U.S. DEPARTMENT OF ENERGY

Response to Findings and Recommendations of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) during Fiscal Years 2010 and 2011

Third Biennial Report to Congress
May 2012

United States Department of Energy
Washington, DC 20585

Message from the Secretary

This is the Department's third biennial report to Congress, provided in response to section 807(d)(2) of the Energy Policy Act of 2005 (EPACT 2005), Pub. L. No. 109-58, enacted in August 2005. EPACT 2005 established Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) to advise the Department of Energy on programs and activities under EPACT 2005 Title VIII, Hydrogen. EPACT 2005 states that the Committee is to review and make recommendations on: 1) the implementation of programs and activities under Title VIII of EPACT; 2) the safety, economic, and environmental consequences of technologies for the production, distribution, delivery, storage or use of hydrogen energy and fuel cells; and 3) the plan called for by section 804 of EPACT, known as the *DOE Hydrogen and Fuel Cells Program Plan* (formerly the *Hydrogen Posture Plan*).

Section 807 of EPACT requires the Department to transmit to Congress, with the budget request, a biennial report responding to the Committee's recommendations. HTAC held six meetings during Fiscal Years 2010 and 2011. This report presents the recommendations of the HTAC during this time period and DOE's relevant responses, and it is being provided to the following members of Congress:

- **The Honorable Joseph R. Biden**
  President, United States Senate
- **The Honorable John Boehner**
  Speaker, United States House of Representatives
- **The Honorable Daniel K. Inouye**
  Chairman, Senate Committee on Appropriations
- **The Honorable Dianne Feinstein**
  Chairman, Senate Subcommittee on Energy and Water Development
- **The Honorable Jeff Bingaman**
  Chairman, Senate Committee on Energy and Natural Resources
- **The Honorable Harold Rogers**
  Chairman, House Committee on Appropriations
- **The Honorable Rodney P. Frelinghuysen**
  Chairman, House Subcommittee on Energy and Water Development
- **The Honorable Fred Upton**
  Chairman, House Committee on Energy and Commerce
- **The Honorable Ralph M. Hall**
  Chairman, House Committee on Science and Technology

If you have any further questions, please contact me or Mr. Jeff Lane, Office of Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Steven Chu

Executive Summary

Section 807(d) of the Energy Policy Act of 2005 (EPACT 2005), Pub. L. No. 109-58, states that the Secretary of Energy (the Secretary) shall transmit a biennial report to Congress describing any recommendations made by the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC or the Committee) since the previous report. EPACT 2005 states that the report shall include a description of how the Secretary has implemented or plans to implement the recommendations, or an explanation of the reasons that a recommendation will not be implemented. During fiscal years (FYs) 2010 and 2011, HTAC provided recommendations to the Secretary in the form of two letters, delivered March of 2010 and March of 2011, as well as two annual state-of-the-industry reports (the 2009 and 2010 *ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee: The State of Hydrogen and Fuel Cell Commercialization and Technical Development*). These documents are provided in the appendices to this report. HTAC met three times in FY 2010 and three times in FY 2011, and held multiple discussions that contributed to the reports and letters to the Department of Energy. This document, the Secretary's *Third Biennial Report to Congress,* responds to the letters from HTAC.

HTAC was established under EPACT 2005 to advise the Secretary on programs and activities under EPACT 2005 Title VIII, Hydrogen. The Committee's charter is to review and make recommendations to the Secretary on: 1) the implementation of programs and activities under Title VIII of EPACT 2005; 2) the safety, economic, and environmental consequences of technologies for the production, distribution, delivery, storage, or use of hydrogen energy and fuel cells; and 3) the plan called for by section 804 of EPACT 2005, also known as the *DOE Hydrogen and Fuel Cells Program Plan* (*Program Plan*, formerly the *Hydrogen Posture Plan*).

The *Program Plan* is a high-level document that presents a coordinated plan for research, development, and demonstration (RD&D) programs that directly relate to hydrogen and fuel cells across the Department of Energy (DOE). The *Program Plan* refers readers to the Multi-Year RD&D Plans prepared by individual DOE offices, detailing the multi-year program agenda, entities involved, program and sub-program milestones, technical and non-technical challenges, and approaches for addressing those challenges.

The body of this report consists of seven recommendations made by HTAC during FY 2010 and FY 2011. It presents the HTAC recommendations, based on the source material, followed by DOE's responses to those recommendations. HTAC's recommendations ranged from specific programmatic issues, such as "increasing communication and information exchange among DOE programs" to broader themes, such as "vigorously supporting the hydrogen and fuel cell option.

Response to Findings and Recommendations of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) during Fiscal Years 2010 and 2011

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I. Recommendation 1: Increase Communication and Information Exchange

In its March 2010 letter to the Secretary, HTAC made the following recommendation to the Department: "Seek increased communication and regular exchange among programs within the office of Energy Efficiency and Renewable Energy, and with other DOE offices that have parallel or compatible research efforts. In smart grid, renewable generation, large scale energy storage, sequestration or low carbon fuels, hydrogen and fuel cells have an important role to play. Frequent communication will lead to better planning and better use of resources."

DOE Response 1

The Department has prioritized intra- and inter-office coordination in order to maximize the effectiveness of its research, development, and demonstration programs. The Department's hydrogen and fuel cell activities have institutionalized this coordination through an Interagency Working Group, an Interagency Task Force, and a Hydrogen Coordination Group. These management structures promote increased coordination between the Office of Energy Efficiency and Renewable Energy (EERE) and other Department offices such as the Office of Nuclear Energy, the Office of Fossil Energy, and the Office of Science, as well as other agencies in the federal government. A mutually beneficial collaboration exists among the EERE Fuel Cell Technologies (FCT) Program and the Basic Energy Sciences and Biological and Environmental Research programs within the Office of Science, in which expertise and guidance is shared through active participation in workshops and reviews. This intra-agency collaboration is being expanded to include other areas of the Department that have complementary programs to EERE's FCT program, such as the Office of Electricity Delivery and Energy Reliability for their Smart Grid and energy storage programs, and the Loan Guarantee Office and ARPA-E for projects relating to fuel cells and hydrogen.

II. Recommendation 2: Increase Collaboration with the Department of Defense

In its March 2010 letter to the Secretary, HTAC made the following recommendation to the Department: "Seek increased collaboration with the Department of Defense, which has a strong interest in fuel cells for the capability they bring to the battlefield and the economy and the flexibility they bring to the domestic base structure."

DOE Response 2

The Department of Defense (DOD) is one of DOE's strongest partners for fostering the widespread commercialization of fuel cells. DOE has a longstanding and fruitful partnership with the DOD that, since 2007, has led to the deployment of more than 100 fuel cell systems providing a cumulative power output of over 1200 kW, with applications ranging from backup and prime power to forklifts.

As part of a memorandum of understanding (MOU[1]), DOE and DOD are installing and operating 18 fuel cell backup power systems at eight military installations across the country. The Departments will test how the fuel cells perform in real world operations, identify any technical improvements manufacturers could make to enhance performance, and highlight the benefits of fuel cells for emergency backup power applications. DOD will manage the project and DOE's National Renewable Energy Laboratory (NREL) will collect performance data.

The FCT Program is also working with the Office of Naval Research to deploy a utility scale grid management system that includes water electrolysis to make hydrogen using off-peak renewable energy. This project is a high profile activity in Hawaii that includes involvement with a local utility and will demonstrate hydrogen as a viable storage technology for managing renewable power on the grid.

The Department has established meaningful partnerships with numerous other federal agencies, including the Department of Commerce, Department of the Interior, the Department of Transportation (DOT), the Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), United States Department of Agriculture, and the General Services Administration. Examples of these partnerships include a NASA deployment of backup power at their Ames Laboratory as well as DOT demonstrations of fuel cell buses provided with technical support from DOE. DOE, along with its partner agencies, developed and published an Interagency Action Plan[2] in FY 2011 to support Hydrogen and Fuel Cell Technologies. These partnerships facilitate early market introduction of hydrogen and fuel cell technologies, increase information and performance data sharing, and encourage state and local involvement from the public sector. They also accelerate market transformation by raising public awareness, building end users' expertise particularly with codes and standards, and increasing market demand. These vital partnerships will continue to play an important role in the advancement of fuel cell technologies.

III. Recommendation 3: Evaluate U.S. Fuel Cell Manufacturing Capability

In its March 2010 letter to the Secretary, HTAC made the following recommendation to the Department: "Conduct an evaluation of U.S. fuel cell manufacturing capability. Rumored bottlenecks in U.S. production would retard commercialization and also increase the risk that new plants and equipment will be built outside the U.S."

DOE Response 3

The Department has implemented several activities to gather information and develop tools needed by the industry to grow their manufacturing processes in step with increasing market demand. A preliminary analysis of information provided by fuel cell manufacturers in the U.S. showed production

[1] http://energy.gov/sites/prod/files/edg/media/Enhance-Energy-Security-MOU.pdf
[2] http://www.hydrogen.gov/pdfs/hydrogen_fuelcell_interagency_action_plan.pdf

capacity greater than 27,500 fuel cell units/year (more than 350MW per year) in 2010[3]. The DOE FCT Program held a pre-Request for Information (RFI) webinar and a follow-up manufacturing R&D webinar to discuss manufacturing techniques and process improvements needed to accelerate fuel cell adoption for stationary, distributed electric power generation, and conducted a fuel cell manufacturing RFI to solicit feedback from the research community and relevant stakeholders to assist in developing funding opportunities for new fuel cell manufacturing research activities. The Program also supported the development of an employment analysis tool by Argonne National Lab to determine the number of jobs associated with specific fuel cell applications, including manufacturing jobs. Finally, the FCT Program held a workshop in August 2011 to identify the current status, barriers, and R&D needs of manufacturing processes for hydrogen and fuel cell systems. The August 2011 workshop focused on key technical challenges to the manufacturing of hydrogen and fuel cell systems today and on identifying priorities for research and development of the manufacturing processes needed to make hydrogen and fuel cells cost-competitive with incumbent technologies.

IV. Recommendation 4: Large, High-visibility Demonstrations of Hydrogen and Fuel Cell Technologies

In its March 2010 letter to the Secretary, HTAC made the following recommendation to the Department: "Consider large, high-visibility demonstrations along the lines of Japan's Hydrogen Town in developing your FY 2012 budget. Activities in the States, such as California's vehicle deployment program, provide partnership opportunities that would leverage federal dollars."

DOE Response 4

The Department agrees that highly visible demonstration projects offer significant benefits not only by validating the performance of the technologies, but also by providing a channel for communicating the status of the technologies as well as their benefits to industry, government officials, and the general public. The FCT Program recently completed the National Hydrogen Learning Demonstration, which was the world's largest demonstration of fuel cell electric vehicles and hydrogen refueling infrastructure to date. DOE invested $141 million in this effort over 8 years with 50% industry cost share. This high-visibility demonstration involved more than 180 fuel cell electric vehicles and 25 fueling stations. The vehicles traveled over 3.5 million miles and the fueling stations produced or dispensed over 150,000 kg of hydrogen (which has been used by a large number of vehicles and buses in addition to those in the Learning Demonstration). These demonstrations validated the performance of key technologies operating in integrated systems under real-world conditions; the resulting data (roughly 100 composite data products) have been made publicly available[4] and continue to be showcased worldwide.

