

**The Hydrogen and Fuel Cell Technical Advisory Committee**  
Washington, D.C.

June 22, 2014

The Honorable Dr. Ernest Moniz  
Secretary of Energy  
U.S. Department of Energy  
1000 Independence Ave. SW  
Washington, D.C. 20585

Dear Mr. Secretary:

Enclosed is the Hydrogen and Fuel Cell Technical Advisory Committee's (HTAC's) Annual Report on Hydrogen and Fuel Cell Commercialization and Technical Development. I am pleased to provide it to you on behalf of my fellow Committee Members, who have endeavored to provide you with a comprehensive, thematic report, along with sufficient detail to create an understandable overview while also writing an easy-to-read document for the widest possible audience.

The Committee is once again pleased to report to you that the working relationship with the Fuel Cell Technologies Office is productive, functional, and cooperative. The Office remains critical to addressing the Department's ongoing efforts on fuel cell durability, costs, advanced research and manufacturing, codes and standards, and infrastructure. The Committee continues to assess these efforts with an ongoing topical subcommittee structure that operates in the mutual interests of both the full Committee and the Program Office.

This Annual Report highlights progress made, as well as challenges, regarding hydrogen commercialization and technical development. It describes both domestic and international developments. It also signals a fundamental conundrum: sustained low levels of Department of Energy funding have slowed progress, and this slow progress negatively impacts market-based funding. The Committee is deeply concerned that increased international support and funding will de-position U.S. leadership, and without increased budgetary support, the United States will fail to demonstrate the priority and progress the Program deserves.

For clarity, this letter includes highlights and concerns captured in the Annual Report that warrant your attention. We conclude with several recommendations for your consideration. We also hope that you have the opportunity to look more closely at the Annual Report itself and that you will enjoy doing so.

**Highlights:**

- Increasing penetration of stationary fuel cell deployments for back-up power, grid security, and expansion of distributed generation capacity.
- More definitive plans by automobile manufacturers for 2014–2017 commercial deliveries of fuel cell electric vehicles (FCEVs).

- Continued commitment to refueling infrastructure in California.
- Establishment and growth of H2USA.
- Rapid growth in fuel cells for material handling applications.
- Key decisions on policy and regulations, and additional work on codes and standards.
- Some improvement in the financial climate for stationary products amidst weakness for early-stage and venture capital-backed investments.
- Demonstration of hydrogen generation using a variety of renewable resources.

**Concerns:**

- Decreased funding for fuel cell and hydrogen research and development.
- Stalled progress toward reaching DOE's own goals set in prior years, due to a lack of funding.
- Delays in achieving both cost and durability targets for automotive fuel cells.
- Difficulty in making progress towards cost reduction targets for hydrogen dispensing.
- Diminished progress in hydrogen storage in pressurized tanks.
- A sustained lack of understanding of hydrogen and fuel cell technologies and applications among stakeholders.
- Multiple years of zero budgeting for the education and communication about hydrogen and fuel cell technology.

The Committee provides recommendations in fulfillment of its Congressional mandate as a part of the Annual Report process. The strength of the recommendations' wording reflects the depth of concern felt by the Committee members, emboldened by the promise and enthusiasm we see and feel with regard to the Program's potential contribution to the Department's opportunities to impact the nation's energy future. We welcome the opportunity to discuss these suggestions with you and/or your designate.

**Recommendations:**

- With respect to both the highlights and concerns, the Committee suggests that the priority and future funding levels for hydrogen and fuel cell technology be increased. Increased funding is critical to progress for commercialization, research and development, infrastructure, and education, and it makes a statement about the fuel cell and technology future to the marketplace and potential investors. FCEVs and stationary fuel cells both contribute to the reliability and security of the nation's future energy system. From the Committee's perspective, we cannot achieve the potential or promise of hydrogen and fuel cell technology in the U.S. energy system at the current priority and funding levels in a time frame that is meaningful, internationally competitive, or serves the nation's interests and defends against potential threats. We know and understand the priority preference that has been demonstrated within the Department as regards battery electric vehicles (BEVs). We are aware of both the progress and near-term successes of the Program, as well as some of its challenges and difficulties. We thus recommend more

priority and emphasis on FCEVs in an “all of the above” world for the fundamental reason that future outcomes will be “no regrets” for doing so.

