2008 ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee

The State of Hydrogen and Fuel Cell Commercialization and Technical Development

Hydrogen and fuel cells offer one of the most promising, sustainable, carbon-friendly pathways to achieving the twin goals of national energy security and reduced greenhouse gas emissions. In this first Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) on the State of Hydrogen and Fuel Cell Technical Development and Commercialization, the HTAC summarizes important accomplishments in 2008. Despite the difficult financial climate over the year, the industry continued to meet growing demand for fuel cells in near-term, specialized markets while research and development proceeded on solving technical and institutional challenges in broad-based transportation and stationary fuel cell applications. The progress made confirms that hydrogen and fuel cells offer clear opportunities, both today and in the future, to become a vital part of the "New Energy Economy."

Commercial Installations and Demonstrations in 2008

The industry continued to make important steps toward commercialization of hydrogen and fuel cells. Highlights of commercial and demonstration activities launched in 2008 are summarized below.

- **Stationary Fuel Cells**
  - » **The number of large (more than 10kW) commercial installations continues to grow.** In 2008, fuel cell manufacturers reported approximately 50 new, large stationary fuel cell installations, providing distributed power to a wide range of operations including communication and data centers, grocery and retail stores, schools, hospitals, office buildings, and wastewater treatment plants. The world's largest fuel cell installation, 4.8 MW of on-site generation capacity in the new World Trade Center towers, will accept delivery of its first fuel cell in early 2009.
  - » **Reliability is backed by improved manufacturer warranties.** Stationary phosphoric acid fuel cells are available with an 80,000-hour warranty on the fuel cell stack. Manufacturers of molten carbonate fuel cells report typical operating life of 40,000 hours between major overhauls.
  - » **Back-up power provides an important early market.** Fuel cells are beginning to replace batteries in back-up power applications at cell and radio towers, as well as other critical communications facilities. The Federal Aviation Administration and the U.S. Department of Defense announced plans to procure 45 fuel cell back-up power units.
  - » **Residential fuel cells are being demonstrated in thousands of Japanese homes.** As part of its "Residential Fuel Cell Extensive Demonstration Project," Japan installed an additional 1,120 polymer electrolyte membrane (PEM) fuel cells to provide electricity and hot water to private homes. Under this program, gas and oil companies have shared the cost to put in more than 3,300 1-kW PEM fuel cell systems in homes throughout Japan since 2005. These systems operate on propane, city gas, or kerosene, and can reportedly reduce a home's primary energy use by 24% and its CO_2 emissions by 39%.
  - » **Denmark is demonstrating residential combined heat and power fuel cells.** Denmark launched a residential demonstration in 2008 to evaluate the use of 1-kW solid oxide or PEM fuel cells to provide combined heat and power to homes using either natural gas- or wind-generated hydrogen.

Hydrogen Infrastructure

» **Two major reports project manageable costs to build early hydrogen infrastructure.** In its 2008 report on the hydrogen transition, the National Academy of Sciences estimated the total, cumulative cost of building and operating enough hydrogen infrastructure to support 5.4 million fuel cell vehicles by 2023 would be $16 billion, or less than $2 billion per year (shared 50:50 by fuel suppliers and government). A 2008 study published by Oak Ridge National Laboratory, which modeled early fuel cell vehicle penetration and infrastructure requirements, reached similar conclusions, projecting cumulative costs to the government of between $7 billion and $27 billion, depending on the aggressiveness of the policy scenarios.

» **The number of operating hydrogen fueling stations in the U.S. reaches 58.** During 2008, two new hydrogen fueling stations were installed in the DOE Hydrogen Learning Demonstration, bringing the total number of stations in the DOE-industry partnership to 16. The largest number of U.S. stations (26) are located in California, and the California Fuel Cell Partnership (CaFCP) reports that another 10 have been commissioned.

