I.0 Introduction

The DOE Hydrogen Program (the Program) is a comprehensive and focused effort that assumed its current form in Fiscal Year (FY) 2004 when President Bush's Hydrogen Fuel Initiative (HFI) integrated a number of existing activities to accelerate research, development, and demonstration (RD&D) of hydrogen and fuel cells technologies. Hydrogen, along with advanced biofuels, plug-in hybrids, and advanced conventional vehicles with improved fuel economy, are part of the DOE Office of Energy Efficiency and Renewable Energy (EERE) portfolio, which is working to achieve the goals of the Advanced Energy Initiative by developing a suite of technologies to improve the way we power our homes, vehicles, and businesses. The Program addresses the full range of barriers 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 addition to EERE, the Program includes the DOE Offices of Nuclear Energy, Fossil Energy, and Science. The Department of Transportation also participates in the HFI, with activities involving codes and standards development, infrastructure safety, and hydrogen vehicle safety.

In FY 2008, Congress appropriated $281 million for the HFI. This represents an increase of $14 million over the FY 2007 appropriation. The FY 2009 budget request for the Program is $268 million (appropriations will not be finalized until after this report goes to press). The Program works with industry through partnerships such as the FreedomCAR and Fuel Partnership, which includes DOE, the U.S. Council for Automotive Research (whose members are Ford Motor Company, General Motors Corporation, and Chrysler LLC), five major energy companies (BP America, Chevron, ConocoPhillips, ExxonMobil, and Shell), and two electric utilities (Southern California Edison and DTE Energy). The Partnership examines the pre-competitive, high-risk research needed to develop the technologies for deploying vehicles and infrastructure that will reduce the nation's dependence on imported oil and minimize harmful emissions. The mission of the Program is to research, develop, and validate hydrogen production, storage, and fuel cell technologies and to overcome the non-technical barriers to the commercialization of these technologies—with the ultimate goals of reducing oil use and carbon emissions in the transportation sector and enabling clean, reliable energy for stationary and portable power generation.

The Program is organized into distinct sub-programs focusing on specific research areas and supporting activities needed to overcome the barriers to hydrogen and fuel cell commercialization. The goals, objectives, and targets of each of the applied research programs are identified in the multi-year program plans for EERE, the Office of Fossil Energy, and the Office of Nuclear Energy; and the basic research areas addressed by the Office of Science are described in *Basic Research Needs for the Hydrogen Economy–Report of the Basic Energy Sciences Workshop on Hydrogen Production, Storage, and Use.* All of these documents are available at www.hydrogen.energy.gov/program_plans.html.

In the past year, the Program made significant advances toward its goals and objectives. Highlights of the Program's accomplishments and progress are summarized below.

PROGRAM PROGRESS & ACCOMPLISHMENTS

Fuel Cells

The Fuel Cell sub-program has made significant advances in increasing the durability of membrane electrode assemblies (MEAs); reducing the projected cost of fuel cell systems; improving membrane performance under hot, dry operating conditions; and characterizing fuel cell materials and components. 3M has mechanically stabilized the membrane used in its MEA, extending its durability in the lab to over 7,300 hours with voltage cycling, as shown in Figure 1. This MEA has the potential to meet the DOE 2010 target of 5,000 hours in an automotive fuel cell system. In addition, the alloy catalyst used for this MEA is approaching the 2010 target for total platinum content (g/kW).

The lower platinum content of alloy catalysts such as these contributed to a reduction in the cost of 80-kW fuel cell systems from $94/kW in 2007 to $73/kW, projected to high-volume manufacturing

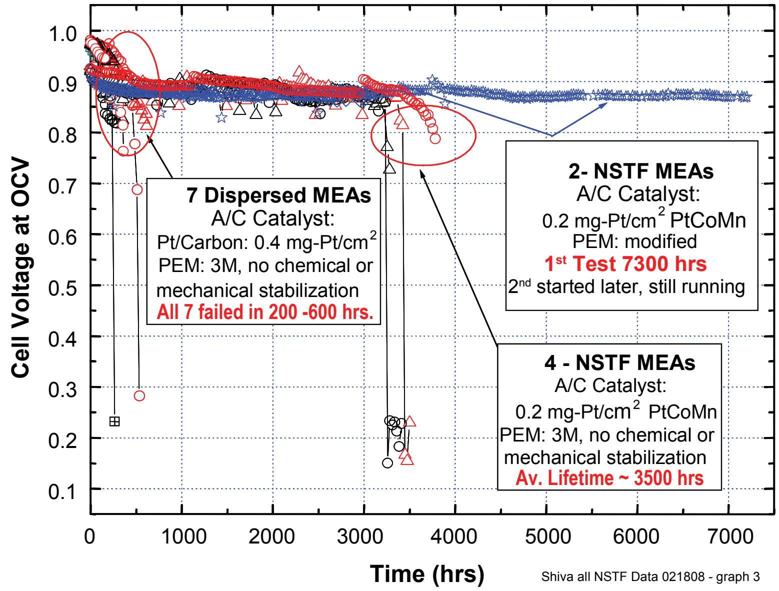


FIGURE 1. 3M nanostructured thin film (NSTF) MEA with stabilized membrane demonstrating greater than 7,300 hours of durability.

(500,000 systems/year). Additionally, eliminating one of the system controllers and switching to screen-printed coolant and end gaskets in the model led to further cost reductions.

While 3M's results are promising for both catalysts and MEAs, fuel cell systems for automotive applications will also need membranes capable of operating under hot, dry conditions. Such membranes will allow vehicle operation over a wider range of conditions and reduce the need for humidification and heat management balance-of-plant components, thereby further reducing cost. Case Western Reserve University demonstrated materials with the potential to meet proton conductivity targets under the most severe conditions, although further progress is necessary to improve the stability and durability of these materials for use in membranes. Giner Electrochemical Systems, LLC has met an interim target for proton conductivity under less severe conditions using dimensionally stable membranes.