- We would be pleased if you would request a review of the HTAC’s work later this year or early next year as we approach the ten-year anniversary of the Committee’s formation and commissioning. The Committee has not yet had the opportunity to present its work, worth, and accomplishments to the Secretary in person. We welcome an opportunity in which both you and members of your leadership team can hear and see firsthand how this Committee of energy technology and public policy expert volunteers is committed to helping shape a part of the nation’s future energy system in support of the ongoing efforts of the Department and its Program Office.

We look forward to continuing our service to you, your leadership team, and the Program Office. It is a pleasure for us to serve the nation with our contributions and to serve on this Committee. Any feedback you might have would be most welcome and appreciated.

Sincerely yours,

A handwritten signature in black ink, appearing to read "John Hofmeister". The signature is fluid and cursive, with a large initial "J" and "H".

John Hofmeister  
Chair

On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee

# 2013 ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee

## Hydrogen and Fuel Cell Technical Development and Commercialization Activity

### Summary

Hydrogen and fuel cells offer numerous economic, environmental, and energy-security benefits and are being developed for use in a variety of industrial, residential, transportation, and utility applications. Hydrogen is an energy-dense fuel that can be generated from a variety of resources, including renewables, thereby addressing energy security and sustainability challenges that face our nation. Fuel cells are energy efficient, clean, and fuel-flexible, and could replace internal combustion engines in vehicles and provide power for stationary and portable power applications. Despite these very attractive attributes and the substantial commercial and technical accomplishments in 2013, the widespread deployment of hydrogen fuel and fuel cells still presents some significant challenges.

This Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) highlights worldwide advancements and challenges with regard to hydrogen and fuel cell commercialization, policy, regulation and code developments, financial climate, and research and development (R&D) during 2013. Among the important achievements during the year, the HTAC considers the following noteworthy:

- There has been significant growth in the deployment of fuel cells in stationary applications (including large power parks, small-scale combined heat and power (CHP), and back-up power) as well as material handling applications. That growth, and the perception that profitability is in sight, has prompted financial markets to drive up stock prices for a number of the key participants.
- Several major automobile manufacturers announced definitive plans to introduce fuel cell electric vehicles (FCEVs) into the market in the 2014–2017 time frame. Four substantial FCEV development partnerships (Toyota/BMW, Honda/GM, Daimler/Ford/Nissan, and Volkswagen/Ballard) were announced during the year. These signals from the automobile manufacturers led to financial and organizational commitments from several countries to increase R&D support and accelerate infrastructure deployment. For example, in the United States, California made a large multi-year financial commitment to infrastructure and a public-private partnership, H2USA, was formed.
- The generation of hydrogen using a variety of renewable resources has been successfully demonstrated and a number of substantial “power-to-gas” (P2G) projects have been launched in Europe.
- A number of important policy and regulatory decisions, particularly in the United States, will help to smooth the pathway to more rapid growth of the hydrogen and fuel cell industry. Nevertheless, implementation may still take time and some critical hurdles remain.

### Commercialization Initiatives

All segments of the hydrogen and fuel cell industry enjoyed significant commercial activity in 2013, with a substantial portion of the activity occurring outside of the United States.

**Fuel Cells for Stationary Applications:** Fuel cells for distributed power continued to dominate the market in 2013, with 80 percent of total fuel cell units manufactured and megawatts shipped in stationary markets.

- In Japan, the Ene-Farm deployment, a heavily subsidized government-sponsored program started in 2009, helped developers install more than 25,000 residential fuel cell CHP systems, bringing the total deployed to more than 65,000. These systems can be fueled by natural gas, propane, or town gas, and reportedly achieve overall energy efficiencies as great as 95 percent. The Japanese government’s new draft energy strategy calls for more than 5 million units to be installed by 2030.
- In Korea, natural gas-powered fuel cell capabilities expanded, in large part through a partnership and licensing agreement between U.S.-based FuelCell Energy (FCE) and POSCO Energy, an independent power producer owned by POSCO, South Korea’s largest steel producer.
  - POSCO Energy began construction of a fuel cell manufacturing facility expected to produce at an initial fuel cell capacity of 100 megawatts (MW) per year in 2015.