» **Renewable hydrogen gains ground with two new stations.** In partnership with BP, Ford, and DOE, the Sacramento Municipal Utility District opened the first solar-assisted hydrogen fueling station, which uses solar-generated electricity to electrolyze water. Construction also began in Orange County, California on the first 100% renewable tri-generation (heat, power, and hydrogen fuel) station using biogas from a municipal waste water treatment plant.

» **Experience with hydrogen vehicle refueling grows.** According to a leading U.S. industrial provider of hydrogen, a total of 80,000 hydrogen vehicle refuelings have occurred to date and that number is growing by 30,000/year in 16 countries. Approximately 75% of all refuelings currently occur in the U.S. and hydrogen vehicle users report that the fueling process is not very different than gasoline fueling.

Energy Storage

» **Studies suggest that hydrogen energy storage can be competitive with peak electricity.** Initial economic studies conducted at the National Renewable Energy Laboratory (NREL) suggest that utility-scale hydrogen energy storage systems may offer a competitive alternative to some electric generation peaking resources (if DOE technology targets are achieved).

» **Demonstration project explores potential for hydrogen to enable continuous use of energy from intermittent wind and solar energy resources.** The Wind2H2 project, a joint venture between NREL and Xcel Energy, entered its second year of operation. The project is exploring system integration issues with co-production of renewable power and hydrogen, with the goal of improving the reliability, dispatchability, and economics of renewable energy by storing it as hydrogen during peak power production periods. The hydrogen can then be converted to electricity when needed or used as a vehicle fuel.

Fuel Cell Vehicles (Cars and Buses)

» **Honda and GM vehicles are delivered to consumers.** The latest generation of Honda and GM hydrogen fuel cell vehicles (HFCVs) hit the road as part of limited commercial demonstration programs in 2008:

– General Motors' Project Driveway placed over 100 Chevy Equinox HFCVs with mainstream customers in New York, California, and Washington, D.C. By year end 2008, Chevy's HFCV fleet had passed the 500,000 miles-driven milestone. A similar Project Driveway program was launched in Europe in November.

– Honda introduced its Clarity HFCV in Japan and California, and selected customers to drive these vehicles in daily use. A total of six Clarity vehicles are on the road in California and the plan is to have a total of 200 by the summer of 2011. The Clarity is reported to get 72 miles per gallon of gasoline equivalent (gge).

– Customers are responding favorably to both products, and requests to participate in the programs far exceed the availability of vehicles.

» **Japanese government begins leasing HFCVs.** In September 2008, Toyota announced that it had begun leasing its latest HFCV to the Japanese government for $7,700/month over a 30-month lease. Although not representative of HFCV costs at higher production volumes, this program indicates the willingness of the Japanese government to buy down the early costs of HFCVs.

» **Existing, mixed-generation vehicle fleets continue to perform.** The Ford fleet of 30 Focus HFCVs achieved over 1,000,000 miles of cumulative operation in 2008. By year end, more than 1.5 million miles were logged on first-generation HFCVs in the DOE Learning Demonstration project.

» **Fuel cell buses show pathway for low-emission public transport.** Successful demonstration of hydrogen fuel cell buses at AC Transit in Oakland, CA has shown that early adoption by operators of bus fleets can yield climate benefits and a 66% efficiency improvement over diesel-powered buses. Three fuel cell buses were used to transport high-profile Chinese and international athletes during the 2008 Beijing Olympic Games.

■ **Other Mobile Applications**

» **Fuel cells offer attractive alternative to batteries in operations with intensive material handling needs.** The Defense Logistics Agency initiated efforts to deploy approximately 100 fuel cell forklifts at four large distribution centers. Because of the life-cycle cost and operation benefits, private sector companies with high-volume operations, including grocers, tire manufacturers, and logistics companies, also announced new fuel cell forklift deployments.

