2007 dollars, based on high-volume projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates. (ii) DOE funding of natural gas reforming projects was completed in 2009 due to achievement of the threshold cost. Incremental improvements will continue to be made by industry. (iii) High-temperature electrolysis activities are ongoing under the Next Generation Nuclear Plant Program.

to 2010 projections.[9] In the area of PEC hydrogen production, the Program demonstrated exceptional stability in quantum-confined MoS_2 nanoparticle photocatalysts with bandgaps optimized at 1.8 eV, showing stable operation over 10,000 voltage cycles of accelerated lifetime testing. In complementary work, novel macroporous scaffolds, which are transparent and conductive, were developed as electrode substrates to support PEC photocatalyst materials, such as MoS_2, in high-efficiency devices.[10] Finally, in the area of biological hydrogen production, the gene mutation responsible for the decrease in chlorophyll antenna size, previously observed to increase light utilization efficiency to 15% from 3% in wild-type organisms, was identified and characterized. Efforts to identify the mutation responsible for light utilization of up to 25% are ongoing, along with R&D to optimize hydrogen production in microalgal cultures.[11]

---

[9] See Report II.E.1, "PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane," and Report II.E.2, "High Performance, Low Cost Hydrogen Generation from Renewable Energy," in the Hydrogen Production chapter of this volume.

[10] See Report II.G.1, "Nano-Architectures for 3rd Generation PEC Devices: A Study of MoS2, Fundamental Investigations and Applied Research," in the Hydrogen Production chapter of this volume.

[11] See Report II.H.4, "Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures," in the Hydrogen Production chapter of this volume.

Hydrogen Delivery

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. In FY 2011, the sub-program continued to make progress in all major areas, including the following examples. A design trade study for a 5,000 pounds per square inch (psi) vessel was completed; this showed a projected 33% increase in capacity at 15°C and ~10% reduction in capital cost (on a per kilogram of transported hydrogen basis).[12] In addition, burst testing on fiber reinforced polymer pipe with 40% through-wall flaws was also completed and demonstrated a 3x margin above the rated pressure for the pipe. Researchers also showed that industry-standard compression fittings will meet Department of Transportation requirements for joint leakage between pipe segments.[13] FY 2011 also saw the development of a two-stage electrochemical hydrogen compressor that achieved 420 bar of compression.[14]

Hydrogen Storage

In FY 2011, the Hydrogen Storage sub-program's materials-discovery projects developed a number of new materials and improved the performance of other materials. Key accomplishments in FY 2011 include: characterization of high surface area sorbents with specific surface areas greater than 6,000 m^2 per gram and excess hydrogen sorption capacities exceeding 8% by weight at 77 K;[15] demonstration of cycling of $Mg(BH_4)_2$ at hydrogen capacities greater than 12% by weight under high-temperature and high-pressure conditions;[16] demonstration of alane slurry with 60% capacity by weight and with kinetics exceeding non-slurried alane;[17] and determination that thermal stability of ionic liquids is dominated by choice of cation. The Hydrogen Storage Engineering Center of Excellence (HSECoE) completed a baseline assessment of storage system models for reversible metal hydrides, cryo-sorbents, and both solid- and liquid-phase off-board regenerable chemical hydrogen storage material systems. The HSECoE assessed these models against the full set of DOE onboard storage targets. Also in FY 2011, the sub-program increased its emphasis on reducing the cost of compressed hydrogen gas storage tanks by initiating new efforts on low-cost, high-strength carbon fiber. Inexpensive storage vessels for compressed hydrogen gas are considered the most likely near-term hydrogen storage solution for the initial commercialization of fuel cell electric vehicles (FCEVs), as well as for other early market applications.

Manufacturing R&D

FY 2011 saw a number of advances in manufacturing of fuel cells and storage systems. Ballard made several improvements that resulted in significant improvement in quality yields and a gas diffusion layer cost reduction of over 60%, while increasing manufacturing capacity nearly four-fold.[18] For example, they improved thickness and basis weight uniformity of gas diffusion layers by adding mass flow meters to the "Many-at-a-Time" coating equipment. W.L. Gore reduced membrane thickness, eliminated membrane backers, reduced scrap with better coating process, and eliminated finishing operations such as electrode and membrane edge trim (Gore previously demonstrated, using their cost model, that a new three-layer membrane electrode assembly process has the potential to reduce membrane electrode assembly cost by 25%).[19] And Quantum saved 17.4 kg of composite from the baseline (all fiber wound) high-pressure hydrogen storage vessel (a 23% savings).[20]

---

[12] See Report III.7, "Development of High Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery," in the Hydrogen Delivery chapter of this volume.