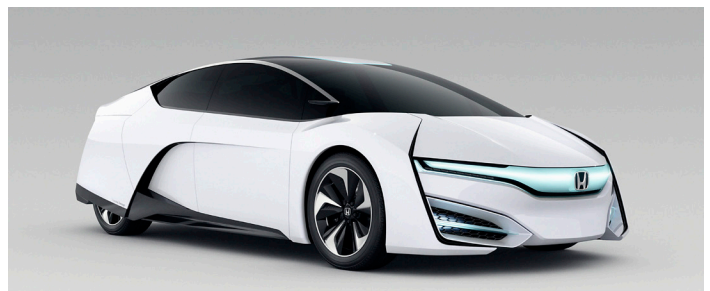
- POSCO's Gyeonggi Green Energy park had 16 operational 3-MW FCE fuel cells by late 2013.
- Korea Hydro and Nuclear Power installed the first stage (20 MW) of a 120 MW fuel cell power plant, located on a former municipal landfill that has been converted to a renewable energy park.
- The United States and Canada expanded commercial deployment of natural gas powered fuel cells.
  - Bloom Energy announced the installation of 50 MW of solid oxide fuel cells (SOFC) at a number of well-known corporations, including a 27 MW installation for Delmarva Power in Delaware. Bloom Energy now has systems totaling more than 100 MW installed in the United States, and completed its first international installation in late 2013 at SoftBank's M-Tower in Fukuoka, Japan.
  - FCE completed a 14.9 MW fuel cell park in Bridgeport, Connecticut, consisting of five fuel cell power plants and an organic rankine cycle turbine as a bottoming cycle. The project is located on a remediated brownfield site in an industrial area, and is under a 15-year agreement with Connecticut Light & Power. FCE also completed installation of a 1.4 MW fuel cell at California State University, San Bernardino.
  - ClearEdge Power expanded its product line to include a 400 kilowatt (kW) phosphoric acid fuel cell system acquired through its purchase of UTC Power. ClearEdge announced that its 400kW stationary fuel cells have reached a total of 1,000,000 hours of field operation.
  - Ballard Power commissioned a 1 MW proton exchange membrane fuel cell (PEMFC) ClearGen™ system at the headquarters of Toyota USA at the end of 2012. It also announced the sale of a 175 kW ClearGen™ system to Azure Hydrogen, its Chinese partner, as a possible prelude to expansion into China and across Asia.
  - FuelCell Energy, which is operating a waste-to-energy demonstration in Fountain Valley, California (Figure 1), reached agreement to demonstrate a comparable "tri-generation" power plant to provide electricity, heat, and renewable hydrogen. The heat will be supplied to Village Farms of Vancouver, British Columbia, a hydroponic greenhouse business, while the renewable hydrogen will be exported for vehicle fueling or industrial applications. The system is expected to be operational in early 2014.



**Figure 1. Hydrogen fueling station at the Orange County Sanitation District's municipal wastewater treatment facility in Fountain Valley, CA. Photo courtesy of Air Products and Chemicals, Inc.**

**Fuel Cells for Transportation Applications:** Global automobile manufacturers continued making major progress toward the commercialization of passenger cars equipped with PEMFC technologies for motive power.

- Honda, Toyota, and Hyundai all confirmed plans to introduce production vehicles in 2014 (Hyundai) or 2015 in Korea, Japan, Northern Europe, and California. Initial sales volumes are expected to be modest.
  - Honda and Toyota unveiled new fuel cell concept vehicles at auto shows in 2013 (see Figures 2a and 2b).
  - Hyundai announced it would produce 1,000 fuel cell vehicles on the Tucson platform, and had shipped a number to Denmark during 2013.



**Figure 2a. Honda fuel cell electric vehicle concept car 2013. Photo courtesy of Honda Motor Company.**

- Three OEM collaborations (Toyota-BMW, Daimler-Ford-Nissan and Honda-GM) and one technology access agreement (Volkswagen-Ballard) were established. The collaborations are intended to share intellectual property, mitigate technological risk, share development costs, promote innovation, and accelerate development and achievement of manufacturing scale



**Figure 2b. Toyota fuel cell electric vehicle concept car 2013.**

*Photo courtesy of Toyota Motor Corporation.*

economies through shared designs. In announcing its collaboration with Nissan and Ford, Daimler delayed its plans to produce vehicles for Germany and other markets until 2017.