» **German consortium launches world's first hydrogen fuel cell powered passenger ship.** The first "Zemship" (Zero Emission Ship), was launched into regular line service on the Alster Lake in Hamburg, Germany. The Zemship uses two 48-kW maritime fuel cells and a lead-gel battery in a hybrid system for propulsion. The ship can transport 100 passengers while being nearly twice as efficient as a standard diesel ship.

» **Fuel cell auxiliary power unit provides low-emission "hotel power" for tractor trailers.** Delphi Corporation and Peterbilt Motors Company demonstrated a Delphi solid oxide fuel cell (SOFC) auxiliary power unit (APU) that kept the battery of a Peterbilt truck charged while supplying an average of 800 watts of electricity to the cab and sleeper for air-conditioning, communications, and lighting over a 10-hour period (while the diesel engine was turned off).

■ **The 2008 Hydrogen Road Tour**

» **Hydrogen Road Tour makes stops across America.** Nine automotive manufacturers showcased their hydrogen vehicles in a two week, coast-to-coast tour involving stops at 31 locations in 18 states.

– The Road Tour was presented by the Department of Transportation (DOT), CaFCP, DOE, and the National Hydrogen Association in partnership with the automotive and hydrogen supplier participants and host organizations.

– The event reached television audiences of over 8.6 million people and facilitated test drives by over 1,600 citizens, including 40 local, state, and federal officials and members of Congress.

Technology Developments in 2008

Very significant progress was reported on hydrogen and fuel cell technology development during 2008, as a result of initiatives by industry, government and public/private partnerships. Several of the most exciting results are summarized here.

■ **Hydrogen Production and Distribution**

» **Distributed production of hydrogen provides near-term option for cost-competitive hydrogen supply.** Distributed steam methane reforming systems, developed over the last several years to generate small (<500 kg/day) amounts of hydrogen at fueling stations, became commercially available.

These systems are an important step toward scale up to 1,500 kg/day, which would enable hydrogen to be produced at less than $3.00/gge. If the hydrogen is used to power a fuel cell vehicle, this translates to less than $1.50/gge on a miles driven basis – since HFCVs are about twice as efficient as conventional internal combustion engine (ICE) vehicles.

» **Small-scale electrolyzers offer near-term options for producing hydrogen from electricity.** Distributed electrolysis units for producing hydrogen by electrolyzing water also are being introduced commercially. The projected cost from high volume distributed production (1,500 kg/day) is $4.80/gge, or $2.90/gge on a miles driven basis. Longer term, water electrolyzers can be integrated with intermittent renewable energy resources, such as wind and solar power, to produce hydrogen for use in fuel cell vehicles and for use as an energy storage medium to buffer the intermittent energy source.

» **New, lower-cost pipeline materials show promise for carrying large quantities of hydrogen over long distances at low cost.** Fiber-reinforced polymer pipelines (FRPP), now widely used in oil and natural gas operations, have the potential to significantly reduce capital cost for pipeline delivery of hydrogen, compared to standard steel pipeline ($600,000/mile versus $1 million/mile). Tests at Oak Ridge and Savannah River National Laboratories have shown FRPP leakage and permeation rates to be comparable to or better than those for steel pipe.

» **Progress is made on nuclear hydrogen production pathway.** The High Temperature Steam Electrolysis (HTE) process being developed at Idaho National Laboratory achieved 5,000 liters/hour of hydrogen production in initial tests. Early successes on two different thermochemical cycles for producing hydrogen using heat from solar or high temperature nuclear reactors were also reported by groups at Sandia and Savannah River National Laboratories.

■ **Hydrogen Storage**

» **Hydrogen vehicle storage tanks offer competitive range performance to current vehicles.** Major automakers announced their intention to use carbon wound high pressure tanks to store hydrogen on board vehicles at 5,000-10,000 psi -- Toyota claims a range of 472 miles (based on the Japanese JC08 mileage testing cycle) is achievable using 10,000 psi tanks in an SUV prototype without compromising cargo capacity. Honda reports a range of 280 miles (based on the official EPA estimated range) is achievable using 5,000 psi tanks in their sedan prototype while still maintaining 13.1 cubic feet of cargo space and 100 cubic feet of passenger space. Weight, cost and fueling time remain as challenges with tank storage technology.