[13] See Report III.6, "Fiber Reinforced Composite Pipeline," in the Hydrogen Delivery chapter of this volume.

[14] See Report III.10, "Electrochemical Hydrogen Compressor," in the Hydrogen Delivery chapter of this volume.

[15] See Report IV.C.4, "New Carbon-Based Porous Materials with Increased Heats of Adsorption for Hydrogen Storage," and Report IV.C.1, "A Biomimetic Approach to Metal-Organic Frameworks with High H2 Uptake," in the Hydrogen Storage chapter of this volume.

[16] See Report IV.A.3, "Fundamental Studies of Advanced High-Capacity, Reversible Metal Hydrides," in the Hydrogen Storage chapter of this volume.

[17] See Report IV.A.6, "Aluminum Hydride," in the Hydrogen Storage chapter of this volume.

[18] See Report VI.2, "Reduction in Fabrication Costs of Gas Diffusion Layers," in the Manufacturing R&D chapter of this volume.

[19] See Report VI.4, "Manufacturing of Low-Cost, Durable Membrane Electrode Assemblies Engineered for Rapid Conditioning," in the Manufacturing R&D chapter of this volume.

[20] See Report VI.9, "Development of Advanced Manufacturing Technologies for Low Cost Hydrogen Storage Vessels," in the Manufacturing R&D chapter of this volume.

In conjunction with the National Renewable Energy Laboratory, the Manufacturing R&D sub-program also held a workshop to prioritize challenges and barriers to manufacturing hydrogen and fuel cell systems and components and to identify R&D activities that government can support to overcome barriers.

Basic Research

The Basic Energy Sciences program within the DOE Office of Science supports fundamental scientific research addressing critical challenges related to hydrogen storage, hydrogen production, and fuel cells. This basic research complements 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 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 Technology Validation sub-program has been focused on conducting learning demonstrations that emphasize co-development and integration of hydrogen infrastructure with FCEVs to permit industry to assess progress toward technology readiness. As the vehicle and infrastructure demonstrations in are coming to a close, the sub-program is increasing its focus on other areas, such as combined hydrogen, heat, and power (tri-generation or CHHP) as well as stationary power applications.

The Program's vehicle and infrastructure demonstrations in the National Hydrogen Learning Demonstration have deployed 155 FCEVs and 24 hydrogen fueling stations to date. Over the course of the demonstration, the vehicles have traveled more than 3 million miles. Vehicles and infrastructure in these demonstrations have validated the status of several key technologies in integrated systems under real-world operating conditions, including vehicular fuel cell efficiency of up to 59%, projected durability of 2,500 hours (nearly 75,000 miles) with less than 10% degradation, a range of more than 250 miles between refueling (the Program has validated one vehicle—not in the Learning Demonstration—that is capable of traveling more than 430 miles on a single fill), and refueling times of approximately five minutes for 4 kg of hydrogen. The Technology Validation sub-program also collected and analyzed data from over 45,000 fuel cell fork truck lift refuelings at Defense Logistics Agency sites.

A major accomplishment in FY 2011 was demonstrating the world's first fuel cell energy station that produces electric power and hydrogen from wastewater treatment gas.[21] The energy station provides hydrogen as a transportation fuel to the public and electric power to the wastewater treatment facility; it also has the potential to operate in "trigeneration" (or combined-heat-hydrogen-and-power) mode, if waste heat from the fuel cell is captured and provided to the facility. The energy station began operation at the Orange County Sanitation District's facility in Fountain Valley, California, sending hydrogen to a fueling station for FCEVs

[21] See Report VII.4, "Validation of an Integrated Hydrogen Energy Station," in the Technology Validation chapter of this volume.

first in February 2011. The combined co-production efficiency of hydrogen and power was 54% at the energy station, exceeding DOE's target of 50% for FY 2011.