Novel characterization work at Oak Ridge National Laboratory (ORNL) and the National Institute of Standards and Technology (NIST) has advanced the development of materials and components. Continuing work at ORNL on microstructural characterization using transmission electron microscopy allows developers to visualize the effects of electrode degradation, while improvements in neutron radiography resolution at NIST provide unprecedented insight into water distribution in operating fuel cells.

Hydrogen Production

Renewable-Based Hydrogen. Progress made this year in reforming bio-fuels helped to reduce the cost of bio-derived hydrogen. The National Renewable Energy Laboratory (NREL) has improved hydrogen yield and system efficiency of bio-oil reforming. Similarly, Ohio State University (OSU) has demonstrated H_2 yields greater than 90% during bio-ethanol steam reforming over non-precious metal catalysts at temperatures below 500°C under neat reaction conditions. Analysis shows that, with these improvements, the NREL and OSU processes have the potential to meet the 2019 hydrogen production cost target of $3.00/gasoline gallon equivalent (gge) including delivery. These improvements include developing catalysts with lifetimes exceeding 1 year; reducing the cost of H_2 by 10X since 2005; increasing reactor size for sugars and sugar alcohols to 10 kg H_2/day – an increase of 700X; and improving hydrogen productivity from bio-derived carbohydrates.

The sub-program also demonstrated progress in other renewable hydrogen production pathways. Cost projections for the active solar thermochemical cycles have been reduced from about $10.00/gge to below $5.00/gge and are showing the potential to meet the 2019 cost target of $3.00/gge. Additionally, the University of Nevada, Las Vegas and the University of Hawaii accomplished the first all-experimental determination of the electronic surface structure of a candidate photoelectrochemical material (WO_3), enabling in situ, real-time material characterization. Furthermore, the J. Craig Venter Institute cloned a novel hydrogenase, along with its structural and accessory genes, using environmental DNA, providing the capability to greatly expand the library of hydrogen producing enzymes.

Another pathway to renewable-based hydrogen is electrolysis powered from renewable energy sources. Giner Electrochemical Systems, LLC has improved stack efficiency from 61% (400 psi) to 67% (1,200 psi) and has tested (see Figure 2) a new dimensionally-stabilized membrane (DSM™) in a single cell which shows an efficiency of 74%. The DSM™ is about 1/10 the cost of the current Nafion®-based one.

Hydrogen from Coal. Significant progress was made in the area of membrane separation technology for the production of hydrogen from coal. Eltron Research, Inc. and Southwest Research Institute® demonstrated, in bench-scale tests, membranes that have the potential to meet nearly all of the Office of Fossil Energy's 2010 hydrogen separation targets. Preliminary cost estimates of the Eltron membrane show that it could be competitive with conventional technology. Southwest Research Institute®, meanwhile, has produced self-supported Pd-Cu alloy membranes that have reduced membrane thickness to 5 microns.

Nuclear Hydrogen. Development and assembly of components into integrated laboratory-scale experiments to test high-temperature hydrogen production processes continues to move forward from last year. In the area of thermochemical cycles, General Atomics, Sandia National Laboratories, and the French Commissariat à l'Energie Atomique produced hydrogen from the Sulfur-Iodine reaction at initial rates of 30-40 liters per hour. Idaho National Laboratory upgraded their integrated laboratory-scale high temperature steam electrolysis system to the full 720-cell configuration and began operations with an initial output of over 5,000 liters per hour.

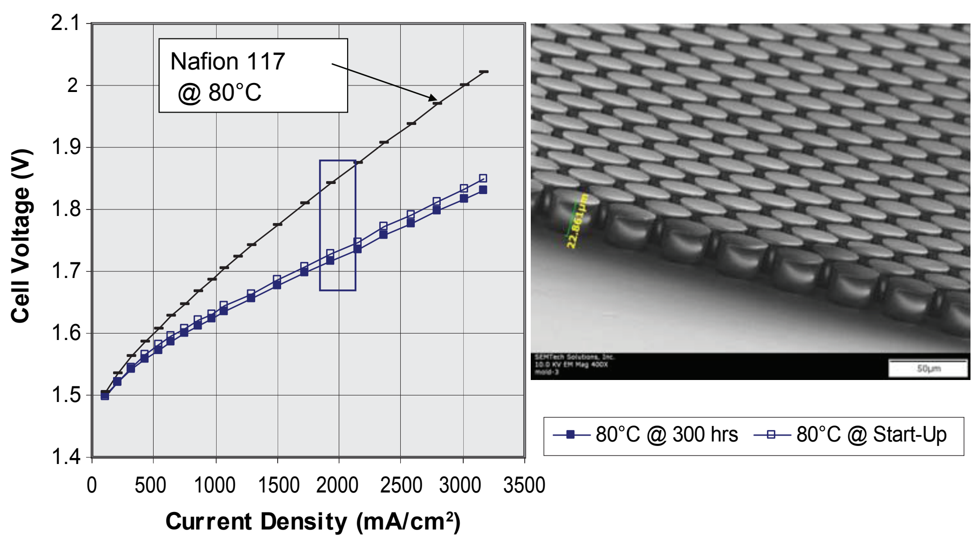


FIGURE 2. Giner's DSM operates at a lower voltage, and therefore higher efficiency, than the state-of-the-art Nafion® membrane throughout the range of operating currents. The image at right depicts the micro mold used to form the Giner membrane.

Hydrogen Delivery

Researchers continued to make major advances in modeling hydrogen delivery infrastructure through the H2A Hydrogen Delivery Model, expanding and improving the analysis of the current costs of hydrogen delivery using pipelines, liquid trucks, and gaseous trucks.