- Although OEMs are reluctant to divulge costs, there are signals that key performance metrics such as power density, range, refueling time, and cold operation are sufficient to justify commercial deployment. Regarding costs, statements from the OEMs suggest that the fuel cell system cost for an 80kW system, based on high-volume manufacturing (500,000 units per year), is reasonably consistent with the U.S. Department of Energy's (DOE's) current modeled cost of \$55/kW, shown in Figure 3. Second generation technology is expected to continue progress toward 2020 cost targets.
- OEMs continue to accumulate durability and practical field fleet experience with earlier generation vehicles.
  - General Motors announced that its fuel cell vehicle fleet, originally launched in 2007 as Project Driveway, is approaching 3 million miles of real-world driving. Individual vehicles have accumulated

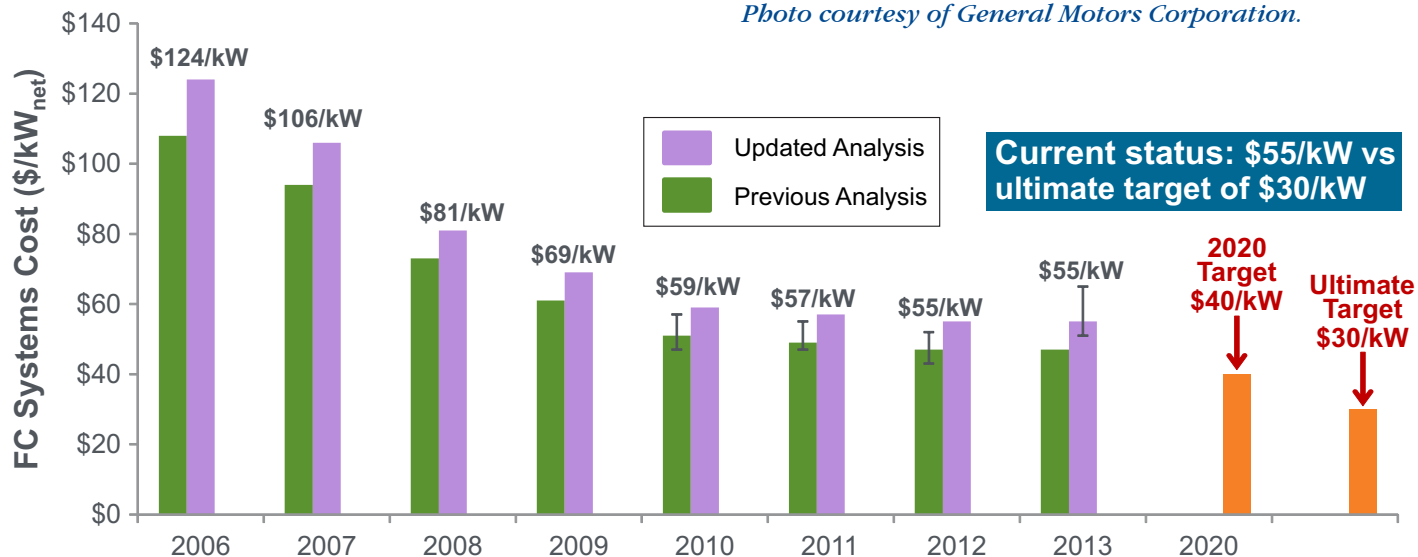
more than 100,000 miles. The first vehicle to cross this milestone is shown in Figure 4.

- Hyundai announced its development fleet has accumulated 2 million miles of driving.
- Mercedes-Benz announced that its global F-Cell fleet had achieved 1 million miles of driving by the third quarter of 2013.
- Progress is also being made on fuel cell applications in buses and other specialty vehicles.
  - The Federal Transit Administration's National Fuel Cell Bus Program awarded \$13.6 million for eight projects focused on advancing the commercialization of U.S.-made fuel cell buses. At the turn of the year, it issued a call for proposals under its Low or No Emission Vehicle Deployment Program; at least \$24.9 M is available for fuel cell and other advanced buses.
  - The University of Delaware announced plans to add two new fuel cell buses to increase its fleet to four. Golden Gate Transit will operate one bus as part of Zero Emission Bay Area (ZEBA).