[3] 2010 Fuel Cell Technologies Market Report, 2011, http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/2010_market_report.pdf

[4] www.nrel.gov/hydrogen/proj_learning_demo.html

DOE is involved in several additional high-visibility demonstration and deployment projects for hydrogen and fuel cells, including:

- Recovery Act deployment of more than 800 fuel cells in backup power and material handling (e.g., forklift) applications. These projects involve several prominent companies and have already led participating companies to plan purchases of 3,000 additional fuel cell lift trucks (with no DOE funding). Data collected from these projects is analyzed and made public by NREL; this allows industry to analyze the cost and performance of fuel cells and helps to establish the business case for investing in fuel cells and hydrogen technologies.
- DOE's Clean Cities Program, which is incorporating fuel cell buses and hydrogen refueling stations in its efforts to deploy alternative fuels and emerging transportation technologies.
- Collaboration with the Department of Transportation's Federal Transit Administration (FTA) on the National Fuel Cell Bus Program. DOE analyzes data from the FTA's bus demonstrations and makes the resulting data products available to the public.[5]
- Collaboration with the Department of Defense to deploy 18 fuel cells for backup power at eight military installations across the country. The Departments will test how the fuel cells perform in real world operations, identify any technical improvements manufacturers could make to enhance performance, and highlight the benefits of fuel cells for emergency backup power applications.
- Collaboration with several state and local organizations to demonstrate the world's first tri-generation system in Orange County, California (partners include the South Coast Air Quality Management District, the California Fuel Cell Partnership, and California Air Resources Board). This project is demonstrating a large stationary fuel cell that operates on biogas and can produce power, heat, and hydrogen.

DOE seeks to catalyze the transition from R&D to demonstration and early deployment by integrating real-world technology demonstrations, public outreach and education, and early market deployments into a well-planned timeline. Therefore, the Department has adopted a selective, strategic approach to its demonstration and deployment activities, and the top priority may not always be the largest demonstration project. Instead, DOE seeks to ensure that its demonstration and deployment efforts demonstrate key R&D innovations, provide high-impact outreach opportunities, and fully leverage the efforts of other federal agencies and state and regional organizations.

V. Recommendation 5: Large-scale Demonstration of Use of Hydrogen to Support Solar or Wind Power-Generation

In its March 2010 letter to the Secretary, HTAC made the following recommendation to the Department: "Consider a large scale project to demonstrate the production and use of hydrogen in support of solar or wind power. A 2009 National Renewable Energy Laboratory study suggests hydrogen can be a

[5] www.nrel.gov/hydrogen/proj_fc_bus_eval.html.

significant energy storage option as the electric power grid accommodates an increasing amount of intermittent generation."

DOE Response 5

Since 2003, the Department has been collaborating with the National Renewable Energy Laboratory (NREL) and Xcel Energy on a wind to hydrogen project sited in Colorado. The partners of the Wind2H2 project have developed an integrated renewable electrolysis system offering high-efficiency, low-cost integrated renewable hydrogen production. Details are at www.nrel.gov/hydrogen/proj_wind_hydrogen.html.

DOE is applying some of the results from the NREL projects in partnership with the Office of Naval Research to implement large-scale renewable energy utilization on the Big Island of Hawaii as one of the first utility-scale systems that provides energy storage and generates transportation fuel. The project will manage the variability of renewable power from an existing 10-MW wind farm and a 30-MW geothermal energy plant. The electrolyzer, when fully operational, will produce hydrogen fuel for shuttle buses operated by the County of Hawaii Mass Transportation Agency.

VI. Recommendation 6: Reaffirm Department's Interest in Fuel Cells as Part of the U.S. Energy Portfolio

In its March 2010 letter to the Secretary, HTAC made the following statement: "…the use of your office to reaffirm the Department's continued interest in fuel cells as a part of the U.S. energy portfolio would be of great value. This relatively simple but critical act of leadership will clear the air of doubts about U.S. support for fuel cells in the long term, materially improve the prospects for U.S. companies, and hasten the day when the nation harvests the fruits of the DOE research investment: greater energy security and less reliance on foreign oil, a greener, smarter grid and jobs for the American workers who will build our energy future."

DOE Response 6

The Secretary and other senior Department officials will continue to promote the advantages of hydrogen and fuel cells as a critical component to the portfolio of technologies required to achieve the President's aggressive climate and energy goals. DOE continues to see impressive technical progress as a result of the ongoing investments in research, development, and demonstration.

In the last year, the Department has published more than 70 news articles, including progress alerts, press releases, and blog posts. Energy Secretary Steven Chu has released a number of statements regarding hydrogen and fuel cells and the Department has hosted several public webinars on a wide range of hydrogen and fuel cell-related topics.

The Office of Energy Efficiency and Renewable Energy released two funding opportunity announcements and their respective award selections this year, $7M focused on independent cost

analysis of fuel cell and hydrogen storage systems, and $7M for innovative hydrogen storage technologies in fuel cell electric vehicles. Secretary Chu and EERE management frequently mention hydrogen and fuel cells during public appearances, including the annual Asia-Pacific Economic Cooperation conference and the 2012 Detroit Auto Show held in January. Examples include:

> *"Targeted investments in cutting-edge hydrogen storage technologies will spur American ingenuity, accelerate breakthroughs, and increase our competitiveness in the global clean energy economy. As we focus on energy security, strengthening our portfolio to include domestically-produced hydrogen and American-made fuel cells for transportation and energy storage applications will create new jobs and reduce carbon pollution."*
>
> *Energy Secretary Steven Chu - December 12, 2011*

> *"Fuel cells are a key part of our portfolio of clean energy technologies, and demonstrations like these help move our innovations from the lab to the market. Our partnership with DOD as an early adopter of energy efficiency and renewable energy technologies will accelerate our transition to a clean energy future."*
>
> *Acting Assistant Secretary for Energy Efficiency and Renewable Energy, Dr. Henry Kelly - November 17, 2011*

> *"Innovations like this demonstrate how American ingenuity and targeted investment can accelerate breakthroughs in the hydrogen and fuel cell industry while driving the clean energy economy forward. By providing the added value of electricity and heat, this approach provides a significant step in overcoming economic challenges with hydrogen refueling infrastructure."*
>
> *Deputy Assistant Secretary for Renewable Energy Steve Chalk - August 16, 2011*

The Department continues to emphasize the inclusion of hydrogen and fuel cells in the clean energy portfolio of technologies and will continue to do so.

VII. Recommendation 7: Reconsider Reductions in Funding for Hydrogen and Fuel Cells

In its March 2011 letter to the Secretary, HTAC expressed the view that the hydrogen and fuel cell option "offers one of the most attractive ways to achieve critical objectives of your Department and the Obama Administration," which include reducing our dependence on foreign oil, enhancing energy security, reducing greenhouse gas emissions, and creating high-quality green jobs. HTAC recommended that this option "should be supported vigorously," adding that "our Committee's considered view on these points has been reinforced by a number of important reports prepared by prominent independent experts, both here in the US and in other countries…" HTAC further urged the Secretary "to reconsider the decision to cut back on funding for our nation's hydrogen and fuel cells (HFC) program, which has been so successful in meeting its objectives, at this critical moment when the technology is rapidly

emerging into commercial markets and HFC products are successfully crossing the 'valley of death,' where the first generation technologies are inherently more expensive." HTAC expressed concerns that the Secretary's decision to reduce funding for hydrogen and fuel cells would "ultimately cause the country to lose its competitive position in what is clearly seen as a massive market opportunity by other nations … send a negative signal to the financial community about investing in continued HFC innovation … drive the emerging supply chain off-shore … and limit our ability to take full advantage of intermittent renewable resources."

DOE Response 7

From 2007 to 2011, the Department invested more than $1 billion in hydrogen and fuel cell technologies, enabling substantial progress in the field. The Fiscal Year 2013 request of $80 million is still a significant budget, and hydrogen and fuel cell technologies are still part of the Department's portfolio. For example, the entire office of ARPA-E had a FY2011 budget of $180 million.

As an example of the Department's investment and ongoing commitment to hydrogen and fuel cells, DOE provided $42 million under the American Recovery and Reinvestment Act to support near-term fuel cell deployments in key emerging markets such as backup power and forklifts. These funds are enabling the deployment of up to 1,000 fuel cells, and they are helping to create domestic jobs immediately in fuel cell manufacturing, installation, and support service functions. This funding is also helping to develop a supply base that could eventually support automotive applications. As these projects come to fruition with the participation and over 50 percent cost-share of major companies it is clear that fuel cells are starting to reach the mainstream. DOE funds have already led to more than 310 patents, 30 commercial technologies in the market, and more than 60 emerging technologies.

Appendices

Appendix A: March 2010 Letter

Appendix B: *2009 ANNUAL REPORT of the Hydrogen and Fuel Cell Technical Advisory Committee: The State of Hydrogen and Fuel Cell Commercialization and Technical Development*

Appendix C: March 2011 Letter

Appendix D: *2010 ANNUAL REPORT of the Hydrogen and Fuel Cell Technical Advisory Committee: The State of Hydrogen and Fuel Cell Commercialization and Technical Development*

Appendix A

March 2010 Letter

March 23, 2010

The Hon. Dr. Stephen Chu
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave. SW
Washington, DC 20585

Dear Mr. Secretary:

Enclosed is the Hydrogen and Fuel Cell Technical Advisory Committee's Annual Report on the State of Hydrogen and Fuel Cell Commercialization and Technical Development. In it we detail the important progress the hydrogen and fuel cell industry has achieved in 2009 on the path to commercialization. Fuel cells certainly are emerging as a success story for your Department. DOE research and investment has helped developers reduce cost, improve performance, and enter markets. More than 30,000 fuel cell units of all kinds are deployed worldwide, with rapid growth projected.

Continuing research is opening doors for lower system costs, better fuel storage and cheaper delivery. Analysis suggests hydrogen is among the credible options for supporting solar and wind power in a greener grid. Fuel cells support all of President Obama's strategic priorities for energy.

Perhaps most significant, the international effort energized by DOE's leadership is producing results in Europe and Asia. Germany, Korea and Japan in particular have announced ambitious commercialization programs. India aims to power its burgeoning telecommunications industry with fuel cells, and expects domestic jobs to be part of the deal. Japan's auto and energy industries have unveiled a plan to deploy two million fuel cell vehicles by 2025. Leading German auto and oil companies have committed to a similar plan. This international success is heartening, but threatens the competitive position of the U.S.