In addition, researchers made advances this year in reducing hydrogen leakage during delivery. Savannah River National Laboratory and ORNL completed leakage measurements on fiberglass-reinforced plastic pipelines (FRPs) and verified that the leakage rate was less than 0.5%. These materials meet the 2012 cost target and have good potential to achieve the 2017 cost target of $1.00/gge, assuming that capacity can be met by bundling existing FRPs and that current FRP technology will meet leakage standards to be developed in 2010. Fuel Cell Energy developed an advanced electrochemical compression technology, the seals for which have been leak-tested to 280 bar and have operated continuously with no hydrogen leakage at a pressure over 140 bar for 2,000 hours, and have completed over 100 cycles from near atmospheric pressure to 205 bar.

Hydrogen Storage

In FY 2008, the Storage sub-program continued to make progress in all three classes of materials under investigation–hydrogen sorbents, reversible metal hydrides, and chemical hydrogen carriers. These achievements involved improvements in operational properties, not just in storage capacity. Examples include the following:

- Metal organic framework materials with open-metal sites have been demonstrated to have initial H_2 binding enthalpies of between 8 and 12 kJ/mol. Such binding energies may potentially increase the low-pressure H-capacity by up to 75% over adsorbents with typical physisorption binding enthalpies of ~5-6 kJ/mol. These tailored materials have volumetric hydrogen densities of 24-45 g/L (crystal, not system, densities).
- Mechanistic studies enabled the identification of non-platinum group metal heterogeneous catalysts that increased the hydrogen release rate from ammonia borane (NH_3BH_3, AB) by a factor of two, which can meet the DOE target from a material perspective. The increased kinetics, especially for the release of the second equivalent of hydrogen, effectively increased the capacity to greater than 9 wt% H_2 at 70°C.
- HRL Laboratories and Lawrence Livermore National Laboratory have incorporated hydrogen storage materials, such as $LiBH_4$, into carbon aerogel scaffolds with improvements in sorption properties. For example, as shown in Figure 3, $LiBH_4$ incorporated into a 13 nm scaffold achieved a 60-fold increase in desorption rates, an increase from 0.2 wt%/h for a bulk reference sample to 12.5 wt%/h for the incorporated sample at 300°C, demonstrating that DOE rate targets could be achieved.
- An improved insulation method has led to doubling of the dormancy time for cryocompressed H_2. This approach offers the advantage of higher gravimetric and volumetric densities than ambient compressed H_2 but requires an insulated container. Other than liquid H_2, this approach comes closest to meeting the DOE 2010 systems targets for weight and volume.

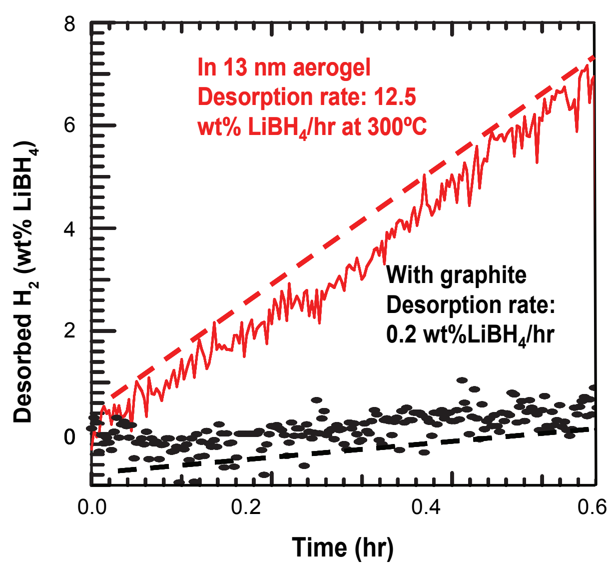


FIGURE 3. Desorption rate of $LiBH_4$ incorporated into a 13 nm aerogel, showing a 60-fold increase over $LiBH_4$ with graphite.

Basic Research

The Office of Basic Energy Sciences (BES) within the DOE Office of Science supports fundamental research addressing critical scientific challenges related to hydrogen storage, production, and fuel cells. This basic research complements the applied research and development projects supported by the other offices in the DOE Hydrogen Program.

In FY 2008, the BES Contractors' Meeting, featuring basic research fundamental to the advancement of renewable hydrogen production (solar and bio-inspired), was co-located with the Hydrogen Production sub-program presentations at the 2008 DOE Hydrogen Program Annual Merit Review and Peer Evaluation Meeting (AMR). In FY 2009, the BES Contractors' Meeting will feature basic research fundamental to hydrogen storage and will be co-located with other hydrogen storage sub-program presentations at the 2009 AMR. A joint BES/EERE meeting on Hydrogen Storage Theory is also planned at the 2009 AMR, which would mark the third time this group of researchers has met to discuss critical issues related to theoretical studies of hydrogen storage. This integrated approach ensures that discoveries and related conceptual breakthroughs achieved in basic research programs provides a foundation for the innovative design of materials and processes that will lead to improvements in the performance, cost, and reliability of technologies for hydrogen production, storage, and use.

In FY 2008, BES continued to gain insight into the fundamental processes that are critical to issues in hydrogen storage, membranes, catalysis, bio-inspired processes, and solar hydrogen production. Researchers developed a unique and highly efficient hybrid hydrogen generator utilizing a special molecular wire to link a highly efficient biological solar absorber with a robust inorganic catalyst, improved understanding of size range and spatial distribution of nano-scale water channels in Nafion® membranes, and created tailored nanorod structures for hydrogen production from solar water splitting that maximize solar absorption and increase the ability to utilize the photocurrent using less expensive catalyst materials.

Technology Validation

In FY 2008, the National Hydrogen Learning Demonstration Project (Figure 4) completed its fourth full year of data collection. The project continued to place generation 2 vehicles in service and to add hydrogen fueling stations, bringing the number fuel cell vehicles in the project to 122 and the number of fueling stations to 16 (hydrogen for the fueling stations is being supplied by truck and through on-site electrolysis or natural gas reforming).