**Figure 4. GM Equinox 100,000-mile fuel cell electric vehicle.**

*Photo courtesy of General Motors Corporation.*



**Figure 3. Modeled fuel cell cost progression for 80 kW automotive system at a projected high-volume production rate of 500,000 units per year. Source: U.S. Department of Energy, Fuel Cell Technologies Office.**

- CTTransit and the Center for Transportation and the Environment (CTE) finalized a deal to deliver the first commercially procured fuel cell bus under a standard Request for Proposal (RFP) process. The bus will use a Ballard FCvelocity®–HD6 fuel cell and a BAE Systems HybriDrive propulsion system.
- US Hybrid agreed with UTC to license its fuel cell system for buses and possibly other heavy-duty vehicle applications.
- Internationally, there has been considerable activity in the fuel cell bus market.
  - Van Hool NV and the Transit Authority in Aberdeen, Scotland, will deploy 10 fuel cell buses powered by a Ballard FCvelocity–HD6 fuel cell module.
  - Ballard signed a non-binding Memorandum of Understanding and a multi-year agreement with its partner Azure Hydrogen Corporation to support Azure Hydrogen’s fuel cell bus program for China.
  - Tata Motors conducted test runs of India’s first hydrogen fuel cell-powered bus.
  - The Karlsruhe Institute of Technology (KIT) in Germany started shuttle service between its campuses using two Mercedes-Benz Citaro FuelCELL Hybrid fuel cell buses.
  - BC transit in Canada went against the trend, shutting down its 20-bus fuel cell fleet in December of 2013 at the end of a 5-year trial.
- Demonstrations in the United States and Taiwan were highlights for the specialty vehicles area.
  - In 2013, DOE launched field demonstrations for fuel cells in delivery vans, airport equipment, and refrigerated shipping containers.
  - In Taiwan, a demonstration of 80 fuel cell scooters from Asia Pacific Fuel Cell Technologies was completed with more than 150,000 miles driven. The units were made available for regular rental and attracted more than 10,000 users.
- Plug Power in Latham, New York currently has an 85 percent market share, but other companies are growing as firms in the United States and Europe introduce fuel cell lift trucks in their warehouses.
- During the year, Plug Power introduced a new 14kW GenDrive® 1900 PEM fuel cell system for materials handling applications. With two on-board 350 bar hydrogen storage tanks holding 3.5 kg of gas, the large Class 1 fork lifts using the GenDrive 1900 will run continuously for eight hours.
- Under the DOE American Recovery and Reinvestment Act of 2009 (ARRA) program, 490 forklifts were deployed with approximately 98 percent reliability over 2 million hours of operation and 300,000 hydrogen fills between 2009 and 2013.

**Fuel Cells for Back-up Power Applications:** Fuel cells are generally regarded as superior to diesel back-up generators in many ways, including greater reliability, lower emissions, better energy efficiency, and ready installation. Reliable back-up is especially important during natural disasters, to power critical infrastructure such as cell networks for communications, power for hospitals, and logistics for food and water supplies. Following Hurricane Sandy in 2012, ClearEdge Power PureCell® fuel cells at Price Chopper supermarkets in Colonie, New York, and Middletown, Connecticut, operated without the grid for five and six days, respectively, allowing these establishments to continue critical operations and keep food available for the public.

- Fuel cell systems have been installed in a number of hospitals to provide back-up power.
  - At St. Francis Hospital in Hartford, Connecticut, two 400-kW ClearEdge fuel cell systems back up the operating room and provide half the building’s electrical needs.
  - Installations completed or planned include FCE systems at Stamford Hospital (4.8 MW) and Waterbury Hospital (2.4 MW) in Connecticut, and a ClearEdge system at St. Helena Hospital (400 kW) and a Bloom Energy system at Sutter Santa Rosa Hospital (600 kW), both in California.
- Ballard Power has reached the 500-unit milestone on shipments of methanol-fueled back-up power units for telecom applications; 215 of these ElectraGen™ units were produced at its plant in Mexico during the first quarter of 2013.
- A 6MW Bloom Energy system was turned on in September 2013 to power 30 servers at an eBay data center in Salt Lake City.

