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.

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. We believe the Hydrogen and Fuel Cell Program should be supported vigorously.

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 pre-commercial 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 to the reality 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 to 30 percent levels, the electricity grid encounters stability challenges that require effective energy buffers. Many state RPS programs already on the books mandate these penetration levels, 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 being manufactured at acceptable cost for some markets, and have operating lifetimes well in excess of the times needed for many stationary, and most 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 H_2 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 hydrogen production over time, but the cost is 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,

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

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.

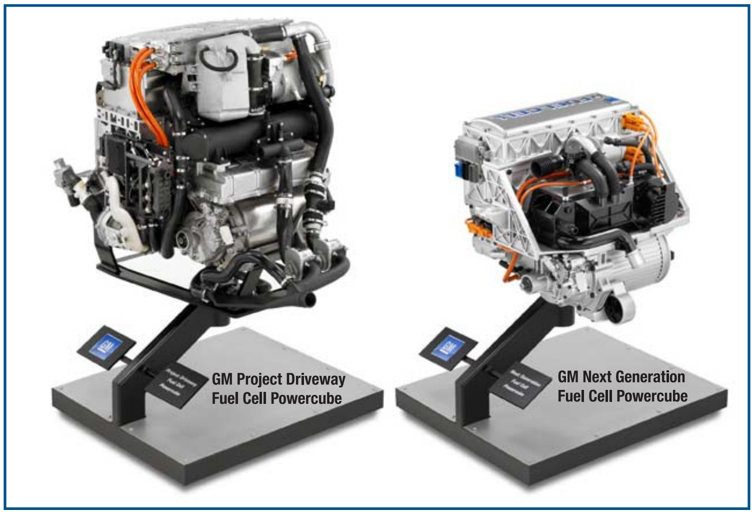
Fuel Cell Cars

- **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:

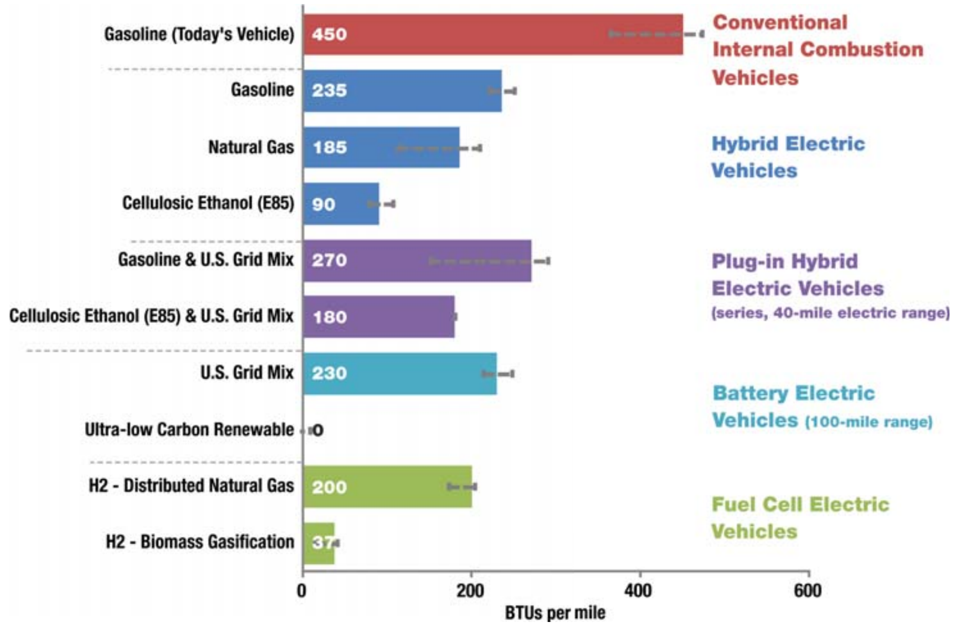
- **A 2010 study published by McKinsey & Company** finds that the costs of ownership of several vehicle power trains are likely to converge in the next 10 to 20 years, and that costs for electrical and hydrogen infrastructures are comparable and affordable. The report, which gathered over 10,000 proprietary 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.

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