Teams continue to collect and provide data to the Hydrogen Secure Data Center at NREL. More than 50 composite data products—which are ranges of technical values that do not identify which company provided the information—have been generated from the collected data. These composite data products cover a number of parameters, such as fuel cell durability and efficiency, fuel economy, vehicle driving range, on-board hydrogen storage performance, vehicle and infrastructure safety events, hydrogen impurities detected in samples from refueling stations, and vehicle refueling rates. The performance and reliability of the vehicles in the learning demonstration continue to improve. Projected fuel cell system durability has increased from 1,600 hours in 2007 to 1,900 hours (57,000 miles) in 2008 with an observed durability of 1,700 hours. Data from the four teams demonstrated net system efficiencies of 52.5% to 58.1%, which is very close to the DOE target of 60%. Vehicle range is now between 196 and 254 miles, up from between 103 and 190 miles.

In addition to the National Learning Demonstration, the sub-program has further developed the Hawaii Hydrogen Power Park, a small-scale distributed generation project providing power and hydrogen fuel. This year the project secured a commitment for funding from the State of Hawaii; approval of funding from the Federal Transit Administration through the National Park Service for the supply of two hydrogen plug-in hybrid electric vehicle shuttle buses; and the support of the Department of Defense to install a fueling station at the Kilauea Military Camp.

The National Hydrogen Learning Demonstration includes four industry teams that are working towards meeting the 2009 targets listed below.

Performance Measure	2009*	2015**
Fuel Cell Stack Durability	2000 hours	5000 hours
Vehicle Range	250+ miles	300+ miles
Hydrogen Cost at Station	$3.00/gge	$2.00 - $3.00/gge

* To verify progress toward 2015 targets ** Subsequent projects to validate 2015 target

FIGURE 4. National Hydrogen Learning Demonstration Project

Safety, Codes & Standards

The Safety, Codes & Standards sub-program continued to develop Web-based safety information tools in FY 2008. Building on work from last year, the sub-program expanded the *Technical Reference for Hydrogen Compatibility of Materials* (http://public.ca.sandia.gov/matlsTechRef/) to include martensitic stainless steels (e.g., 400-series, 17-4 PH), semi-austenitic stainless steels (e.g., 17-7 PH), and polymers. Furthermore, the sub-program developed and released an online Permitting Compendium for Hydrogen Facilities, a one-stop information resource to facilitate the permitting of hydrogen fueling stations and stationary fuel cell installations.

In addition to managing these online resources, the sub-program continued to provide valuable safety input and technical data to the codes and standards development process. The sub-program introduced a technically traceable, risk-informed approach for separation distances for hydrogen fueling stations to the NFPA 55 and NFPA 2 code committees; developed safety information materials for emergency responders and authorities having jurisdiction; and worked with the Hydrogen Safety Panel to promote safety practices across the Program.

Education

Based on feedback from the past year, the Education sub-program continued to expand safety education resources by updating "Introduction to Hydrogen Safety for First Responders" to include an audio narration, an extended video explaining the basic properties of hydrogen, an expanded codes and standards module, an expanded stationary facilities section, and the addition of early market fuel cell information on specialty vehicles. Since its launch in January 2007, registered users have totaled approximately 7,000 and consist of the fire prevention/protection community, law enforcement, industry, universities, military, non-profits, and national and international users. In addition, the sub-program completed beta versions of hands-on safety training "Hydrogen Safety for First Responders" and "Introduction to Hydrogen Safety for Code Officials."

The sub-program extended its end-user, state and local government, public, and student education efforts as well. New efforts include publishing a set of case studies on early market fuel cells to educate early adopters on the basics and value proposition of the technology; organizing the Bi-Monthly Informational Conference Call Series for State and Regional Hydrogen and Fuel Cell Initiatives;

participating in the planning committee of the Hydrogen Road Tour with the U.S. Department of Transportation; deploying radio spots across the country, collaborating with the Orlando Magic to promote "Increase Your H2IQ", and launching a MySpace page targeted at teens and young adults as part of the "Increase Your H2IQ Public Information Program"; and disseminating the "H2 Educate!" middle school curriculum materials through one-day teacher training workshops and completing an iterative prototype testing and revision of the "HyTEC" high school curriculum.

Systems Analysis

The Systems Analysis sub-program continued to focus on the development of core models for hydrogen analysis and on conducting resource, infrastructure, well-to-wheels, and hydrogen quality analysis for different hydrogen production and delivery pathways. Significant progress was made in FY 2008 in the areas of scenario and early market analysis and in the development of the Macro-System Model.

In FY 2008, ORNL published the 2010–2025 Scenario Analysis for Hydrogen Fuel Cell Vehicles and Infrastructure last year, the researchers issued their report this year. The report included feedback from industry, academia, and national models on vehicle penetration scenarios and the requisite infrastructure to support these scenarios. The analysis suggests that costs over the early transition period are feasible, between $10 billion and $50 billion over 14 years. Analysis was also conducted to understand the impacts of government purchase programs on fuel cell cost and well-to-wheels greenhouse gas reductions from early market adoption of fuel cells for distributed power and forklifts. The analysis was conducted with the ORNL HyTrans and the Argonne National Laboratory (ANL) GREET models. Using conservative assumptions for scale economies and learning-by-doing, the analysis found that a federal acquisition program could catalyze a sustainable North American polymer electrolyte membrane (PEM) fuel cell industry, driving costs down enough to make fuel cell products competitive with incumbent technologies by 2015.