Dozens of countries tracked US leadership and US progress, and emulated US research. The US-inspired International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) has 18 members and interest from others. DOE technology targets and commercialization time tables are the international benchmarks of success. The US now finds itself, in fact, competing with these former followers for scientific, technological and marketplace leadership -- and competing for the jobs that accompany commercial deployment.

DOE is a partner in this success. DOE-led research in materials and catalysts reduced the cost of components for early commercial systems. Hydrogen production costs are already at DOE target levels and delivery costs declined significantly in 2009, although much work remains on storage and delivery and on renewable hydrogen generation. Preliminary research has identified storage materials with the potential to achieve DOE's performance goals, suggesting that further inquiry may well lead to advanced storage systems for second or third generation fuel cell vehicles.

CONGRESSMAN ROBERT S. WALKER
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DOE now projects that the volume production cost of fuel cell passenger vehicle engines based on 2009 technology is already within the range of high-end conventional engines. This suggests fuel cell vehicles can be cost competitive within a few years, if vigorous federal and private research continues.

Researchers and governments are supporting a variety of technologies to reduce oil use and greenhouse gas emissions. A look at these efforts reinforces a key finding from two recent National Academies studies conducted for the DOE: a portfolio approach to research, development, demonstration and market transition is essential to meeting the nation's energy and environmental goals.

The commitment to fuel cells as part of a portfolio approach has been reaffirmed around the world. In Germany, a public-private partnership of fuel providers, auto manufacturers and the government adopted a program to double the number of hydrogen fueling stations in Germany while developing a business plan for 500 to 1,000 stations, to meet the auto industry's commercialization time table. In Japan the government is reviewing a proposal by auto and oil companies to deploy two million vehicles and 1,000 fueling stations between 2015 and 2025.

The Department's position has an impact far beyond the motor vehicle industry. Developers of fuel cell power generation systems, for example, are finding lucrative markets outside the US but are under pressure to include manufacturing rights as part of the deal. The Korean government, as a case in point, has announced a plan to support the installation of two million residential fuel cell systems by 2020. Korea's goal is to supply 20% of the world's demand for fuel cells, creating 560,000 sector jobs for Korea. With US capital markets largely focused elsewhere, US fuel cell companies are looking to Europe, Asia and the Middle East for financial support and market opportunity.

Retaining a strong knowledge base and a successful manufacturing base in the US will be a challenge; yet it will be far less costly to retain our current lead than to attempt to buy it back in 10 or 20 years, as we are learning in the case of batteries, wind and solar power.

Recommendations

As you work with the Appropriations Committees to develop a final budget for your Department, we hope you will make clear your support for a portfolio approach to energy technology development that includes a continued aggressive program in fuel cells and hydrogen. We would like to offer these concrete recommendations for your consideration:

1. Seek increased communication and regular exchange among programs within the office of Energy Efficiency and Renewable Energy, and with other DOE offices that have parallel or compatible research efforts. In smart grid, renewable generation, large scale energy storage, sequestration or low carbon fuels, hydrogen and fuel cells have an important role to play. Frequent communication will lead to better planning and better use of resources.
2. Seek increased collaboration with the Department of Defense, which has a strong interest in fuel cells for the capability they bring to the battlefield and the economy and the flexibility they bring to the domestic base structure.

3. Conduct an evaluation of US fuel cell manufacturing capability. Rumored bottlenecks in US production would retard commercialization and also increase the risk that new plants and equipment will be built outside the US.
4. Consider large, high-visibility demonstrations along the lines of Japan's Hydrogen Town in developing your FY 2012 budget. Activities in the States, such as California's vehicle deployment program, provide partnership opportunities that would leverage federal dollars.
5. Consider a large scale project to demonstrate the production and use of hydrogen in support of solar or wind power. A 2009 National Renewable Energy Laboratory study suggests hydrogen can be a significant energy storage option as the electric power grid accommodates an increasing amount of intermittent generation.
6. Most important, the use of your office to reaffirm the Department's continued interest in fuel cells as a part of the US energy portfolio would be of great value. This relatively simple but critical act of leadership will clear the air of doubts about US support for fuel cells in the long term, materially improve the prospects for US companies, and hasten the day when the nation harvests the fruits of the DOE research investment: greater energy security and less reliance on foreign oil, a greener, smarter grid and jobs for the American workers who will build our energy future. We are happy to suggest venues in the US and internationally for such a discussion.

Thank you for your leadership in the energy arena. We hope that HTAC's continued focus on hydrogen and fuel cells is of value to your commitment to addressing the nation's energy needs in the years ahead.

Sincerely,

Robert S. Walker
Chairman

Enclosures

Appendix B

2009 Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee

"The State of Hydrogen and Fuel Cell Commercialization and Technical Development"

2009 ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee

The State of Hydrogen and Fuel Cell Commercialization and Technical Development

The hydrogen and fuel cell industry made significant strides in 2009, especially considering the challenging economic climate, DOE hydrogen program budget uncertainties, and the shifting policy framework upon which much of the industry relies. Independent studies by the National Academy of Sciences (NAS), the International Energy Agency (IEA) and others clearly showed that the potential for hydrogen and fuel cells is real - that hydrogen-based solutions can be significant in helping the nation meet its greenhouse gas targets and reducing its dependence on foreign energy sources. And real world demonstrations this year provided exciting confirmation of fuel cell vehicle performance expectations in terms of driving range, efficiency, durability and the adequacy of today's on-board storage technology. The challenges ahead for hydrogen and fuel cell development are as much systemic as technical, and for those challenges there is need for national leadership in providing the focus necessary to make the cleanest and most abundant of the energy options a significant component of the nation's energy portfolio strategy moving forward.

Commercial Deployments in 2009

Spurred by government incentives, a growing track record in use, and decreasing costs, sales of fuel cells are increasing, particularly in stationary, back-up power, and material handling applications. *Fuel Cell Today* estimates worldwide shipments of approximately 24,000 fuel cell units in 2009, an increase of 41% compared to 2008. Highlights of commercial deployments launched in 2009 are summarized below.

Power Generation & Electric Grid Support

- **The demand for multi-megawatt fuel cell systems for power generation and utility grid support applications is on the increase.** The Connecticut Public Utility Commission approved the installation of nine FuelCell Energy (FCE) molten carbonate fuel cell power plants, totaling 27.3 megawatts (MW), in five separate grid-connected projects. In Korea, POSCO Power ordered 68 MW of molten carbonate fuel cells from FCE, and Samsung installed 4.8 MW of UTC fuel cells at a power plant outside Seoul.
- **To demonstrate the use of fuel cells in electric grid support,** the Ohio utility, First Energy, announced that it will purchase a 1 MW, trailer-based polymer electrolyte membrane (PEM) fuel cell system from Ballard Power. The project will demonstrate fuel cell capabilities to provide feeder peak management, defer distribution system asset upgrades, deliver zero local CO_2 emissions, and provide power conditioning for high quality power.

Combined Heat and Power

- **Retail and manufacturing companies are beginning to see the value in the combined heat and power (CHP) benefits provided by fuel cell systems.** Whole Foods Market announced a second store to install a UTC 400 kW fuel cell system. UTC will also provide a 200 kW phosphoric acid fuel cell system to provide heat and power to a Coca Cola facility in New York State. In anticipation of the need for qualified technicians to support CHP systems, Plug Power commissioned a 5 kW unit installed at Union College in New York to be used for educational purposes.

- **Japan is leading the world in the adoption of residential fuel cell systems to provide home heat and power.** Nippon Oil announced that it expects to sell 2,500 residential fuel cell systems in 2009; this better than expected sales has prompted a production increase for residential fuel cells in Japan. Moreover, Toyota is forming a coalition with Kyocera, Osaka Gas, and Aisin Seiki to develop solid oxide fuel cells for residential use.
- **South Korea announced a program to subsidize 80% of the cost of residential fuel cells.** Starting in 2010, the South Korean government will cover 80% of a homeowner's cost to purchase and install a fuel cell for heat and power. The size of the subsidy will fall to 50% between 2013 and 2016, and to 30% from 2017 to 2020.

Back-up and Remote Power Generation

- **Back-up and remote power applications provide an important and growing early market for fuel cell systems.** Wireless TT Info Services Ltd, an arm of a major telecom operator in India, contracted with Plug Power for the purchase, installation and maintenance of 200 GenSys fuel cell systems to provide continuous power for off-grid cell towers in India. Motorola announced that it will use Ballard fuel cells in back-up power systems for 123 base stations in Denmark's TETRA-standard public safety communication network. In the U.S., the DOE is working with the Federal Aviation Administration and the Department of Defense (DOD) to install 43 emergency back-up power systems. In late 2009, the Army Construction Engineering Research Laboratory, in collaboration with DOE, issued a solicitation for 36 PEM fuel cell systems, ranging in size from 1 to 28 kW, as emergency back-up power for buildings and operations at 16 federal facilities (including DOD, DOE, and NASA sites).

Material Handling Equipment

- **The DOD has emerged as a key early adopter, and is establishing a clear business case for fuel cell forklifts.** Following successful demonstrations in 2008, the Defense Logistics Agency (DLA) placed 40 fuel cell forklifts and an indoor hydrogen refueling facility into operation at a Susquehanna, PA supply depot, and has began purchasing 40 fuel cell forklifts for two other DLA supply depots in Georgia and California.

- **Sales of fuel cell forklifts are rapidly expanding to commercial facilities.** Fuel cell developers and hydrogen refueling equipment manufacturers are targeting the multi-billion dollar North American market opportunity to supply hydrogen and fuel cell lift trucks to distribution centers and manufacturing plants. Compared with battery-powered forklifts, fuel cell forklifts have a greater range, take less time to recharge and cool before use, are not prone to voltage drops as power discharges, and do not suffer from downtime during battery change-outs. Fuel cell systems also require less space for refueling, and do not face concerns about battery life and disposal. Five new DOE projects funded by the American Recovery and Reinvestment Act will help deploy more than 300 fuel cell forklifts at Fed Ex, Genco, Sysco, and East Penn Manufacturing. Other fuel cell forklift customers include Central Grocers, Nestle Water, Wal-Mart, Whole Foods, Bridgestone, and Coca Cola. Several of these applications are fueling at a rate of 10,000 to 15,000 fuelings per year, providing valuable product development and user experience consistent with expected retail personal vehicle fueling. Dispensing products and safety systems have changed dramatically as a result of this experience.

Technology Developments in 2009

Government and industry demonstration projects continued to validate fuel cells and hydrogen technologies in a variety of other applications. Rapid developments in technology over the last few years have led to announcements by global automakers and government agencies in Europe and Asia that suggest commercial introductions of fuel cell vehicle technologies and hydrogen fueling infrastructure may happen sooner than many believed. In the U.S., government officials grappled with financial constraints stemming from the overall economic recession and nearly eliminated the budget for the DOE's hydrogen technology R&D programs. Fortunately, the U.S. Congress was able to restore funding levels for hydrogen and fuel cells R&D to roughly those of the previous year (~$240 million). This set of events, while disruptive, did create a positive result - a more coherent and compelling voice coming from the U.S. hydrogen industry than ever before.