Safety, Codes and Standards

The Safety, Codes and Standards sub-program continued to support critical R&D to establish key requirements and address knowledge gaps in safety, codes and standards. Building on work from previous years, the sub-program continued to facilitate collaborative activities among relevant stakeholders in an effort to harmonize domestic and international regulations, codes, and standards. Significant accomplishments include the development of *National Fire Protection Association (NFPA) 2: Hydrogen Technologies Code*, which consolidates all building codes and requirements for hydrogen installations in the United States into a single document. NFPA 2 also includes a qualitative risk assessment introduced by DOE for separation distances for hydrogen bulk storage. Another achievement was the development of an international hydrogen fuel specification standard (ISO TC 197 WG 12), which was led by the United States and ensures performance and durability of PEM fuel cells. In addition, a final draft of a Global Technical Regulation for hydrogen-fueled vehicles has been submitted to the United Nations Economic Commission for Europe. The sub-program also took a leadership role in international coordination by co-organizing the International Conference on Hydrogen Safety in California with Sandia National Laboratories.

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. FY 2010 appropriations supported these activities.

To support early market outreach, the Education sub-program implemented several end-user, state and local government, and safety and code official education activities. Accomplishments include the development of a model to analyze the economic impacts on early market deployment of fuel cells in primary power, backup power, and material-handling applications through a user-friendly spreadsheet tool used to calculate impacts on production, installation, and utilization at a regional or national level. The tool will be available for beta testing at the end of 2011. Videos were also developed to be aired on TV and posted online to YouTube and other sites, including the development of two segments for MotorWeek entitled "Hydrogen and Fuel Cells Emerging Markets" and "Vehicles and Infrastructure Update." In FY 2011, the sub-program also organized, publicized, and facilitated 10 webinars on hydrogen and fuel cell topics of interest to state policymakers, local leaders, and end users, including: "The Top 5 Fuel Cell States: Why Local Policies Mean Green Growth," "Hydrogen and First Responders," "Financing Fuel Cell Installations," and others.

Systems Analysis and Integration

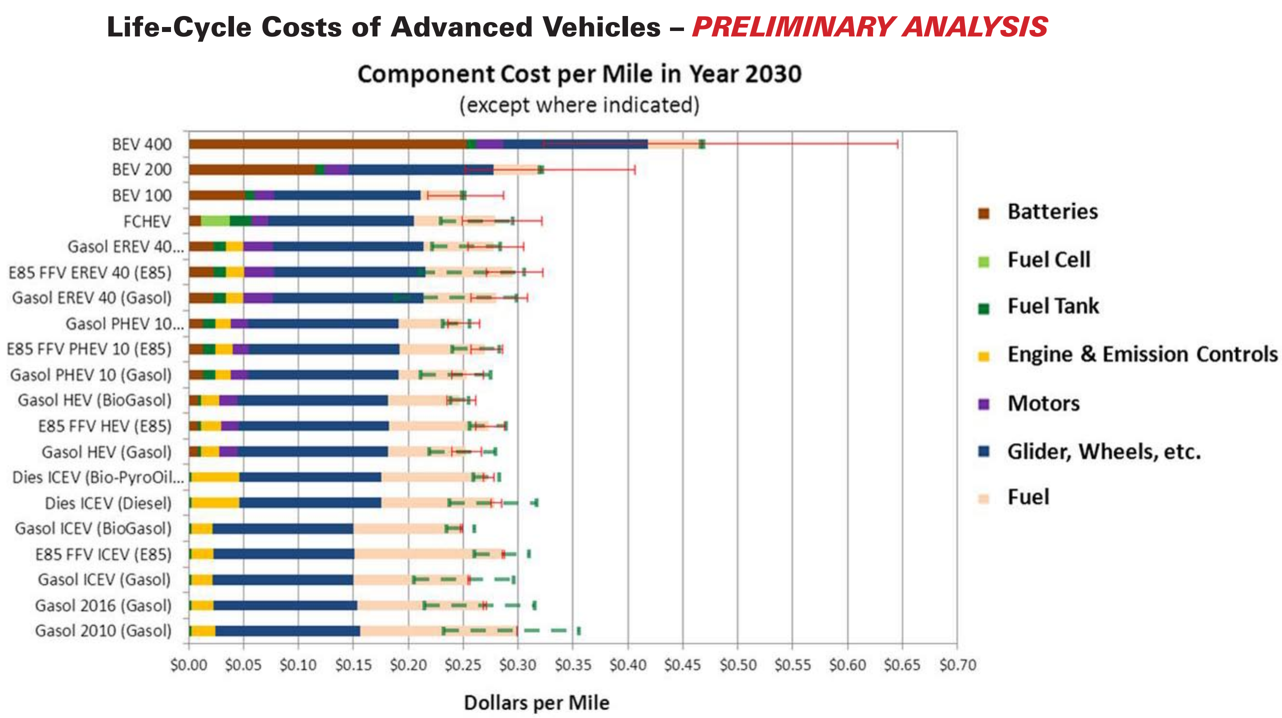
Systems Analysis supports decision-making by providing a greater understanding of technology gaps, options, and risks. Analysis is also conducted to assess cross-cutting issues, such as integration with the electrical sector and use of renewable fuels. Particular emphasis is given to assessing stationary fuel cell applications, fuel quality impacts on fuel cell performance, resource needs, and potential infrastructure options.