**Fuel Cells for Materials Handling:** The U.S. materials handling market has been a growth sector for fuel cells, with hydrogen-powered fuel cell forklift fleets operating in warehouses, distribution centers, and manufacturing facilities for major companies including BMW, Coca-Cola, Fed-Ex, and Wal-Mart.

- According to Fuel Cells 2000, more than 4,000 fuel cell forklifts are in use in the U.S. today.

- Late in the year, Ceramic Fuel Cells Ltd. reported an order from Synergy International in Estonia for 1000 BlueGen™ solid oxide systems over the next two years.
- Fuel cell backup power systems are in operation for China Mobile, China Unicom, and China Telecom, the three main mobile phone network operators in China.

**Hydrogen for Grid Support Applications:** Electrolyzers are being evaluated for use in grid balancing systems to help smooth out generation from wind turbines and solar systems. These systems would provide a load when grid demand is low and renewable power sources are available, and in some cases provide hydrogen to fuel conventional generators when renewable power is not available. This type of grid support is increasingly necessary as the percentage of intermittent renewable generation on electric grids increases.

- Approximately 30 P2G projects have been launched in Europe, in response to the growing amount of renewable generation connected to national power grids.
- Several companies announced major hydrogen energy storage projects and plans.
  - Eleven companies established the North Sea Power to Gas Platform to develop technology for the conversion of renewable power into hydrogen via electrolysis.
  - Hydrogenics Corporation and eight partners are collaborating on a 5-year energy storage research, development and demonstration project in Belgium.
  - Hydrogenics and E.ON launched commercial operation of its P2G facility in Falkenhagen, Germany (see Figure 5). Hydrogenics will also install a 1-MW hydrogen energy storage system in Hamburg, Germany.
  - ITM Power won a competitive tender process to supply a 360kW P2G energy storage plant for a Thüga Group project, the company's first major commercial sale of a large hydrogen production unit in Germany.
  - The Hydrogen Mini Grid System (HMGS) in Rotherham, UK, operated by ITM Power, will convert wind power to hydrogen for vehicle fuel and backup power generation.
  - ITM Power was also awarded a €350,000 (US\$463,000) grant to work with a consortium on the CommONEnergy project funded under the EU's Seventh Framework Program. The project



**Figure 5. Hydrogenics P2G facility in Falkenhagen, Germany.**  
*Photo courtesy of Hydrogenics.*

will demonstrate energy-efficient technologies and energy storage solutions for non-residential buildings.

- Acta S.P.A signed a Letter of Intent with Ecoisland Partnership to run a domestic renewable energy storage trial project for a house on the Isle of Wight, for which Acta S.P.A will provide an electrolyzer and hydrogen storage tanks.

**Hydrogen Infrastructure:** Although the worldwide hydrogen fueling infrastructure is still in its infancy, this year saw significant new commitments of financing for stations. The number of fully operational hydrogen fueling stations globally exceeded 220 in 2013, though many are not open to the public (Figure 6 shows a typical station).

- As signals from the auto industry began to make it clear that the vehicles are coming, infrastructure activities in Japan, Germany, and California accelerated and focused on public accessibility.
  - In Japan, where 17 demonstration stations are operating, the government agreed to support 100 stations, in partnership with Japanese oil and hydrogen companies. The government committed \$46 million in 2013 with another \$72 million anticipated in 2014 for a network of stations across southern Japan. The first 19 of the new-generation commercial stations were announced late in 2013.
  - In Germany, the H<sub>2</sub> Mobility initiative announced a plan to expand the current network of 15 stations to 100 public hydrogen stations in the next four years and to 400 stations by 2023, with a \$463 million investment from as-yet unidentified sources.





**Figure 6. Hydrogen fuel dispenser in Torrance, CA. Photo courtesy of National Renewable Energy Laboratory.**

- In California, new legislation (AB8) provides up to a \$20 million per year commitment to fund hydrogen fueling stations until there are at least 100 public stations. After awarding \$12 million to support seven stations early in 2013, the California Energy Commission made available \$29.9 million late in the year for another round of stations.
- Several initiatives aimed at coordinated planning for infrastructure roll-out launched this year.
  - H2USA, a public-private partnership focused on supporting the build-out of hydrogen fueling infrastructure, formed in the spring. During the year, H2USA held organizing meetings and began fundraising.
  - Twenty corporate partners established Mobilité Hydrogene France to support a public-private infrastructure deployment plan in France.
  - UK H<sub>2</sub>Mobility expanded its operations and new partner involvement to include the Greater London Authority, the Welsh Government, and Transport Scotland.
  - H<sub>2</sub>Mobility Swiss was established.