The Macro-System Model was completed to link models of different architecture and enable complete hydrogen pathway analysis. The model, which was peer-reviewed, was used to analyze delivered hydrogen cost, well-to-wheels parameters, and hydrogen losses for several pathways. The results of nine analyses using the Macro-System Model were compared to results from the European Commission-funded HyWAYS project to analyze hydrogen pathway cost and well-to-wheels oil use and greenhouse gas emissions. The comparison showed that the results were fundamentally the same, although there were discrepancies, such as a financial focus on business cases in the Marco-System Model as compared to a focus on policy support in the HyWAYS project,

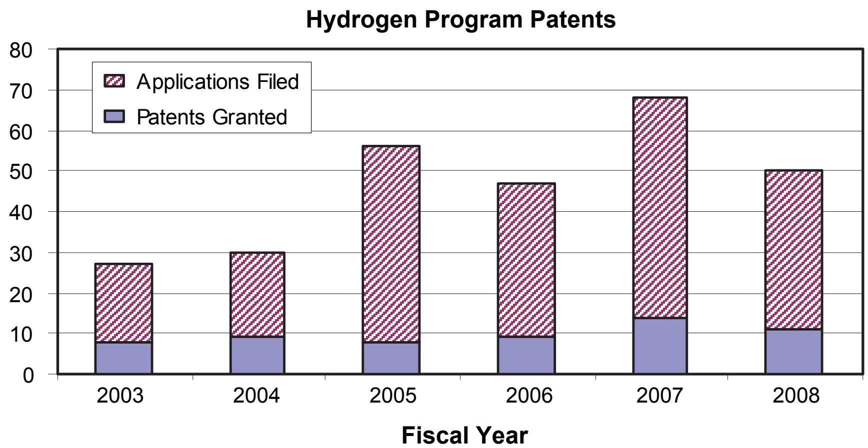
In addition to these successes, researchers published analytical results in four other areas of hydrogen and fuel cell technology. ANL found that fuel cells in distributed power generation and lift truck applications could lead to greenhouse gas and energy benefits over battery and combustion technologies, especially when comparing total fuel cycle energy use. Analysis by TIAX LLC showed that platinum leasing and recycling could reduce fuel cell system cost by $3/kW to $6/kW. Finally, NREL developed the Hydrogen Demand and Resource Analysis Tool (HyDRA), a tool identifying geographic resource availability and hydrogen production costs.

Manufacturing R&D

Research funded through the Manufacturing sub-program demonstrated improvements in hydrogen storage and fuel cell stack manufacturing processes and in quality assurance techniques. Profile Composites reduced the high-rate manufacture cycle time of 35-MPa carbon composite tanks from 7-9 hours to 30 minutes; Protonex Technology Corporation reduced fuel cell stack build times by a factor of four; and ASME Standards Technology demonstrated a Modal Acoustic Evaluation technique for detecting defects in high-pressure tanks.

New Patents

One indicator of the robustness and innovative vitality of a research and development program is the number of patents applied for and granted. Each year, the DOE Hydrogen Program tracks the number of patents that are filed by or awarded to projects it sponsors. In FY 2008, 11 new patents were issued for discoveries or technologies developed in DOE Hydrogen Program projects; 39 more applications were filed or are in the process of being awarded.



NEW PROJECTS SELECTED AND NEW SOLICITATIONS ISSUED

In FY 2008, the DOE Hydrogen Program competitively selected many new projects to address key barriers in the development of hydrogen and fuel cell technologies. These included:

- Eight projects ($18 million over three years; $26.4 million with cost share) to conduct RD&D activities in hydrogen production and delivery, including hydrogen compression, off-board storage, liquefaction, and electrolysis.
- Ten projects (up to $15.3 million over five years; cost share amount undetermined) to develop novel hydrogen storage materials, develop efficient methods for regeneration of hydrogen storage materials, and increase hydrogen binding energies to enable room temperature hydrogen storage.
- Thirteen projects ($4.4 million over up to three years; $5.2 million with cost share) in the areas of state and local government outreach; early deployment and education; and university programs.
- One project (anticipated for up to 3 years; $0.3 million for H-prize administration; $1.0 million for the initial hydrogen storage H-prize) to administer and advertise the H-prize competitions, raise funds to contribute to the cash prizes, and work with DOE to develop criteria for the selection of judges and prize winners.
- One project ($0.45 million over three years) in electrolyzers for hydrogen production from nuclear power plants.
- Six projects ($5.5 million over two to three years; $7.5 million with cost share) in hydrogen production from coal.
- Five projects ($12.8 million over four years; $21.7 million with cost share) in research and development (R&D) of manufacturing processes for fuel cell and hydrogen storage systems.

In June 2008, the Program announced a new funding opportunity soliciting applicants to conduct R&D in advanced fuel cell technology. This solicitation concentrates on the major topics that need to be addressed to advance the development and use of fuel cells for automotive, stationary, and portable power applications; to demonstrate fuel cells in distributed energy systems; and to support market transformation projects that provide real-world operation data. Total estimated funding available is $130 million, pending congressional appropriations, with an expectation of about 50 selected projects and a private sector cost share of approximately $40 million. The solicitation closed in August; selections are expected in January.

INTERNATIONAL ACTIVITIES

International Partnership for the Hydrogen Economy

The International Partnership for the Hydrogen Economy (IPHE), which includes 16 member countries (Australia, Brazil, Canada, China, France, Germany, Iceland, India, Italy, Japan, New Zealand, Norway, Republic of Korea, Russia, the United Kingdom, and the United States) and the European Commission, is a forum for governments to work together to advance worldwide progress in hydrogen and fuel cell technology research, development, and deployment. IPHE is also a forum for international R&D managers, researchers, and policymakers to openly share program strategies.

Since its inception, the IPHE has endorsed a total of 30 collaborative projects that cover a broad range of topics including hydrogen production, hydrogen storage, fuel cell technology, demonstration of fuel cell technology in light-duty vehicles and buses, and the socio-economic impacts of hydrogen production. In 2008, the IPHE published a Hydrogen and Fuel Cell Brief for Policymakers and initiated three new global IPHE projects focusing on Hydrogen Highways, Renewable Hydrogen Production, and an International Youth Competition. For more information, please visit www.iphe.net/.

International Energy Agency

The International Energy Agency's (IEA's) Implementing Agreements provide a mechanism for member countries to share the results of research activities. The DOE Hydrogen Program participates in two of these–one supporting fuel cell R&D activities and one supporting hydrogen R&D activities.