» **R&D is progressing on novel, high energy density storage materials.** The DOE is supporting a wide range of basic and applied R&D efforts to find novel materials and concepts for storing hydrogen in lower volume/lower mass systems through its National Hydrogen Storage Project. The Center of Excellence teams have produced numerous materials and concepts with higher capacity and more favorable energetics and performance for vehicular applications. Though none of the materials yet meet DOE technical targets, promising examples include high-capacity metal borohydrides, metal hydride nanoconfinement, alane, amine-borane formulations, "hybrid" metal and boron doped sorbents, high surface area metal organic framework materials (MOFs), and new room-temperature sorbents such as metal catalyzed carbons and MOFs.

■ **Fuel Cells**

» **Recent analysis projects vehicle fuel cell system cost of $73/kW.** Research and development led to a decrease in the modeled cost estimate of an 80-kW automotive polymer electrolyte membrane (PEM) fuel cell system. The 2008 modeled cost estimate, projected for a manufacturing volume of 500,000 units per year, dropped from $94/kW in 2007 to $73/kW in 2008. The 2015 cost target is $30/kW.

» **R&D leads to several promising approaches to reduce or eliminate platinum content.** Major players continued to work on lowering platinum (Pt) content to reduce fuel cell cost, and several innovative approaches for significantly reducing total Pt content, or eliminating it altogether, emerged. Though still in the very early stage, these new developments hold promise for significant cost reduction.

» **Vehicle fuel cell durability improves toward commercial targets.** A number of fuel cell manufacturers have announced substantial progress in performance lifetime for fuel cells (principally a membrane life issue). Most automotive fuel cell manufacturers are comfortable claiming 2,000 hours for stacks, and some privately say 5,000 hours (equivalent to a 150,000 mile life of a car) is achievable. In 2008, 3M Inc. announced that their membrane electrode assembly, the core component related to stack durability, operated over 7,300 hours with load cycling, and Plug Power announced that it had reached 10,000 hours in field operation of their fuel cell packs designed for forklift duty cycles. These are major steps forward in establishing the commercial feasibility of fuel cells for vehicles.

» **Strategies have been developed for fuel cell vehicle start-up in freezing temperatures.** Nearly every leading fuel cell manufacturer has indicated that the freeze protection and cold-start problems have been successfully addressed. For example, in 2008 Nuvera achieved vehicle startup to 50% power in 30 seconds at -20°C (-4°F).

» **High-temperature membrane R&D provides path for simpler, lower-cost systems.** Progress has been made on high-temperature membranes that allow PEM fuel cells to operate at 120°C, well above the 80°C limit of conventional membranes. High-temperature membranes that can operate in dry conditions can reduce cost by eliminating the need for humidification and allowing easier heat rejection, which leads to reduced cooling system requirements.

■ **Safety/Codes and Standards**

» **Safety of hydrogen for use as a fuel continues to be proven.** Studies in Japan indicated that slow leaks in a hydrogen fueling system pose very little risk of hydrogen ignition. A compressor unit fire at a White Plains, NY hydrogen fueling station demonstrated that safety systems performed as designed to control the fire quickly. There were no personal injuries and minimal property damage.

» **First responder training programs have been developed for incidents involving hydrogen and HFCVs.** More than 7,000 first responders in the United States have been trained on hydrogen safety procedures through industry, state, and federal-sponsored training programs.

» **Significant progress has been made on codes and standards, both in the U.S. and internationally.** For example, the DOT's Pipeline and Hazardous Material Safety Administration (PHMSA) published its final rule allowing transport of fuel cells and a wide range of fuels on board U.S. passenger aircraft as carry-on baggage. This new rule also provides for routine cargo shipment of fuel cells and fuel cell cartridges by road and rail, as well as international ocean shipment in bulk.