Hydrogen Infrastructure

- **Worldwide, there are more than 370 hydrogen fueling stations operational and in planning.** The number of operating hydrogen stations in the U.S. reached 69 in 2009, with the number of additional planned U.S. stations at 38. Of the 69 operating stations, nine were opened in 2009, with three in New York, two in California, and one each in Colorado, South Carolina, West Virginia, and Michigan. This brings the total number of operational stations in California to 27, more than in any other state.

- **Countries in Europe and Asia made major commitments to hydrogen fueling infrastructure build-out.** In the U.S., only California made similar commitments.

  - In Germany, leading auto and energy companies joined with government to commit to a comprehensive nationwide hydrogen fueling network by 2015, to support a complementary

incentive program for production and sale of more than 100,000 battery- and fuel cell-electric cars annually, beginning in 2012.

- » Thirteen Japanese oil and gas companies announced a collaborative effort to develop hydrogen vehicle fueling infrastructure by 2015. This coincides with Toyota's announcement that it will begin selling affordable FCVs in 2015.
- » Denmark announced an ambitious clean vehicle program with the objective that all new vehicles sold after 2025 will be either electric or hydrogen powered.
- » South Korea continues efforts to develop a Hydrogen Highway, with six stations operating and four planned.
- » The California Fuel Cell Partnership announced an action plan for deploying 46 hydrogen fueling stations in California by 2017 to service the 50,000 FCVs expected to be on the road by that date.

- **Renewable hydrogen production continues to gain ground, with a number of demonstration facilities opened or planned in 2009.** In Hawaii, the Air Force is demonstrating a hydrogen production and fueling station. The hydrogen is produced by electrolysis using an integrated solar photovoltaic and wind energy system. Also in Hawaii, a fuel cell shuttle bus demonstration program is under development, with the hydrogen to be produced by off-peak geothermal electricity. A combined heat, power and hydrogen generation system based on a molten carbonate fuel cellusing waste water biogas feed has been factory tested and will be commissioned in Orange County, California in 2010. The hydrogen will directly feed a fueling station providing distributed renewable hydrogen.

- **The number of safe hydrogen refuelings grew at a rapid pace.** Spurred by the increasing sales of fuel cell forklifts, the number of safe hydrogen refuelings in the U.S. material handling market reached 120,000 in 2009, up from 20,000 in 2008. The DOE's Technology Validation Program has also demonstrated over 115,000 kilograms of dispensed hydrogen for light-duty vehicles.

Energy Storage

- **Research on the potential for hydrogen systems to serve as viable energy storage options continues to be encouraging.** The National Renewable Energy Laboratory (NREL) published a report titled, "Life Cycle Cost Analysis of Hydrogen Versus Other Technologies for Electric Energy Storage," which examined the economics of hydrogen energy storage in comparison to other bulk energy storage technologies available today. The report concludes that bulk hydrogen energy storage has the potential to become economically competitive with other types of bulk storage in some situations. Much more work is needed to improve system costs, reliability and efficiency to realize this potential, and the report suggests that these improvements are realistically achievable.

Fuel Cell Vehicles (Cars and Buses)

- **The commitment of global automakers to fuel cell vehicles (FCVs) continued to grow.** In 2009, seven automakers (Daimler, Ford, GM/Opel, Honda, Hyundai/KIA, Renault/Nissan, and Toyota) signed a letter of understanding to energy companies and government agencies affirming that a "significant number" of hydrogen FCVs could be commercialized beginning in 2015 onward, and urging the development of a supporting hydrogen fuel infrastructure in focused markets in Europe (Germany), the U.S., Japan, and South Korea.
- **Next-generation FCVs show exciting test results.** In a road-test conducted by Toyota, Savannah River National Lab, and National Renewable Energy Lab, the Toyota Highlander Fuel Cell Hybrid Vehicle achieved an estimated range of 431 miles on a single full tank of compressed hydrogen gas, and an average fuel economy of 68.3 miles per gallon of gasoline equivalent. This compares to the Toyota Highlander Hybrid's EPA-estimated rating of 26 miles per gallon fuel economy and full-tank range capacity of about 450 miles. The new Kia Borrego fuel cell hybrid SUV claims a driving range of 426 miles and 62% system efficiency.
- **Light duty fuel cell vehicle announcements in 2009** included Mercedes-Benz production of a 200 car series of its latest FCV, the B Class F-Cell; commercial leasing of the Mazda Premacy Hydrogen RE Hybrid; U.K.-based Riversimple's introduction of a small,

urban fuel cell car, which it plans to start marketing in 2013; and Kia's unveiling of its sport-utility Borrego FCV. GM's Project Driveway program, which placed 100 Chevy Equinox fuel cell vehicles in consumer hands for real-world driving, achieved over 1 million miles in 2009, and GM announced that its next-generation fuel cell system is half the size, 220 pounds lighter and uses less than half the precious metal of the current generation Equinox FCV.

- **New fuel cell buses introduced in 2009** include the Mercedes Citaro Diesel-Electric Hybrid and Proton Power's triple-hybrid passenger bus (which does not use a combustion engine at all, and is powered by a fuel cell, batteries, and ultra capacitors). Canada also began taking delivery of what will become the world's largest fleet of hydrogen fuel cell buses for the 2010 winter Olympics in Whistler, British Columbia.
- **Government-industry demonstration partnerships continue to tally progress.** The DOE Fuel Cell Technologies' Technology Validation Program, which is working with U.S. industry to demonstrate 140 hydrogen fuel cell vehicles and 20 hydrogen stations, reached more than 2.3 million miles of real-world driving. The program, which includes mostly first-generation FCVs, reported average efficiencies of up to 58%, driving range up to 254 miles, and 2,500-hour durability, which is on track for meeting early targets. In California, partnerships of auto companies, energy companies, and local, state and federal government have placed 298 FCVs on the road since 2001, with close to 2.5 million miles traveled.

Technical and Economic Analysis

- **A number of significant studies were published in 2009 that provided much-needed information about the potential costs and contributions of various light duty transportation alternatives to lowering oil imports and reducing greenhouse gases (GHG)**. These independently conducted studies arrived at corroborating conclusions, which, among other things, suggest that the U.S. should take a portfolio approach to addressing the nation's energy, environmental and economic issues. A portfolio of hydrogen, electric and biofuel powered vehicles can make significant and synergistic contributions to improving all of these key factors. In the long run, only hydrogen can cut greenhouse gas pollution to levels desired by policy makers, while simultaneously; 1) enabling America to reach energy quasi-independence, 2) nearly eliminating controllable urban air pollution by the end of the century, and 3) doing so at infrastructure and vehicle costs competitive with all other alternatives. As evidence of the growing belief in this assertion, 16 international associations issued a joint statement at the Copenhagen climate negotiations highlighting the benefit hydrogen and fuel cell deployment can have towards mitigating climate change. The studies are listed below:

  - » The National Research Council's supplement to its 2008 study "Transitions to Alternative Transportation Technologies: A Focus on Hydrogen," entitled "Transitions to Alternative Transportation Technologies: Plug-In Hybrid Electric Vehicles."
  - » UC Davis' "Study on Transition Costs for New Transportation Fuels: A Comparison of Hydrogen Fuel Cell and Plug-In Hybrid Vehicles."
  - » The National Hydrogen Association's "Energy Evolution Report."
  - » The International Energy Agency's "Transport, Energy and CO_2: Moving towards Sustainability."

Research Progress in 2009

Basic and applied research and development continues to make progress towards resolving the remaining cost and performance barriers for fuel cells and hydrogen production, delivery, and storage infrastructure. Some of the most significant research and development (R&D) results are summarized below.

Fuel Cells

- **Projected fuel cell system costs, using today's best technology, continue to decline.** DOE's fiscal year 2009 modeled cost assessment, projected for a manufacturing volume of 500,000 80-kW automotive PEM fuel cell systems per year with today's best technology, dropped from $73/kW in 2008 to $61/kW in 2009. This brings fuel cell cost into the range of high-end internal combustion systems and suggests that fuel cell vehicles can be cost-effective within a few years if produced at high volumes.
- **Researchers continue to make progress on improving durability and lowering cost of fuel cells.** For PEM fuel cells, lowering platinum (Pt) catalyst loading is a major cost reduction goal. Researchers at 3M Company demonstrated a membrane with 40% lower Pt content than in 2008, and researchers at Los

Alamos National Laboratory demonstrated two promising material sets for high-performing catalysts that use no platinum. Also in 2009, a partnership funded by DOE's Solid State Energy Conversion Alliance (SECA) demonstrated greater than 5,000-hour fuel durability from a solid oxide fuel cell stack running on coal-derived syngas, with degradation rates far below SECA's current targets.

Hydrogen Production and Distribution

- **Lower-cost pathways for renewable hydrogen production are being developed.** Researchers in the DOE R&D program increased the efficiency and yield of hydrogen production from cellulosic biomass and bio-derived liquids, bringing this pathway closer to the 2014 cost targets. Production of hydrogen from water using renewable powered electrolyzers is another promising renewable pathway, and researchers continue to make progress on reducing capital costs and improving system efficiency and durability. An independent review released in late 2009 shows that the modeled high-volume cost of today's technology for on-site, distributed hydrogen production from electrolysis (including compression, storage, and dispensing at 1,500 kilograms/day) ranges from $4.90/kg to $5.70/kilogram, which translates to approximately $2.45-2.85/gge assuming a 50% efficient FCV.

- **Hydrogen production from coal syngas moves closer to commercial targets.** Eltron Research and Southwest Research Institute® have demonstrated hydrogen separation membranes that meet nearly all of DOE's targets for 2010. Cost estimates suggest the technology could lower electricity cost, increase thermal efficiency, and improve CO_2 capture compared to conventional technologies.
- **Progress was made on nuclear hydrogen production pathways.** Three processes for nuclear hydrogen production were tested in 2009. An integrated lab-scale high-temperature electrolysis unit was operated for 45 days at Idaho National Laboratory and achieved a peak output of 5,650 liters of hydrogen per hour. The Savannah River National Laboratory successfully demonstrated operation of a hybrid sulfur electrolyzer without any limitations due to sulfur build-up. The Sulfur-Iodine (SI) thermochemical cycle being developed jointly by Sandia National Laboratories, General Atomics and the French Commissariat à l'Energie Atomique (CEA) achieved integrated operation, producing about 100 liters of hydrogen per hour.
- **The projected cost of gaseous and liquid hydrogen delivery pathways continued to decrease.** Hydrogen delivery cost reductions are being made possible by R&D on higher-capacity tube trailers and lower-cost pipeline materials, compression, and liquefaction technology. DOE's updated Hydrogen Delivery Scenario Analysis Model (HDSAM) also suggests that high-pressure (700 bar) or cryo-compressed fueling offers low or no station cost penalties, while providing hydrogen vehicles with a much longer driving range.