The IEA Advanced Fuel Cells Implementing Agreement (AFCIA) currently comprises six tasks: 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 Applications. The participating countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, South Korea, the Netherlands, Norway, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. The United States participates in all of the AFCIA's tasks except Fuel Cells for Portable Applications. The members plan to renew the implementing agreement beyond 2008, when it is currently scheduled to end. Information about the IEA Advanced Fuel Cells Implementing Agreement is available at www.ieafuelcell.com.

The IEA Hydrogen Implementing Agreement (HIA) is focused on RD&D and analysis of hydrogen technologies. Two tasks added this year, "Photoelectrochemical Hydrogen Production: Advanced Materials for Waterphotolysis" and "Large Scale Hydrogen Infrastructure and Mass Storage", bring the number of approved tasks under the HIA to nine. These new tasks seek to leverage international investment in materials R&D for photoelectrochemical water splitting and in lowering the cost of delivering hydrogen to the point of use. The seven continuing tasks are: Integrated Systems Evaluation & Analysis, Hydrogen Safety, Biohydrogen, Fundamental and Applied Hydrogen Storage Materials Development, Small-Scale Reformers for On-site Hydrogen Supply, Wind Energy and Hydrogen Integration, and High Temperature Production of Hydrogen. 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, the United Kingdom, and the United States.

This year, the IEA HIA awarded the inaugural IEA HIA Individual Prize to Dr. Gary Sandrock, a U.S. researcher, who was instrumental in growing the hydrogen storage research collaboration to over 50 experts participating from 15 countries in the past 10 years. The IEA HIA Individual Prize was created to celebrate hydrogen research and development distinguished by technical excellence and harmony in international cooperation that contributes to the understanding and advancement of basic and applied hydrogen science. As part of the Integrated Systems Evaluation task, the IEA HIA completed a number of case studies[1] in hydrogen systems that synthesized lessons learned and technology operating experience that is instrumental to lowering the barriers for market introduction

[1] IEA HIA website, http://www.ieahia.org/page.php?s=d&p=casestudies

and adoption. These case studies, including a proposed hydrogen power station with carbon capture in the United Kingdom, the EPACOp project (Expérimentation de 5 Piles A Combustible sur sites OPérationnels) in France to test PEM fuel cells under "real world" conditions for residential and commercial applications, and a hydrogen house in Italy, provide the DOE Program insight into progress made by other member countries.

OTHER PROGRAM ACTIVITIES

Hydrogen Quality

The quality of hydrogen fuel is expected to play a large role in the ultimate performance, durability, and cost of fuel cell systems. Higher quality fuel allows for lower fuel cell system costs, while higher fuel quality requirements correlate to higher lifecycle costs for hydrogen production, purification, distribution, storage, and analytical systems. To quantify these relationships and to develop a roadmap to define R&D priorities in this cross-cutting area, DOE established the Hydrogen Quality Working Group, which includes participants from the automotive and energy industries, the national laboratories, and the DOE Hydrogen Program.

The Hydrogen Quality Working Group is developing a model to analyze the tradeoffs for hydrogen production and fuel cell performance based on various levels of hydrogen quality. For this analysis, the Working Group has developed a model of the pressure-swing adsorption hydrogen purification system. Using this model, researchers have assessed the effect of allowable CO concentrations on hydrogen production costs. While reducing CO concentration in hydrogen fuel is not expected to significantly impact the cost of hydrogen production, the cost of measuring CO concentrations at the proposed low levels of 0.1 ppm can increase the dispensed cost of hydrogen significantly. Work continues to develop this model further and to seek experimental verification of the results.

Parallel work by researchers at Los Alamos National Laboratory has explained the effect of H_2S on fuel cell performance and degradation. This analysis demonstrates that while H_2S can block Pt sites irreversibly under normal operating conditions, performance can be partially recovered by a hold at open circuit voltage, with longer holds providing greater recovery.

Market Transformation

The Program is undertaking market transformation activities to promote early commercialization of hydrogen and fuel cell power systems. The goal of these activities is to validate the technologies in integrated systems in real-world operation, eliminate non-technical barriers, help companies bridge the "valley of death" between development and commercialization, increase the opportunities for market expansion, and enable agencies to meet the energy efficiency goals outlined in the President's Executive Order 13423, which "requires agencies to reduce greenhouse gases through a reduction in energy intensity of 3% a year or 30% by the end of fiscal year 2015."

The pathway to fuel cell vehicle commercialization will likely include the introduction of direct hydrogen PEM fuel cells in near-term markets with fewer technological challenges than the automobile market. The most promising near-term market opportunities for PEM fuel cells in this size range are in specialty vehicle and backup power applications. PEM fuel cell systems are commercially available for use in these applications, and they offer several potential advantages over current technologies, including lower emissions, lower operational and maintenance requirements, longer runtimes, and other improvements in productivity.

The Federal government can play a critical role in supporting and enhancing the market introduction of new technologies by being an early adopter and gathering operating performance data. To that end the Interagency Task Force (ITF), consisting of senior-level representatives from fifteen agencies, was formed. This year, the ITF convened twice, first to discuss commercially available products and deployment opportunities and second to discuss financing mechanisms such as energy service agreements and utility energy service contracts for fuel cell deployment.

As a result of ITF activities, the DOE Hydrogen Program is actively collaborating with the Department of Defense to deploy fuel cell lift trucks; supporting installation of fuel cells in backup power applications at the Federal Aviation Administration, the U.S. Army at Fort Jackson, the California National Guard, and the U.S. Marine Corps; and sponsoring fuel cell vehicle use at the U.S. Postal Service and the Environmental Protection Agency. In addition, DOE commissioned HDR, a nationally recognized independent architecture and engineering firm, to conduct an engineering evaluation to assess the technical feasibility and confirm performance assumptions for installing fuel cells at DOE's Germantown data center. The study found that a combined heat and power fuel cell system dedicated to the data center would increase availability of the data center from 99.9% to 99.999%, improve energy efficiency by about 2.3 times, and avoid 84% (by weight) of the emissions currently associated with grid power.