Accomplishments in FY 2011 include the development of a hydrogen cost threshold in the range of $2-$4/gasoline gallon equivalent (in 2007 dollars) to assist DOE in focusing and prioritizing R&D options. The cost threshold represents the cost at which hydrogen FCEVs are projected to become competitive on a cost-per-mile basis with the competing fuel/vehicle combination–gasoline in hybrid-electric vehicles. A graphical representation of the hydrogen threshold, relative to current projected production and delivery costs is shown in Figure 2 in the "Hydrogen Production" section of this Introduction. Also in FY 2011, a comparison of cost estimates for non-automotive fuel cells showed a 50% or greater reduction in costs between 2008 and 2010.[22] Despite these large cost reductions, the analysis concluded that the continuation or enhancement of current policies such as the investment tax credit and government procurement combined with progress by industry will be necessary to establish a viable domestic fuel cell industry. In addition,

[22] Greene, David et al. "Status and Outlook for the U.S. Non-Automotive Fuel Cell Industry: Impacts of Government Policies and Assessment of Future Opportunities" Oak Ridge National Laboratory, May 2011.

infrastructure analysis revealed that synergies between fuel cells for stationary power generation and transportation could be realized in the early phases of market adoption of hydrogen for light-duty fuel cell vehicles. Model results that indicate hydrogen produced from combined hydrogen, heat, and power systems could result in smaller stations with higher capital utilization and lower hydrogen cost; this hydrogen could supplement hydrogen supplied from distributed natural gas–based steam methane reforming, particularly for the early years of FCEV penetration scenarios where hydrogen demand and station sizes are initially small.

In FY 2011, the Systems Analysis sub-program collaborated with counterparts in the DOE Vehicle Technologies Program and the DOE Biomass Program to prepare and release an EERE-wide request for information (RFI) on the total cost of operation of future light-duty vehicles, including petroleum fuels and alternative fuels pathways, based on three levels of technology success. Comments from the public were requested on the projected cost reductions and the financial analysis approach used in estimating the cost per mile for each pathway. Responses to the RFI are due on December 16, 2011. Figure 3 shows the preliminary EERE estimates of costs per mile that were released for comments under the RFI.



BEV – battery electric vehicle; FCHEV – fuel cell hybrid electric vehicle; Gasol – gasoline; EREV – extended range electric vehicle; FFV – flexible fuel vehicle; PHEV – plug-in hybrid electric vehicle; HEV – hybrid electric vehicle; ICEV – internal combustion engine vehicle

FIGURE 3. Preliminary EERE Estimates of the Life-Cycle Costs of Several Advanced Vehicle Pathways. Error bars illustrate the sensitivity of costs per mile to fuel prices (green) and vehicle technology success (red).

Market Transformation

To ensure that the benefits of its efforts are realized in the marketplace, the 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 and by overcoming 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 2011 activities primarily involved project startup and kickoff from FY 2010 appropriations. The Market Transformation sub-program is currently focused on building on past successes in material handling equipment (e.g., lift trucks) and emergency backup power applications, which received support from Recovery Act funding. These Recovery Act projects are highly leveraged with an average of over half the funds or cost share 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 on Recovery Act projects, see "American Recovery and Reinvestment Act Projects" under the "Other Program Activities" section of this Introduction.) The Market Transformation sub-program is seeking to expand on the success of these activities by exploring other potential and emerging applications for market viability.