Hydrogen Storage

- **DOE's hydrogen storage R&D narrows focus.** Down-select processes were completed or underway at each of DOE's three hydrogen storage materials Centers of Excellence (Chemical Hydrogen Storage, Hydrogen Sorption, and Metal Hydride), which allows the program to focus future R&D on the most promising materials or combinations of materials in these three classes. R&D at the Centers has improved both operational properties and storage capacity of innovative hydrogen storage systems.
- **R&D helps improve technology for compressed and cryogenic tanks.** The design of vehicle hydrogen fuel tank systems for 350- and 700-bar compressed gas storage were revised and improved by DOE researchers, increasing capacity and reducing incremental cost. Lawrence Livermore National Laboratory also designed and fabricated a cryogenic vessel for cryo-compressed hydrogen storage with promising cost results compared to conventional liquid hydrogen.

- **Storage Engineering Center of Excellence was launched in 2009.** This new CoE will address systems integration and prototype development for on-board vehicular hydrogen storage systems, and build upon efforts of the materials Centers of Excellence. The Engineering COE is planned as a five-year effort and may produce up to three sub-scale prototype systems as its final output.

Financial Climate in 2009

The economic recession that began in 2008 was detrimental to the fuel cell market in a number of ways. First, the credit crunch reduced companies' ability to obtain capital via debt or equity. The policy mechanisms and incentives in the Recovery Act mitigated this to some extent, especially the Advanced Energy Manufacturing Tax Credit and the extension of the Investment Tax Credit (ITC). In addition, the recession caused a dramatic decline in the price of oil and gas, making higher cost alternatives like hydrogen even less attractive to investors and consumers. As the economy began to recover in late 2009, however, the energy commodity prices have steadily risen, and experts predict continued increases in energy prices. Particularly if a carbon policy is adopted, hydrogen and other low-carbon alternatives will gain traction in the years to come. Overseas, a number of countries see hydrogen and fuel cells as a major opportunity for both growth and energy independence.

Positive Indicators

- Energy legislation passed late in 2008 extended the Investment Tax Credit for fuel cell systems through 2016. The legislation also expanded the annual tax credit cap for fuel cells from $500 to $1500 per 0.5 kW per year and provided a two-year opportunity for grants in lieu of credits.
- BASF has opened a new fuel cell production facility in New Jersey and has moved its German operations to that facility.
- Versa Power announced the construction of a new manufacturing facility from which to build its 10-kW solid oxide fuel cell systems for clean power generation from coal syngas.
- Bloom Energy, a California company that engineers solid oxide fuel cell (SOFC) technology for distributed electricity and hydrogen production, raised venture capital funding in 2009, though challenges remain to address major commercialization concerns.
- P21 GmbH, a developer of PEM fuel cells, raised capital from a Dutch venture fund.

Negative Indicators

- U.S. automakers have scaled back their fuel cell vehicle development programs. GM is currently the only U.S. automaker that is actively pursuing commercialization of FCVs.
- Although a few venture backed companies engaged in developing hydrogen and fuel cell technologies were able to raise capital in 2009, several others had to close their doors when they were unable to raise capital in a frigid venture financing environment.

Despite extremely difficult economic conditions in 2009, hydrogen and fuel cells continued to make exceptional progress, and the world community demonstrated its enthusiasm by proceeding with commercialization and infrastructure development efforts. In the U.S., the results of real-world performance testing and independently conducted studies provided clear confirmation that hydrogen could and should be embraced as a critical component in addressing the nation's energy, environmental, and economic issues. Other nations, while recognizing the substantial challenges ahead, have now taken the next step to initiate a transition to hydrogen, while U.S. commitment has slowed or been put on a longer-term trajectory. HTAC fully understands that commercial deployment of a hydrogen infrastructure and vehicle fleet is a demanding task, but the Committee believes that the US leadership position in the hydrogen and fuel cell arena is at stake.

The Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) was established under Section 807 of the Energy Policy Act of 2005 to provide technical and programmatic advice to the Energy Secretary on DOE's hydrogen research, development, and demonstration efforts. http://www.hydrogen.energy.gov/advisory_htac.html

Appendix C

March 2011 Letter

The Hydrogen and Fuel Cell Technical Advisory Committee

Washington, D.C.

March, 2011

The Hon. Dr. Stephen Chu
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave. SW
Washington, DC 20585

Dear Mr. Secretary:

It is with great pleasure, but with some dismay, that we enclose with this letter the 2010 Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC). Our pleasure comes from being able to report to you on the robust accomplishments of the past year in the hydrogen and fuel cell (HFC) industry, and our dismay is that the Department's Hydrogen and Fuel Cell Program has been singled out for major cuts in funding in the proposed 2012 budget, when all other significant energy options have received increases. We hope that as you read our report you will come to share our view that the HFC option offers one of the most attractive ways to achieve critical objectives of your Department and the Obama Administration:

- Reduce our dependence on foreign oil,
- Enhance energy security,
- Reduce greenhouse gas emissions, and
- Create high quality green jobs here at home.

It therefore should be supported vigorously. Our Committee's considered view on these points has been reinforced by a number of important reports prepared by prominent independent experts, both here in the US and in other countries – reports that we have studied carefully and which are summarized in this and our two previous Annual Reports.

As is abundantly clear from our Annual Report, R&D on hydrogen and fuel cell technologies over the past few years has led to the development of products that are being adopted in commercial material handling, telecom, and building system applications today. These commercial deployments make it obvious that HFC products are a currently available option – not some distant dream.

In addition, other nations, notably Japan, Korea, China, and the European Union (EU), have made very public policy and financial commitments, memorialized in government-industry compacts and MOUs, to bring hydrogen and fuel cell vehicles (HFCVs), and the infrastructure to fuel them, to market in 2015 or earlier. Already these nations are aggressively preparing for the 2015 roll-out, with a rapidly growing hydrogen infrastructure and numerous hydrogen-powered precommercial vehicles already on the road, while the US has far fewer HFCVs and a very modest network of refueling stations to date. Companies that operate in these hydrogen-friendly nations will become the technology leaders of the future. These companies will spend the next 5 to 10 years perfecting designs and driving cost out of the fuel cell and hydrogen infrastructure. This is a substantial threat to U.S.-based companies that will be forced to go off-shore for critical HFC technologies or face substantial competitive headwinds.

We urge you to reconsider the decision to cut back on funding for our nation's HFC program, which has been so successful in meeting its objectives, at this critical moment when the technology is rapidly emerging into commercial markets and HFC products are successfully crossing the "valley of death," where the first generation technologies are inherently more expensive. The World's automotive companies are already ramping up their supply chain for HFCV production launches in just a few short years. We on your Advisory Committee feel that the decision to slash one of the most successful programs in EERE defies logic and is seriously ill-advised. We are deeply concerned that it:

- Will ultimately cause the country to lose its competitive position in what is clearly seen as a massive market opportunity by other nations. We have already allowed that to happen in other energy technologies and we should not let it happen again. We must choose to lead or resign ourselves that these technologies will be controlled by foreign governments and companies. If US consumers ultimately end up buying HFCVs only from foreign automakers, that will be a sad outcome indeed.
- Sends a negative signal to the financial community about investing in continued HFC innovation, and will likely drive the emerging supply chain off-shore as well, both of which will negatively impact current HFC jobs (around 30,000) and constrain future growth (projected by DOE's own analysis to be up to 675,000 HFC industry jobs by as early as 2035).
- Will limit our ability to take full advantage of intermittent renewable resources. When the penetration of wind and solar grows beyond the 20-30 percent levels, the electrical grid encounters stability challenges that require effective energy buffers. Many state RPS programs already on the books mandate this penetration level, making storage options essential. Hydrogen production offers an attractive way to capture the value of these renewables when the grid cannot accept their output. The EU and Japan are already aggressively working on projects to use hydrogen as a way to capture stranded wind capacity and shift solar output to the utility system peak.

Our hope is that you will make it a personal goal to look carefully at the reality of what is going on in the HFC industry. We suggest that you consider:

- Driving as many as possible of the superb HFC vehicles that are currently being leased to regular customers in several regions throughout the country. We can help arrange a "ride and drive" for you and your immediate team, and would be pleased to do so.
- Talking to the customers who use fuel cells today (Sprint, Whole Foods, FedEx, etc., as described in our Report) to hear their story.
- Reviewing real data with a truly open mind, to test whether the "miracles" you have said are needed have, in fact, already happened:
    - Fuel cells are manufacturable at acceptable cost and have operating lifetimes well in excess of the times needed for many stationary, and all automotive, applications. Continued R&D will further reduce cost and improve performance, just as ongoing R&D will do for batteries and advanced biofuels, but the fuel cells we know how to make today are already commercially ready.
    - Natural gas can be reformed to produce H2 at a cost of $3-4/kg (1kg is 1gge).On a cost/mile basis in an HFCV this translates to $1.50-2.00/gge, while reducing carbon emissions for the same physical outcome (i.e. miles driven) by 50% or more. When renewables can produce electricity at 5-6¢/kWh, H2 production using renewable electricity

and employing electrolyzers that are already available commercially (but will be produced in the near future in much larger numbers at lower cost) will also be cost effective. New technology resulting from continuing R&D will certainly reduce the cost of production over time, but H2 costs are already very competitive with gasoline.

- High pressure (700 bar) storage systems are able to achieve vehicle ranges in excess of 400 miles. For larger scale energy storage, when H2 is stored at the same pressure as air in underground caverns, it enables more than 150X the energy storage in the same volume. Continued research will doubtless lead to ever better storage solutions at ever lower cost, but current approaches are more than adequate for first generation commercial applications.
- All the components required for a robust H2 infrastructure have been developed and are being used today in commercial hydrogen stations around the world. The National Academy, the EU, and industry analysts all point out that the cost of early development of the infrastructure is quite reasonable compared to the incentives being provided to stimulate other alternative technologies. Infrastructure cost is clearly important, but it is not a substantial barrier to early vehicle deployments. Vehicles will be introduced initially in selected geographies, like Los Angeles and Oahu in the U.S., and in Germany, Korea, and Japan. We urge you to talk with the California Fuel Cell Partnership, the leading automakers, the industrial gas companies, and your counterparts in Germany, Korea, and Japan, to learn their views. It is important to note that the recently published EU study, based on proprietary cross-industry data, confirmed the National Academy's earlier conclusion that H2 infrastructure costs are comparable to those needed to support electric vehicles.

Finally, we urge you to engage with your HTAC, whose members devote substantial time and their broad-based expertise to serving you and the Hydrogen and Fuel Cell Program. We commit to sharing real data, careful analysis, and actual commercial experience with you, and to engaging in dispassionate dialog on the facts. We are certain that if you are willing to look seriously at the reality of what has been accomplished and is currently being supported by the HFC Program, and the extent to which the global HFC industry has progressed, you will become convinced that the HFC option deserves a much more prominent place in the nation's advanced energy portfolio than the recent budget proposals signal.

