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