By purchasing fuel cells to meet their energy needs, Federal agencies can play a role in reducing technology cost. As shown in Figure 5, federal purchases of 2,000 units per year would reduce manufacturing costs by more than a factor of 3. In addition, higher volume purchases are expected to expand the domestic supplier base and increase public awareness.

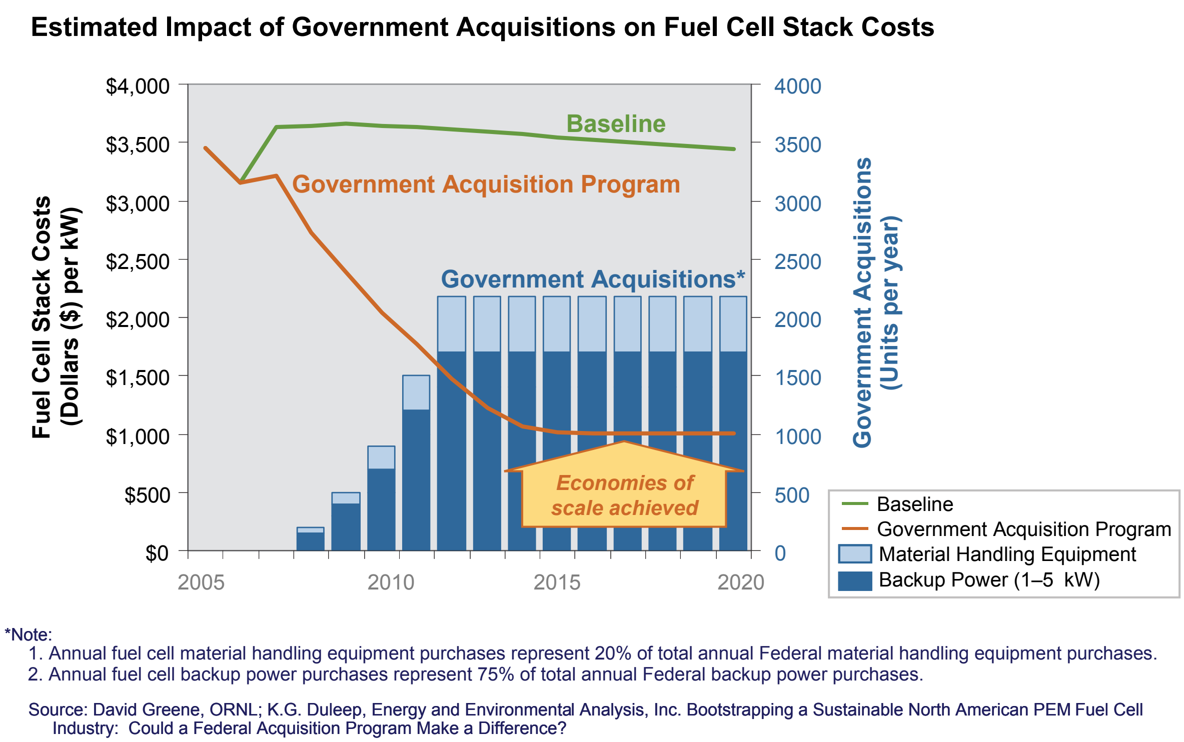


FIGURE 5. Federal acquisitions of fuel cells can reduce the cost per kW of fuel cell stacks.

EXTERNAL COORDINATION, INPUT, AND ASSESSMENT

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

Underpinning the ITF, the staff-level Hydrogen and Fuel Cell Interagency Working Group (IWG), co-chaired by DOE and the White House Office of Science and Technology Policy, meets monthly to share expertise and information about ongoing programs and results, to coordinate the activities of Federal entities involved in hydrogen and fuel cell RD&D, and to ensure efficient use of taxpayer resources. The working group has an ad-hoc committee to provide a forum for more focused collaboration on biomass-to-hydrogen production and the use of fuel cells for rural and agricultural applications (led by DOE and the Department of Agriculture). The IWG's public Web site, www.hydrogen.gov, serves as a portal to information about all federal hydrogen and fuel cell activities, programs, and news. Among its features is an interactive map developed by the regulatory ad-hoc committee with direction from the Department of Transportation to illustrate the current U.S. statutes and regulations that may be applicable to hydrogen.

DOE Utilizes Expertise from Stakeholder Community and Government Partners

Hydrogen and Fuel Cell Technical Advisory Committee. The Hydrogen and Fuel Cell Technical Advisory Committee (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 safety, economic, and environmental issues related to hydrogen. 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.

The HTAC met three times between August 2007 and August 2008. The committee's initial recommendation was to elevate the level of participation in the Interagency Task Force on Hydrogen and Fuel Cells (ITF) to the functional level of Assistant Secretary or higher, to ensure appropriate decision-making membership from each agency. DOE has implemented this recommendation. In its first biennial report to the Secretary, the committee commended the Program, among other things, for a Posture Plan considered, "well thought out and comprehensive," for dedicating "a large percentage of the research and development budget to activities at the component level," and for, "connecting technology objectives with market value."[2] As required by the Energy Policy Act (EPACT), the Secretary's biennial report to Congress is scheduled for release this year, describing HTAC's recommendations, addressing how DOE will implement those recommendations, and providing an explanation for those recommendations that will not be implemented.