With sincere regards,

Robert W. Shaw Jr.

Dr. Robert W. Shaw, Jr.
HTAC Chair
On behalf of all of the HTAC Members

Appendix D

2010 Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee

"Hydrogen and Fuel Cell Commercialization and Technical Development Activity"

2010 ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee

Hydrogen and Fuel Cell Commercialization and Technical Development Activity

2010 was a year of significant activity for hydrogen and fuel cell technologies in multiple applications. Fuel cell markets for stationary generation, back-up power, and material handling applications continued to expand by providing added value to customers, and automotive applications progressed as fuel cell vehicle deployment moved from demonstration fleet applications to real-world consumers. Many automakers confirmed 2015 as the target for large-scale deployment, and studies affirmed that hydrogen and fuel cell technologies can offer substantial, cost-effective reductions in greenhouse gases and petroleum consumption as part of a portfolio of technologies to meet our national energy and environmental goals.

Fuel cell system cost, durability, and performance continue to improve and have met or exceeded all of the milestones set by the industry and DOE. Low-carbon and renewable hydrogen production technologies are advancing, and analysis shows that some central and distributed production, distribution, and dispensing pathways can be competitive with gasoline on a per-mile bases at a commercial scale while offering substantial reductions in greenhouse gases and petroleum use. Public investment in research, development, and demonstration has contributed substantially toward the commercial readiness of these technologies, but more is needed to address the remaining challenges as the global competition for clean energy technologies intensifies.

Commercial Deployments in 2010

Sales in the material handling, combined heat and power (CHP), back-up power, and auxiliary power sectors led expansion in the global commercial market for fuel cells in 2010. These early commercial applications provide performance advantages for consumers, build valuable experience and customer awareness, and provide revenue to support the supply chain of fuel cell and hydrogen suppliers. Several of these applications are becoming cost competitive with incumbent technologies; however, government funding continues to be an important driver of sales. Funding from the American Recovery and Reinvestment Act (ARRA) enabled the installation of more than 400 fuel cells in 2010, putting DOE on track to meet its goal of up to 1,000 fuel cell installations with ARRA funds.

Material Handling Equipment

- **Rising sales volumes, reductions in first costs, and a strong track record of operating success are moving fuel cell forklifts toward sustainable long-term markets.** For example, Plug Power reported sales of more than 400 lift trucks in the fourth quarter of 2010 alone without federal government subsidy.[1] ARRA funding supported the placement of over 290 forklifts that gained 149,000 hours of use in commercial operations in the first half of 2010. Participating companies include Sysco, GENCO, Kimberly-Clark, Whole Foods, Wegmans, Coca-Cola, and FedEx. In addition, 75 forklifts in two Defense Logistics Agency (DLA) distribution depots gained 150,000 hours of use.

- **The DLA and ARRA projects logged more than 44,000 refueling events** at 12 forklift refueling facilities with no major safety incidents, dispensing almost 24,000 kilograms (kg) of hydrogen.

- **User experience with fuel cell forklifts has been positive.** Nissan North America realized productivity savings of 35 hours per day in its Smyrna, Tennesse plant by redirecting staff time previously spent changing and recharging forklift batteries in 60 tugs. Nissan also eliminated more than 70 electric battery chargers that used almost 540,000 kilowatt-hours (kWh) of electricity annually.[2]

Back-up and Remote Power Generation

- **Government grants (ARRA) and federal early adoption increased U.S. fuel cell back-up power installations.** With ARRA funding, U.S. companies like Sprint, AT&T, and PG&E installed more than 50 fuel cell back-up power (BUP) units at U.S. cell tower sites. The U.S. Army base at Fort Jackson, South

[1] Citations and references for the 2010 HTAC Annual Report may be found at http://www.hydrogen.energy.gov/pdfs/2010_htac_report_refs.pdf

Carolina, installed 10 fuel cell BUP systems, reporting zero power interruptions to critical loads during three 2010 grid power outages, and provided hands-on experience to fuel cell technician students from Midlands Technical College.

- **Other major U.S. and international telecommunication providers recognized the benefits of fuel cells for off-grid and remote power support.** In late 2010, T-Mobile placed fuel cell BUP systems at 35 sites in Florida, and Motorola deployed more than 100 in their U.S. network. Many countries are increasingly using fuel cell BUP systems to provide continuous power for off-grid cell towers as well. For example, IdaTech shipped over 350 back-up power systems in 2010, mainly to telecommunications companies in Southeast Asia and Central and South America.

Stationary Power Generation (including CHP)

- **Retail stores, office buildings, and manufacturing facilities are increasingly using fuel cell systems for heat and/or power generation.** Companies such as Whole Foods, Albertson's, Coca-Cola, FedEx, UPS, Adobe, Walmart, Cox Enterprises, Bank of America, Safeway, Cypress Semiconductor, eBay, Google, and Price Chopper use stationary fuel cells to provide reliable prime and back-up power for continuous operation while cutting emissions and lowering operating costs. In 2010, Whole Foods installed a fuel cell for CHP at a third supermarket; the 400 kilowatt (kW) UTC fuel cell has an 80,000 hour guarantee and is expected to deliver power at over 60% efficiency.[3]

- **The demonstration of fuel cells in single- and multi-family buildings is expanding.** In May 2010, Barksdale Air Force Base began using a 300 kW molten carbonate fuel cell system (FuelCell Energy) to provide electricity, heat, and hot water for dormitory residents. In addition, two apartment buildings in the New York region became the first large-scale residential buildings powered by fuel cells in the United States. Each building's fuel cell generates enough power to supply 675 apartments and reduces resident utilities bills by 50% compared to a traditional building. Federal and state grants enabled the developers to pay back the capital costs within five years.

- **Strong government support is increasing the international use of fuel cells for residential power generation.** In Japan, government incentives and the dedication of several manufacturers (Panasonic, Toshiba, and Eneos) to supplying the commercial market have spurred the sale of thousands of residential CHP fuel cell systems. Toyota continues partnering with Aisin Seiki Company to develop solid oxide fuel cells for residential use. In South Korea, a new government program is subsidizing up to 80% of the installed costs of a residential fuel cell, with the goal of installing at least 1,000 systems by 2012. By 2020, the program aims to install more than 100,000 residential fuel cells.[4] In mid-2010, the United Kingdom announced a feed-in tariff for low-carbon residential generation up to 5 kW that will pay British homeowners for every unit of low-carbon power generated or sold to the grid.

- **Many countries are showing interest in hydrogen and fuel cells for baseload power generation and grid support.** POSCO Power of Korea, one of 15 power producers influenced by South Korea's new renewable portfolio standard, has already installed more than one-third of its planned 68 megawatts (MW) of fuel cells at a power plant outside Seoul. In Canada, Enbridge and FuelCell Energy are demonstrating a hybrid fuel cell power plant that will provide energy to about 1,700 Canadian homes. Italy's Enel launched a first-of-its-kind 100% hydrogen-fueled 12 MW combined cycle power plant near Venice that will generate close to 60 million kWh per year from by-product hydrogen provided by nearby petrochemical plants. FirstEnergy and Ballard Power began testing the peak generating capacity and load management of a utility-scale proton exchange membrane (PEM) fuel cell system at FirstEnergy's plant in Eastlake, Ohio that has the potential to provide peak power to more than 600 homes.

Technology and Demonstration Activities in 2010

Automakers, energy companies, and government agencies around the world are converging on 2015 as the target date for full commercial introduction of fuel cell vehicles and hydrogen fueling infrastructure. To prepare for large-scale deployment, automakers are leasing next-generation fuel cell vehicles (FCVs) to regular customers with positive results. Publicly available hydrogen infrastructure is expanding in targeted regions throughout the world in step with vehicle deployment. Studies and demonstration projects are highlighting hydrogen's energy storage potential to support electric grids and integrate variable renewable energy sources.

Hydrogen Infrastructure

- **GM and The Gas Company (TGC) announced plans to build 20-25 retail hydrogen stations on Oahu by 2015.** The plan, known as the Hawaii Hydrogen Initiative (H2I), joins 12 public and private sector stakeholders in an effort to make hydrogen available to Oahu's one million residents and seven million annual visitors before mass production of FCVs. TGC makes enough hydrogen as a by-product in its Oahu-based synthetic natural gas production plant to power 10,000 FCVs and has capacity to produce more, particularly from locally sourced bio-products such as animal fats, vegetable oil, and landfill gas. TGC will distribute hydrogen via its existing 1,200-mile gas pipeline system, tapping into it at key locations and separating the hydrogen for use by local fueling stations. H2I also established other ways to integrate hydrogen infrastructure to enable the state to meet its clean energy objectives.

- **California continues adding fueling infrastructure to keep pace with vehicle rollout.** California has the largest number of FCVs and hydrogen stations nationwide; to date, approximately 300 vehicles have driven over 3.5 million miles in California, filling up at 20 private and 4 public hydrogen stations throughout the state. An additional 16 hydrogen stations were either funded or started construction in 2010 and will be opened to the public in 2011, establishing an early network in targeted clusters across the state. The location and capacity of these new stations will be matched to automakers' vehicle deployment plans, which anticipate thousands of vehicles by 2014 and tens of thousands of vehicles after 2015.[5]

- **SunHydro opened its first hydrogen station in Wallingford, Connecticut, as part of the "East Coast Hydrogen Highway."** Sister companies Proton Energy Systems and SunHydro completed the first of nine planned privately funded renewable hydrogen stations that will be open to the public and will make it possible for a hydrogen fuel cell vehicle to travel from Maine to Miami. The Wallingford station generates hydrogen on-site using a solar-powered electrolyzer.[6]

- **The global hydrogen fueling infrastructure is expanding, with Germany, Japan, and South Korea anticipating over 300 stations combined by 2017.** Germany's public-private Clean Energy Partnership, which includes 13 member companies from Germany, France, the United Kingdom, Norway, Sweden, Japan, and the United States, is adding two new renewable hydrogen stations in Berlin. As of November 2010, the total number of stations in Germany is 27, with as many as 15 more planned in the regions of Berlin, Hamburg, and North Rhine-Westpahlia by 2013. Canada is home to the largest fueling station in the world, a 1,000 kg/day station in Whistler, British Columbia, built for the fleet of 20 fuel cell buses launched during the 2010 Winter Olympics. Japan's Hydrogen and Fuel Cell Project currently operates 14 hydrogen stations and one hydrogen liquefaction facility, with Japanese car and energy companies planning for as many as 100 fueling stations in four Japanese cities by 2015. South Korea continues efforts to develop its own Hydrogen Highway, with six stations in operation and four additional stations planned.