Specific accomplishments in FY 2011 include a joint effort by the Department of Defense's (DOD's) U.S. Army Corps of Engineers and the Program, which was conducted under the Memorandum of Understanding (MOU) signed between DOE and DOD in July 2010. The project consists of installation of emergency backup power fuel cells at eight DOD locations across the country. Additionally, demonstration and testing of fuel cell-powered mobile lighting prototypes were conducted at the National Aeronautic and Space Administration Kennedy Space Center and the San Francisco International Airport, among others. Activities conducted at entertainment industry events such as the 2011 Golden Globe Awards and 2011 Grammy Awards ceremonies had the added value of exposing fuel cell technology to the public.[23] Also in FY 2011, a total of 22 hydrogen-powered buses were deployed at federal facilities and national labs across the country to demonstrate hydrogen buses and infrastructure with widespread public visibility. The 12-passenger buses are used for special events, campus tours, new employee orientations, and as part of shuttle bus fleets. The buses were shown to thousands of attendees at special events throughout the year. During FY 2011, the technical viability of using landfill gas (LFG) as a cost-effective source of hydrogen production was demonstrated at BMW's assembly plant in South Carolina. Once fully implemented, this project will represent a "first-of-its-kind" LFG-to-hydrogen production project in the nation, and serve as a model for future adoption of renewable biogas as a feedstock for hydrogen production.[24] Finally, in FY 2011, the substantial effects of market transformation became apparent in the material-handling equipment sector when successful DOE projects led industry to plan deployments of more than 3,000 fuel cell forklifts with no additional DOE funding.[25]

OTHER PROGRAM ACTIVITIES

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 market. 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–this funding is supporting the deployment of up to 1,000 fuel cell systems in emergency backup power, material handling, and combined heat and power applications. Twelve projects were competitively selected to develop and deploy a variety of fuel cell technologies including polymer electrolyte, solid oxide, and direct-methanol fuel cells in stationary, portable, and specialty vehicle applications. In FY 2011, ARRA investments led to 610 additional fuel cell deployments into the market. As of the end of September 2011, more than 460 fuel cell lift trucks and more than 370 fuel cell backup-power systems for cellular communications towers and stationary backup-power systems had been deployed, and over 80% of the ARRA project funds had been spent by the projects. A total of 46 direct jobs have been created or retained as a result of the Fuel Cell Technologies ARRA projects (if supply chain and other indirect jobs are included, the total jobs created or retained is estimated to be more than 180 from these ARRA projects alone). These projects are helping to build a competitive domestic supply base, reduce costs, and demonstrate the economic and performance benefits of fuel cells as a competitive option for stationary, portable, and specialty vehicle applications.

Tracking the Commercialization of Technologies

One indicator of the robustness and innovative vitality of an R&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. DOE-funded R&D has resulted in more

[23] See Report X.1, "Fuel Cell Mobile Lighting," in the Market Transformation chapter of this volume.

[24] See Report X.7, "Landfill Gas-to-Hydrogen," in the Market Transformation chapter of this volume.

[25] DOE Hydrogen and Fuel Cells Program Record #11017, http://hydrogen.energy.gov/program_records.html.

than 310 patents and more than 60 emerging technologies while 30 hydrogen and fuel cell technologies have entered the market.[26] DOE also tracks the impact of its funding in terms of industry revenues and investment–for example, $70 million in funding for specific projects that were tracked was found to have led to more than $200 million in industry revenues and investment.