The Financial Climate for Hydrogen and Fuel Cells

The climate for investing in innovative hydrogen and fuel cell technology and products became more challenging during the year. The rapid rise in the price of gasoline (and indeed all petroleum products) during the first nine months of 2008 created favorable conditions for financing alternative fuel options such as hydrogen. However, the worldwide economic meltdown in the fourth quarter led to dramatic reductions in fuel prices, which in turn focused attention away from energy issues, at least in the short term. Some indicators for the financial health of the hydrogen and fuel cell industry are:

Negative indicators

■ No Initial Public Offerings (IPO's) of companies occurred in 2008 and a number of small public companies operating in the hydrogen and fuel cell field were facing severe financial pressure. The private equity/venture capital market in the field was virtually shut down.

■ Hard hit by the world financial crisis, automotive companies face an uncertain future for their ambitious HFCV programs.

Positive indicators

■ Partially off-setting the dire news from the financial community was the launch of a new European Fuel Cell and Hydrogen Joint Technology Initiative (JTI). The JTI marks a strong commitment by the

European community to bringing hydrogen and fuel cell technology to market. The funding available through JTI initiatives exceeds 1 billion euros ($1.27 billion). An additional 500 million euros ($637 million) is available through Germany's NOW program.

- In the U.S., the Federal Investment Tax Credit for fuel cell installations was extended to 2016 and increased to $3,000/kW (or 30% of the cost, whichever is less) as part of the Emergency Economic Stabilization Act of 2008.

Major Reports on Hydrogen and Fuel Cell Initiatives

During 2008 a number of important studies led to the publication of landmark reports on the progress and potential of hydrogen and fuel cells, particularly in light vehicle applications. Among them:

- "Transitions to Alternative Transportation Technologies – a Focus on Hydrogen" was published by the National Research Council in response to a congressional mandate in EPACT 2005. The second in a series of two National Academy reports on hydrogen, the 2008 report made a strong case that hydrogen vehicles were an essential element in achieving substantial reductions in CO_2 emissions from, and gasoline use by, the light vehicle fleet. The study also emphasized the importance of "substantial and durable" incentives to ensure that policy objectives are met over time.
- "The Future of Hydrogen: An Alternative Transportation Analysis for the 21st Century," a complementary study conducted by the National Hydrogen Association, arrived at conclusions very similar to those in the National Academy study.
- "Effects of a Transition to a Hydrogen Economy on Employment in the United States," a DOE report to Congress on job creation potential in the field, concluded that up to 675,000 new jobs could be created by 2050 if an aggressive roll-out of hydrogen and fuel cell systems occurred.
- "Hydrogen Fueling Infrastructure Assessment": Late in 2007 GM and Shell together published an insightful analysis of the requirements for a phased roll-out of a national hydrogen infrastructure. This report, which was widely discussed in 2008, made it clear that the

"hydrogen infrastructure problem" was not nearly as daunting as many had assumed.

- "Vision for Roll-Out of Fuel Cell Vehicles and Hydrogen Fuel Stations": This vision paper from the California Fuel Cell Partnership provides a clear roadmap for roll-out of a hydrogen-based transportation system in California.
- "HyWays – the European Hydrogen Roadmap": This influential report, published by the European Commission in February 2008, shows that hydrogen energy could reduce oil consumption in road transport in the EU by 40% by 2050.
- "Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements": This study, published by Oak Ridge National Laboratory, addresses production and deployment of hydrogen-fueled vehicles and the hydrogen production and delivery infrastructure needed to support those vehicles.

In HTAC's view, the 2008 accomplishments in the hydrogen and fuel cell arena are very noteworthy. The independent analyses conducted by a number of highly reputable organizations point to the importance of hydrogen and fuel cells in the "New Energy Economy" and make it clear that a high priority should be placed on continuing the momentum of 2008 into 2009 and beyond.

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