- **Next-generation refueling components and systems are moving to market.** Developers are making progress in reducing the capital, operating, and maintenance costs associated with hydrogen compression. Linde North America introduced a novel "Ionic Compressor" system that uses an ionic liquid in direct contact with hydrogen to replace relatively high-maintenance, inefficient mechanical piston systems. Air Products offers compression-less hydrogen fueling with its new "composite pressure vessel" trailer, which is connected directly to the fuel dispensing unit.

Fuel Cell Cars

- **DOE's Technology Validation program continues to provide valuable data on early-generation fuel cell and hydrogen infrastructure performance and operating experience.** Started in 2004, the cost-shared industry-government program includes 152 fuel cell vehicles that have accumulated 114,000 hours and 2.8 million miles of real-world driving, demonstrating ranges over 400 miles between fill-ups and fuel cell efficiencies of up to 59%. The program's 24 fueling stations have produced and/or dispensed over 134,000 kg of hydrogen.

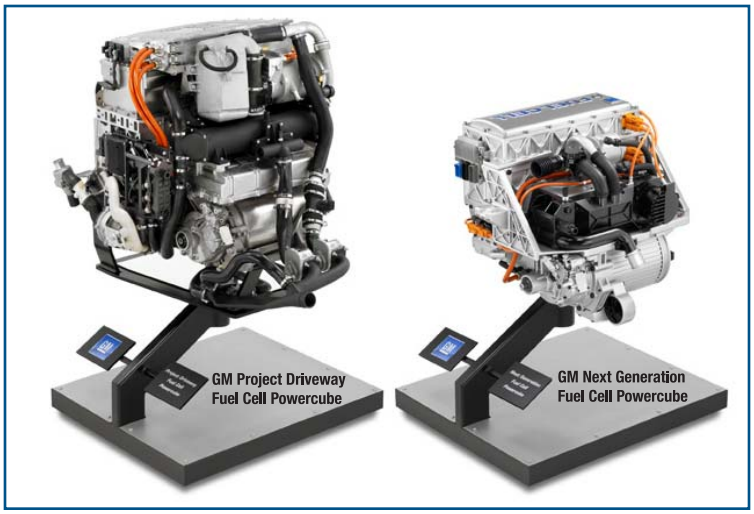
- **Other U.S. government agencies continue to sponsor hydrogen vehicle demonstrations.** For example, DoD's Army Tank Automotive Research, Development, and Engineering Center operated 11 hydrogen FCVs and 10 hydrogen internal combustion engine (ICE) vehicles at four locations in 2010, reporting a very high rate of customer satisfaction.

- **Next-generation FCVs are hitting the road, building on technology advances and lessons learned from earlier generations.** While early-generation technology showed better-than-expected results, next-generation FCV technology will be substantially improved. For example, Ford's fleet of 30 FCVs, launched in 2005, has reached a combined total 1.3 million miles driven, well beyond the anticipated life span for these early-generation vehicles. Third-party testing of Toyota's latest-generation fuel cell sport utility vehicle, the Highlander FCHV-adv, validated a driving range of 431 miles on a single tank of compressed hydrogen gas, an average fuel economy of 68.3 miles per gallon of gasoline equivalent, and cold-start capability down to -30°C. General Motors' next-generation fuel cell electric vehicle (FCEV) is expected to have a fuel cell system that is 50% smaller, 220 pounds lighter, and uses less than half the precious metal of the current Equinox FCEV.

- **Automakers are converging on 2015 for high-volume production of FCVs.** In a move that builds on previous statements from seven of the world's leading automakers, 13 Japanese companies (3 automakers and 10 energy companies) formed a partnership to expand the introduction of hydrogen FCVs in 2015 and develop a supporting hydrogen station network. The companies plan to build at least 100 filling stations by 2015, centered around four major Japanese cities. The Japanese Ministry of Economy, Trade, and Industry has pledged to support the development of hydrogen infrastructure ahead of the start of FCVdeployment.[7] Additional relevant announcements include the following:
  - Toyota plans to introduce a fuel cell sedan in 2015, priced to sell at $50,000.
  - Hyundai could introduce FCVs as early as 2012 (500 vehicles), increasing production to 10,000 per year in 2015 at a cost below $50,000.
  - General Motors introduced its "production intent" FCEV system and restated its plan to introduce a commercial vehicle by 2015.
  - Daimler began small-series production of its Mercedes-Benz B-Class F-Cell vehicle and plans to increase production to tens of thousands of vehicles by 2015–2017.

Fuel Cell Buses

- **U.S. fuel cell bus (FCB) demonstration projects continue to show strong performance.** In August 2010, AC Transit and UTC Power announced some significant milestones for its three-bus demonstration fleet in California, which has carried more than 695,000 passengers. The latest-generation UTC fuel cell system in one bus passed 7,000 operating hours with its original fuel cell stacks and no cell replacements. Compared to the control fleet of diesel buses, the FCBs also achieved 60% better fuel economy, reduced maintenance by 80%, and reduced greenhouse gas emissions (GHG) by 43% (using hydrogen produced from natural gas).



- **Federal demonstrations are collecting systematic data on FCB performance.** The National Renewable Energy Laboratory (NREL) has collected data for DOE and the U.S. Department of Transportation on nine FCBs in service at sites in California, New York, Massachusetts, Connecticut, South Carolina, and Texas. Since 2006, the buses have been driven more than 395,000 miles, consumed more than 80,000 kg of hydrogen, and demonstrated a fuel economy that is at least 53% higher than diesel or compressed natural gas buses.[8]

- **Hydrogen bus programs around the world are expanding.** The European Commission completed the CUTE project, which included 33 hydrogen fuel cell and 14 hydrogen ICE buses that operated in 10 cities on three continents, transporting more than 8.5 million passengers and traveling more than 2.5 million kilometers. A new project under the European Fuel Cell and Hydrogen Joint Technology Initiative, known as the "Clean Energy for European Cities" project, will deploy up to 28 hydrogen fuel cell buses in 5 major European regions. High-profile events showcasing full-size FCBs included the 2010 World Expo in Shanghai, China and the 2010 Winter Olympics in Vancouver, for which British Columbia, Canada, launched the largest fleet of FCBs to date (20 full-size buses).[9]

Energy Storage

- **A recent NREL study concludes that hydrogen may be suitable for utility-scale energy storage.** The analysis compared hydrogen and competing technologies for utility-scale energy storage systems and explored the cost and GHG emissions impacts of interaction on hydrogen storage and variable renewable resources. The study concluded that hydrogen energy storage is competitive with batteries and could be competitive with compressed air energy storage and pumped hydro in certain locations.

- **Projects are exploring the use of hydrogen for energy storage.**
  - The Naval Air Warfare Center, China Lake, California, is developing a field deployable Regenerative Fuel Cell system that will use a photovoltaic system to create hydrogen via high-pressure electrolysis combined with a PEM fuel cell to power the system load during dark periods.
  - To reduce overall system cost and increase system efficiency, AREVA developed their new "GreenBox" technology, which combines their electrolyzer and PEM technologies into an integrated storage system.
  - In Canada, a partnership between the federal government, BC Hydro, Powertech, and General Electric in Bella Coola, British Columbia, is converting excess off-peak electricity and storing it as hydrogen via an electrolyzer, and reducing diesel consumption by an estimated 200,000 liters per year and GHG emissions by an estimated 600 tons per year.
  - The "Ikebana" pilot project in Russia is using hydrogen for energy storage. It aims to improve power generation efficiency with a variety of power sources, including renewable energy.
  - Germany's Enertrag AG, one of the world's largest wind power companies, is building Germany's first hybrid power plant, which uses excess wind energy to produce hydrogen for energy storage and for transport applications. The 6.7 MW plant will have a hydrogen storage capacity of 1,350 kg. Also in Germany, the RH2-WKA project in Mecklenburg-Western Pomerania is developing a hydrogen storage system in conjunction with its 180 MW wind park to balance fluctuating wind energy.

Research and Analysis in 2010

Basic and applied research is making progress toward resolving remaining cost and performance barriers for fuel cells. Expanded analysis confirms the need for a portfolio of technologies that can meet medium- and long-term energy and environmental goals.

Technical and Economic Analysis

Several new studies published in 2010 assessed the potential costs and benefits of various alternative fuel technologies, including their contributions to reducing oil imports and GHG emissions. The reports include the following:

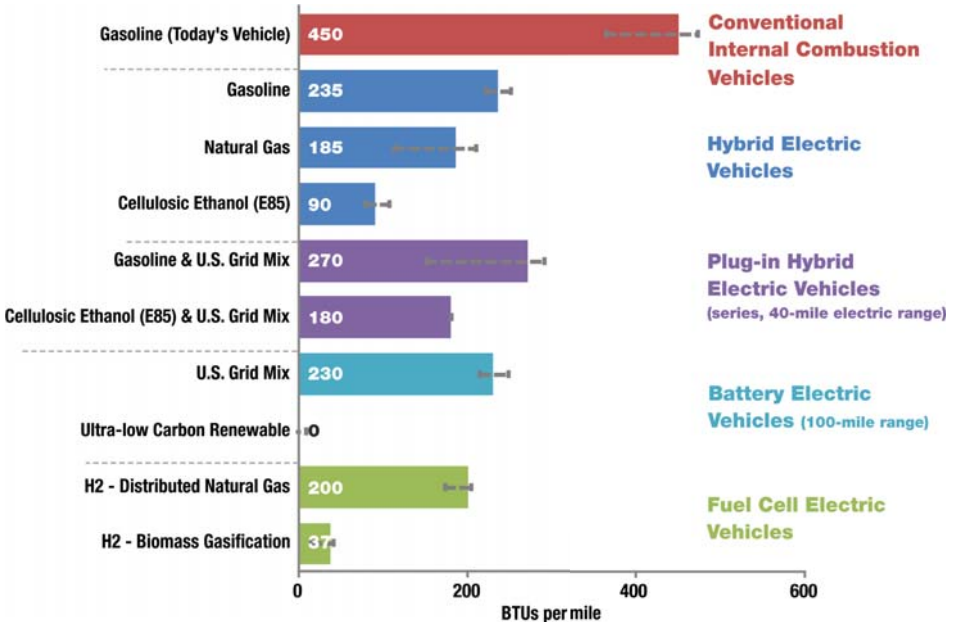
- **A 2010 study published by McKinsey & Company** finds that the costs of ownership of several vehicle power trains are likely to converge in the next 10 to 20 years, and that costs for electrical and hydrogen infrastructures are comparable and affordable. The report, which gathered over 10,000 proprietary data points from more than 30 industry stakeholders, suggested an evolution from today's ICEs toward a portfolio of technologies, in which battery electric vehicles (BEVs) are specifically attractive in the small-car segments and urban mobility patterns, and hydrogen FCVs are "the best low-carbon substitute" in the medium- and large-car segments, which account for 50% of all cars and 75% of carbon dioxide emissions.[10]

- **The third biannual National Research Council review of the FreedomCAR and Fuel Partnership** included two key findings: (1) improved ICEs with biofuels, plug-in hybrid electric vehicles, and BEVs, and hydrogen FCVs are the primary alternative pathways for substantially reducing petroleum consumption and greenhouse gas emissions; and (2) the hydrogen fuel cells research program is an effective public research effort, and government-industry collaboration should continue.[11]

- **A new report by Fuel Cells 2000** profiles fuel cell use by many well-known companies, including warehouses, stores, office and manufacturing facilities, hotels, data centers, and telecommunications sites. Collectively, these companies ordered, installed, or deployed more than 1,000 fuel cell forklifts, 58 stationary fuel cell systems (15 MW total), and more than 600 fuel cell units at telecommunications sites.[12]

- **An updated well-to-wheels analysis** of the GHG performance for various vehicle/fuel combinations shows that fuel cell vehicles operating on hydrogen from natural gas or biomass are among the lowest emitters of GHGs per mile (see chart next page).[13]

Well-to-Wheels Greenhouse Gas Emissions of Alternative Transportation Options (grams of GHG/mile)



Source: Well-to-Wheels Greenhouse Gas Emissions and Petroleum Use for Mid-Size Light-Duty Vehicles, U.S. Department of Energy, Offices of Vehicle Technologies and Fuel Cell Technologies, October 25, 2010, http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf.