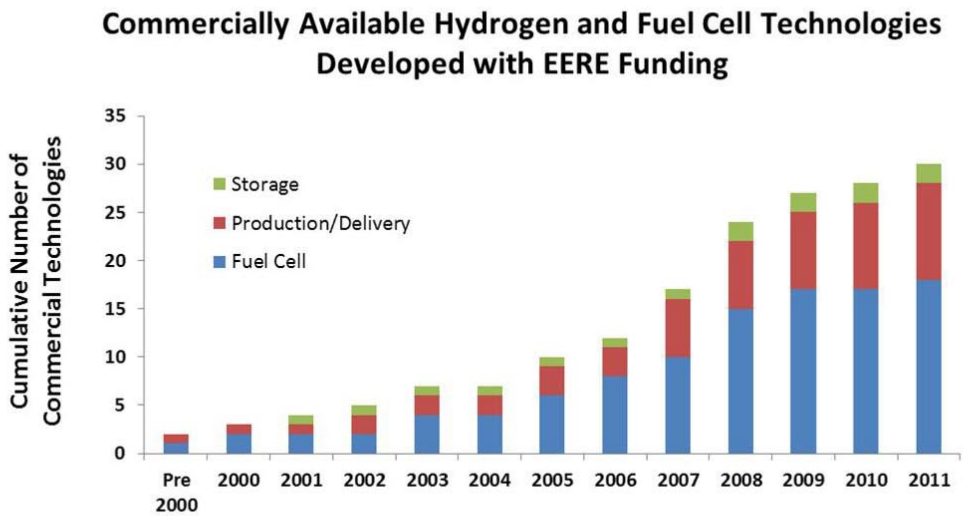


FIGURE 4. Cumulative Number of Commercially Available Technologies Developed with Funding from the Fuel Cell Technologies Program

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[27] (IPHE), 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 2011, the 15th Steering Committee Meeting was held in Vancouver, Canada, on May 13 and 14. An IPHE Roundtable with Stakeholders is planned for November 17 in Berlin, along with the 16th Steering Committee Meeting also in Berlin on November 18th.

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[28] (AFCIA) and the Hydrogen Implementing Agreement[29] (HIA). These agreements provide a mechanism for member countries to share the results of research, development, and analysis activities. The AFCIA currently includes six annexes: Molten Carbonate Fuel Cells, Polymer Electrolyte Fuel Cells, Solid Oxide Fuel Cells, Fuel Cells for Stationary Applications, Fuel Cells for Transportation, and Fuel Cells for Portable Power. The participating countries are Australia, Austria, Belgium, Canada, Denmark,

[26] *Pathways to Commercial Success: Technologies and Products Supported by The Fuel Cell Technologies Program*, Pacific Northwest National Laboratory, September 2011, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pathways_2011.pdf.
[27] http://www.iphe.net/
[28] www.ieafuelcell.com
[29] www.ieahia.org

Finland, France, Germany, Italy, Japan, South Korea, the Netherlands, Mexico, Sweden, Switzerland, Turkey, 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 are Australia, Canada, Denmark, the European Commission, Finland, France, Germany, Greece, Iceland, Italy, Japan, South Korea, Lithuania, the Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, Turkey, 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 2011. In March 2011, HTAC released its third annual report, which summarizes hydrogen and fuel cell technology domestic and international progress in RD&D projects; commercialization activities; and policy initiatives. More information about HTAC, including its annual reports, is available at: http://www.hydrogen.energy.gov/advisory_htac.html

Federal Agency Coordination—the Interagency Task Force and the Interagency Working Group

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 focus on facilitating federal deployment of hydrogen and fuel cells in emerging technology applications such as stationary power and specialty vehicles. In June 2011, DOE hosted the first ITF meeting of this administration. During this meeting, Deputy Secretary of Energy Daniel Poneman announced a DOE and DOD collaboration with the Army Corps of Engineers to deploy emergency backup power units for critical loads at eight DOD locations across the nation. In addition, ITF members provided feedback on the recently drafted *Interagency Action Plan*.

The Hydrogen and Fuel Cell Interagency Working Group (IWG), 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.

DOD-DOE MOU Workshops

DOD and DOE entered into an MOU for the purpose of coordinating efforts to enhance national energy security and demonstrate federal government leadership in transitioning to a low-carbon economy. A key focus area of the MOU is DOD-DOE collaboration on a broad range of innovative, technology-driven solutions to reduce petroleum use, among other objectives.[30] As a large developer and end user of technology, DOD will aim to speed the movement of innovative energy technologies and technical expertise from DOE's research laboratories to military end users, using military installations as test beds and early markets. Activities undertaken through this collaboration can also help DOD installations meet the requirements of additional regulations that affect their strategies for energy use.

[30] *Memorandum of Understanding between U.S. Department of Energy and U.S. Department of Defense,* DOE and DOD, July 22, 2010, www.energy.gov/news/documents/Enhance-Energy-Security-MOU.pdf.

In support of this MOU, the Program held a series of workshops with DOD and other stakeholders focusing on hydrogen and fuel cell activities. The "Waste-to-Energy Using Fuel Cells" workshop was held on January 13, 2011, the "Shipboard Auxiliary Power Unit" workshop was held on March 29, 2011, and the "Aircraft Petroleum Use Reduction" workshop was held on September 30, 2010. Presentations and outcomes can be found in the Market Transformation section of the Program's workshops Web page, which is located at http://www1.eere.energy.gov/hydrogenandfuelcells/wkshp_proceedings.html.