National Academy of Sciences. The National Research Council (NRC) of the National Academies provides ongoing technical and programmatic advice to the DOE Hydrogen Program. The NRC conducted a review of the Program between 2002 and 2004 to provide recommendations for improvement, which were outlined in the council's report, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs.*[3] Following this review, in 2005 the NRC established the Committee on Review of the FreedomCAR and Fuel Program, to conduct an independent review of the research and development program of the FreedomCAR and Fuel Partnership. This committee has twice reviewed the Partnership to offer recommendations on the Partnership's technical direction, strategies, funding, and management. The NRC's recommendations regarding the Partnership were published in a 2005 report, entitled *Review of the Research Program of the FreedomCAR and Fuel Partnership: First Report*[4], and a 2008 report, entitled *Review of the Research Program of the FreedomCAR and Fuel Partnership: Second Report.*[5] In parallel with the second review, the NRC conducted a study to determine the investments in R&D, demonstrations, education, and infrastructure that will be required for the development of fuel cell technologies and for the successful transition from petroleum to hydrogen-fueled vehicles in a significant percentage of the U.S. vehicle market by 2020. This report, entitled *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen*,[6] required by

[2] "Letter Report to Secretary of Energy Samuel Bodman," Hydrogen and Fuel Cell Technical Advisory Committee, October, 2007. (http://www.hydrogen.energy.gov/pdfs/htac_letter_report_attach.pdf)

[3] National Research Council and National Academy of Engineering, Committee on Alternatives and Strategies for Future Hydrogen Production and Use, The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs, (Washington, D.C.: National Academies Press, 2004).

[4] National Research Council of the National Academies; Committee on Review of the FreedomCAR and Fuel Research Program, Phase 1; Board on Energy and Environmental Systems, Division on Engineering and Physical Sciences, Transportation Research Board; *Review of the Research Program of the FreedomCAR and Fuel Partnership: First Report,* (Washington, DC: National Academies Press, 2005).

[5] National Research Council of the National Academies; Committee on Review of the FreedomCAR and Fuel Research Program, Phase 2; Board on Energy and Environmental Systems, Division on Engineering and Physical Sciences, Transportation Research Board; Review of the Research Program of the FreedomCAR and Fuel Partnership: Second Report, (Washington, DC: National Academies Press, 2008).

[6] National Research Council of the National Academies; Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies; Board on Energy and Environmental Systems, Division on Engineering and Physical Sciences; to

EPACT section 1825, was also published this year. The study concluded fuel cell vehicles and hydrogen production technologies could be ready for commercialization in the 2015-2020 timeframe, that up to 2 million hydrogen fuel cell vehicles that could be operating by 2020 and that by 2050 they could account for more than 80 percent of new vehicles entering the fleet. The committee also found that while use of alternatives such as improved fuel economy, increased penetrations of hybrid vehicles and biomass derived fuels could provide significant reductions in U.S. oil use and CO_2 emissions over the next two decades, in the long-term, the transition to hydrogen-fueled vehicles could achieve greater and sustainable reductions in U.S. oil consumption and CO_2 emissions.

DOE has addressed the recommendations from NRC's first review and incorporated many of them into the Program (details are available upon request). In the Phase II Report, the NRC found that the Partnership is "well planned, organized, and managed," and that "there has been significant progress in most areas since the Phase I report." Recommendations include continuing support for hydrogen storage and fuel cell research; continuing studies of the transition to hydrogen, extended into 2030 - 2035; and maintaining adequate support for technical validation.

Government Accountability Office. At the request of the House Committee on Science and Technology, the Government Accountability Office (GAO) conducted a review of the HFI. Specifically, GAO was given the task of assessing the extent to which federal agencies implementing the HFI have (1) made progress in meeting the R&D targets of the initiative; (2) worked with industry to set and meet R&D targets; and (3) worked with other federal agencies to develop and demonstrate hydrogen technologies. The GAO report commended DOE for making important R&D progress, for effectively aligning its R&D priorities with industry, and for working with other agencies in coordinating activities and facilitating scientific exchanges. The GAO recognized DOE's increased efforts in stationary and portable fuel cell technologies—and the role these may play in paving the way for fuel cell vehicles in the future. The GAO also acknowledged the creation of the ITF to coordinate efforts at the policy level.

The GAO report also stated that difficult technical challenges lie ahead, particularly in hydrogen storage and delivery, fuel cell cost and durability, and hydrogen infrastructure deployment. The GAO recommended that the *Hydrogen Posture Plan* be updated to provide an overall assessment of what DOE reasonably expects to achieve by its technology readiness date, including how this may differ from previous posture plans, and a projection of anticipated R&D funding needs. The Program is currently updating the *Hydrogen Posture Plan* to reflect the progress made in all areas of the Program and any changes to the activities, milestones, deliverables, and timeline.

FY 2008 Annual Merit Review and Peer Evaluation. In addition to soliciting feedback from these expert and stakeholder groups, the DOE Hydrogen Program holds an Annual Merit Review, which provides an opportunity for the Program to obtain an expert peer review of the projects it supports and to report its accomplishments and progress. In 2008, DOE held this review from June 9–13 in Arlington, Virginia. Over 1,000 people attended the review, and 295 projects were presented, of which 232 were peer-reviewed.[7] The AMR also provides a forum for promoting collaborations, exchange of ideas, and technology transfer. Reviewers evaluate the Program's projects and make recommendations to the principal investigators and to the Program. DOE uses these evaluations to make project funding decisions for the upcoming fiscal year. This year, there were 167 contributing reviewers—the report compiling their comments is available at www.hydrogen.energy.gov/ annual_ review.html. The next review will be held May 18–22, 2009, in Arlington, Virginia.

IN CLOSING...

We are pleased to present the *U.S. Department of Energy's 2008 Hydrogen Program Annual Progress Report*. The report is divided into chapters and organized by technology area (e.g., Hydrogen Storage, Fuel Cells, etc.). Each chapter opens with an overview written by a DOE Technology Development Manager that summarizes the progress and accomplishments of this fiscal year. The 278 projects outlined in this document represent the work of the many innovative scientists and engineers

Alternative Transportation Technologies: A Focus on Hydrogen, (Washington, DC: National Academies Press, 2008).

[7] Not all of the projects presented were reviewed, because projects from the DOE Office of Science are reviewed through a process managed by the Office of Science that involves different evaluation criteria and projects that have ended are not reviewed.

supported by the Hydrogen Program. It is they who are responsible for the progress reported herein and the technical accomplishments outlined previously. We thank them for their hard work and steady progress.

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