Fuel Cell Technologies

- **Projected high-volume transportation fuel cell system costs, using today's best available technology, declined to $51/kW.** The DOE fiscal year 2010 modeled cost assessment, projected for a manufacturing volume of 500,000 80–kW automotive fuel cell systems per year using today's best technology (including balance of plant), represents a 30% reduction in cost since 2008 and an 80% reduction in cost since 2002.[14] These reductions are largely due to R&D efforts that enabled reduced platinum group metal content (down from 0.35 to 0.18 grams [g]/kW), increased power density (up from 715 to 813 mW/cm^2), and simplified balance of plant. At the current level of platinum (0.18 g/kW), the cost of platinum for a medium-sized fuel cell car would be $510, compared to a cost of $140 to $175 for platinum used in the catalytic converter of an equivalent gasoline-powered car.*

- **The DOE fuel cell R&D portfolio continues to show progress.** Significant R&D progress lowered fuel cell costs and improved durability and performance by, for example, using catalysts with low or no platinum (Pt), increasing power density, improving water management, reducing impacts of contaminants, and simplifying and lowering the cost of the balance of plant. Some research highlights include the following:

  - Brookhaven National Laboratory, Los Alamos National Laboratory, Argonne National Laboratory, and 3M each developed innovative low or no Pt catalysts with ex-situ activity levels that exceed DOE targets, and scale-up efforts are underway.

  - Case Western Reserve University and 3M developed membranes for PEM fuel cells that achieve high conductivity at higher temperatures (above 100°C), which could reduce cost and increase power yield.

  - 3M's new nanostructured thin-film (NSTF) catalyst was incorporated into membrane electrode assemblies (MEAs) in short stacks (>20 cells) that demonstrated total platinum group metal (PGM) content of less than 0.2 g PGM/kW, successful 10°C cold- and -20°C freeze-starts, and lifetimes of 2,000 hours under various automotive drive cycles. New NSTF-based MEAs with catalyst loadings of 0.15 mg total PGM/cm^2 also demonstrated 6,500 hours of operation under automotive load cycling.

  - A new process for making nanofiber composite membranes was developed and demonstrated by Vanderbilt University. The process may significantly increase the durability of polymer-based membranes without compromising performance.

- **The Solid State Energy Conversion Alliance (SECA), supported by DOE's Office of Fossil Energy, realized considerable advances in large-scale solid oxide fuel cell (SOFC) technology.** SOFC stack scale-up efforts resulted in greater than 25 kW stacks based on large active area (greater than

* Calculations assume an 80 kW fuel cell system and a platinum cost of $1,100 per troy ounce, which is the value used in DOE's fuel cell cost analysis. A range of 4–5 grams was assumed for the amount of platinum in the catalytic converter of a comparable ICE vehicle.

Challenges to Commercialization

Although hydrogen and fuel cell technologies are now being offered in early commercial markets, their widespread adoption faces key challenges:

- Some hydrogen and fuel cell technologies must continue to improve performance and reduce cost to be competitive with the capabilities and cost of incumbent technologies.
- Although safe, lightweight, low-volume hydrogen storage systems are available now, their cost remains an issue.
- The public has little awareness of hydrogen and fuel cell systems, and a misconception that hydrogen is unsafe and unreliable still prevails.
- It is critical that R&D reduce the cost of producing and delivering clean hydrogen to end users. Coupled with this is the need to improve emissions-free methods of hydrogen production.
- Current regulations and standards do not reflect real-world use of hydrogen and fuel cell technologies and need to be synchronized among countries.

400 cm^2) planar cells. Laboratory testing validated the achievement of SECA's 2010 cost goal: $700/kW for the system power block and $175/kW for the SOFC stacks based upon mass production (2007 dollars). Laboratory-scale testing also demonstrated degradation rates of less than 1%/1,000 hours in intermediate-duration testing.

Hydrogen Production, Distribution, and Storage

- **Researchers addressed ways to reduce capital costs and improve the overall efficiency and performance of distributed and centralized low-carbon and renewable hydrogen production and delivery.** For some pathways (e.g., distributed natural gas reforming and biomass gasification), estimated high-volume costs for delivered hydrogen are already at or near the newly established DOE target of $2.00–$4.00 per gallon of gasoline equivalent (gge). For other pathways, continued R&D is needed to bring costs down.
- **DOE's Fuel Cell Technology Program reassessed the cost threshold at which hydrogen is projected to become competitive with gasoline in hybrid electric vehicles (HEVs) in 2020 to be between $2.00–$4.00/gge (formerly $2.00–$3.00/gge).** The reassessment accounts for changes in technology options, feedstock costs, and gasoline prices, and this year also includes an incremental cost of ownership for FCVs over gasoline HEVs of zero to four cents per mile over the vehicle's life.[15] The new threshold, developed with input and review from stakeholders including Hydrogen and Fuel Cell Technical Advisory Committee members, industry, international stakeholders, and laboratory experts, will help prioritize hydrogen technology R&D needs.
- **The projected cost of several key hydrogen delivery modes dropped considerably between 2005 and 2010,** including a 30% reduction in tube trailer delivery costs, a 20% reduction in pipeline delivery costs, and a 15% reduction in liquid hydrogen delivery costs. These modeled cost reductions are made possible by various technical advances, such as new materials for tube trailers and pipelines, liquefaction process improvements, and improved compressor technology.[16]
- **Several projects reduced the cost of hydrogen from renewable sources.** For example, research at Proton Energy reduced catalyst loading by 55% and optimized a flow field design to reduce electrolyzer cell costs by over 20%. United Technologies Research Center demonstrated the use of an inexpensive base-metal catalyst in converting woody biomass to hydrogen. Efficiency improvements can also lead to cost savings. For example, Lawrence Berkeley National Laboratory improved photosynthetic solar-to-chemical energy conversion from 3% to 25% for photobiological hydrogen production by maximizing chlorophyll's ability to absorb light. Stanford University demonstrated novel nanoparticle catalysts to optimize photoelectrochemical water splitting for producing hydrogen from sunlight.[17]
- **On July 22, 2010, DOE created a new "Energy Innovation Hub" that will develop revolutionary methods to generate fuels directly from sunlight.** The new Joint Center for Artificial Photosynthesis, led by the California Institute of Technology, will receive up to $122 million over five years to demonstrate a scalable and cost-effective solar fuels generator that mimics the photosynthetic system "to produce fuel from the sun 10 times more efficiently than typical current crops." One of the intermediate products in the process is hydrogen from direct separation of water, which could become a source of renewable hydrogen.

Regulations, Codes, and Standards

A diverse array of codes and standards are required to integrate hydrogen and fuel cells into buildings, vehicles, electronics, and other equipment. Many organizations are engaged in critical efforts worldwide to develop consistent, harmonized codes and standards to facilitate commercialization and international trade. Great progress has been made in the last five years, in part due to DOE's involvement in (1) conducting research needed to inform science-based codes and standards; (2) coordinating and prioritizing the efforts of the various organizations and agencies involved in codes and standards development; and (3) informing code officials, emergency personnel, and others responsible for implementing codes and ensuring public safety. Key accomplishments in 2010 include the following:

- **DOE research informed codes and standards development.** The National Fire Protection Association published the 2010 code for compressed gases and cryogenic fluid based on Sandia National Laboratory's hydrogen release behavior data and updated separation distances for bulk hydrogen storage using a quantitative risk assessment approach. DOE researchers also tested forklift tank materials to enable design qualification.
- **R&D enabled the development of harmonized domestic and international fuel quality specifications,** including standardized sampling and analytical methodologies that were developed with ASTM International.
- **DOE-sponsored training reached hundreds of code officials.** The DOE Hydrogen Program supported permitting workshops that reached more than 300 code officials and published several online courses. DOE supported the development of an advanced, prop-based course for first responders that was delivered to almost 400 trainees from 18 states. The web-based Introduction to Hydrogen Safety for First Responders course averaged 300-500 unique visits per month in 2010, for a total of 17,000 visits since January 2007.

Financial Climate in 2010

Although financial markets strengthened in 2010, the climate for the financing of hydrogen and fuel cell companies, both private and public, remains weak. Analysts and investors continue to view companies in the hydrogen and fuel cells market with considerable caution, given the relatively slow pace of market development and the long path to profitability. However, there have been some encouraging developments—several small private and public companies raised needed capital, while only a few were unsuccessful and had to close facilities or shut down entirely. The continued success of commercial applications such as forklifts, distributed generation, and back-up power, and automotive companies' recently announced plans for large-scale vehicle deployment in 2015, have helped rekindle a degree of interest from the financial community that has not been seen in recent years.

As hydrogen and fuel cell technologies progress, worldwide momentum is building toward their commercialization in stationary, distributed generation, material handling, and automotive markets. Fuel cell forklifts, CHP systems, back-up power units, and fuel cell cars and buses are creating positive value for users today in early commercial and pre-commercial markets. Globally, as consumers and governments increasingly emphasize the need to diversify the transportation and power sectors with clean, low-carbon energy carriers, the value proposition for hydrogen and fuel cells will grow and the pace of commercialization will accelerate. United States researchers, technology developers, and government funding agencies have made important contributions to the current state of hydrogen and fuel cell technology. With continued commitment in the United States, we can overcome the remaining challenges and reap the full economic and environmental benefits of these promising technologies. Without such commitment, we risk being left behind as other nations bring these technologies to market.

The Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) was established under Section 807 of the Energy Policy Act of 2005 to provide technical and programmatic advice to the Energy Secretary on DOE's hydrogen research, development, and demonstration efforts.
http://www.hydrogen.energy.gov/advisory_htac.html