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[31] and the R&D activities of the U.S. DRIVE Partnership.[32] On May 19, 2011, Secretary Chu announced U.S. DRIVE, a cooperative partnership with industry to accelerate the development of clean, advanced, energy-efficient technologies for cars and light trucks and the infrastructure needed to support their widespread use. Formerly known as the FreedomCAR and Fuel Partnership, U.S. DRIVE (Driving Research and Innovation for Vehicle efficiency and Energy sustainability) works together 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.

FY 2011 Annual Merit Review and Peer Evaluation

The Program's Annual Merit Review (AMR) took place May 9-13, 2011, providing an opportunity for the Program to obtain an expert peer review of the projects it supports and to report its accomplishments and progress. For the third 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 1,700 participants attended, and the Hydrogen and Fuel Cells Program had 207 oral presentations and 87 poster presentations. More than 200 of the Program's projects were peer-reviewed, and there were 210 contributing reviewers. The report summarizing the results and comments from these reviews is available at http://www.hydrogen.energy.gov/annual_review11_report.html. In 2012, the AMR will be held May 14-18 in Arlington, Virginia.

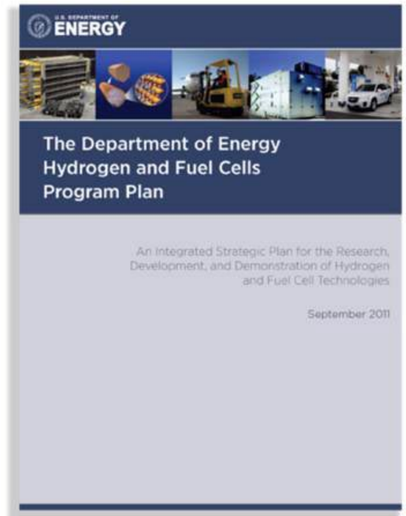
IN CLOSING...

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

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

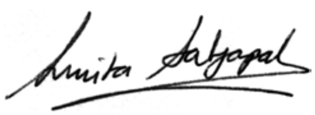
[32] Review of the Research Program of the FreedomCAR and Fuel Partnership: First Report, National Research Council, National Academies Press, 2005, http://www.nap.edu/catalog.php?record_id=11406; Review of the Research Program of the FreedomCAR and Fuel Partnership: Second Report, National Research 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.

supply base that will be needed for fuel cell 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 2011, including DOE press releases, progress alerts, success stories, and blogs.



Finally, a major undertaking in FY 2011 was the complete revision of the Program's strategic plan (the *Hydrogen and Fuel Cells Program Plan*),[33] which outlines the strategy, activities, and plans of the DOE Hydrogen and Fuel Cells Program, covering hydrogen and fuel cell activities within the EERE Fuel Cell Technologies Program and the DOE offices of Nuclear Energy, Fossil Energy, and Science. It describes the Program's activities, the specific obstacles addressed by each sub-program, the strategies employed, key milestones, and future plans for each sub-program and the Program as a whole. The last time the *Plan* had been updated was in 2006 (then it was known as the *Hydrogen Posture Plan*). The new version reflects extensive input from stakeholders, the Hydrogen and Fuel Cell Technical Advisory Committee, and public feedback on the draft version that was posted online for public comment.

We are pleased to present the U.S. Department of Energy's *2011 Hydrogen and Fuel Cells Program Annual Progress Report*. The report is divided into chapters and is organized by technology area (e.g., fuel cells, hydrogen storage, etc.). Each chapter opens with an overview written by a DOE technology development manager that summarizes the progress and accomplishments of the previous fiscal year. The projects outlined in this document represent the work of the many innovative scientists and engineers supported by DOE. They are the ones responsible for the progress and technical accomplishments reported in this year's *Annual Progress Report*. We would like to recognize them for their hard work, commitment, and continued progress.



Sunita Satyapal
Program Manager
Hydrogen and Fuel Cells Program
Fuel Cell Technologies Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

[33] *The DOE Hydrogen and Fuel Cells Program Plan*, U.S. Department of Energy, September 2011, http://www1.eere.energy.gov/hydrogenandfuelcells/program_plans.html.