- A number of corporate participants announced technical and operational initiatives and results. These include:
  - Air Products and Chemicals Inc., in collaboration with Bennett Pump Company, announced a new consumer-friendly hydrogen dispenser to be installed in 10 stations in California.
  - Linde, in cooperation with Wystrach GmbH, has developed a light-weight 500-bar composite storage tank allowing delivery of 1,100 kg of hydrogen in a single tube trailer.
  - Danish company H2Logic demonstrated it could install a modular fueling station in 48 hours. The station will be used to fuel Hyundai vehicles delivered to Copenhagen.
  - The Toyota Tsusho Corporation and Air Liquide signed a new joint venture to build hydrogen fueling infrastructure in Japan.

As the year drew to a close, a number of infrastructure financing and operational initiatives were percolating, particularly in California where early vehicle roll-outs are anticipated. One Toyota executive commented, “We’ve seen players we never heard of before suddenly come out of the woodwork.” All of which suggests that 2014 and beyond may be a very interesting time for infrastructure development.

## Policy, Regulations, Codes and Standards

**Codes and Standards:** Significant progress was made in 2013 on the development of codes and standards relevant to hydrogen and fuel cells.

- The NFPA2 Hydrogen Technologies Code was referenced in the International Fire Code (IFC), effectively making NFPA2 the U.S. national hydrogen code.
- SAE J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles was completed.
- NFPA 55 Code for Compressed Gases and Cryogenic Fluids was revised to more clearly address hydrogen storage.
- A new Canadian Standards Association (CSA) standard (ANSI/CSA FC-1) was issued for stationary fuel cells.
- The Global Technical Regulation on hydrogen and fuel cell vehicles was issued.

Despite these developments, many code compliance issues remain.

**Policy:** International progress on policies supporting hydrogen and fuel cell R&D and deployment continued in 2013, and individual states also launched leadership programs and policies.

- The European Union, Japan, and others made significant new financial commitments for research, demonstration, and infrastructure deployment.
  - Europe’s Horizon 2020 program allocated \$926 million over seven years for a cost-shared program.
  - Japan’s hydrogen and fuel cell R&D budget doubled in 2013 to \$400 million.
  - China renewed its alternative-energy vehicle subsidy program to address air quality issues. FCEVs, including buses, qualify under the subsidy for the first time, and will be eligible for an \$8,000 rebate.
  - The United Kingdom Office of Low Emission Vehicles launched Driving the Future Today, which outlines the UK’s technology-neutral strategy for promoting and adopting ultra-low emission vehicles (ULEVs). The strategy outlines development of a hydrogen fueling infrastructure to support FCEVs, including buses.
- The California Governor’s office released the “2013 ZEV Action Plan” that includes a goal to have 1.5 million zero-emission vehicles, including hydrogen fuel cell vehicles, on the road by 2025.
- The New Jersey Economic Development Authority (EDA) and the New Jersey Board of Public Utilities (BPU) launched a second round of the Large Scale Combined Heat and Power/Fuel Cell Program, which supports CHP and stand-alone fuel cell projects with a generating capacity of greater than 1 MW, with up to \$3 million available per project.
- Connecticut released its 2013 Comprehensive Energy Strategy, which outlines strategies for meeting its energy needs in a cleaner, more reliable way. To meet the “20% by 2020” renewable portfolio standard, the state will have to increase its Class I resources (fuel cells, solar, and wind) by 3 gigawatts (GW).

## Financial Climate

During the course of 2013, there was a major change in the financial climate for hydrogen and fuel cell companies.

- At the beginning of the year the climate was gloomy.
  - United Technologies completed the sale of its fuel cell assets to ClearEdge Power, but had to sweeten the deal with \$48 million in cash. In total, UTC

reportedly took a charge of approximately \$227 million on the transaction.

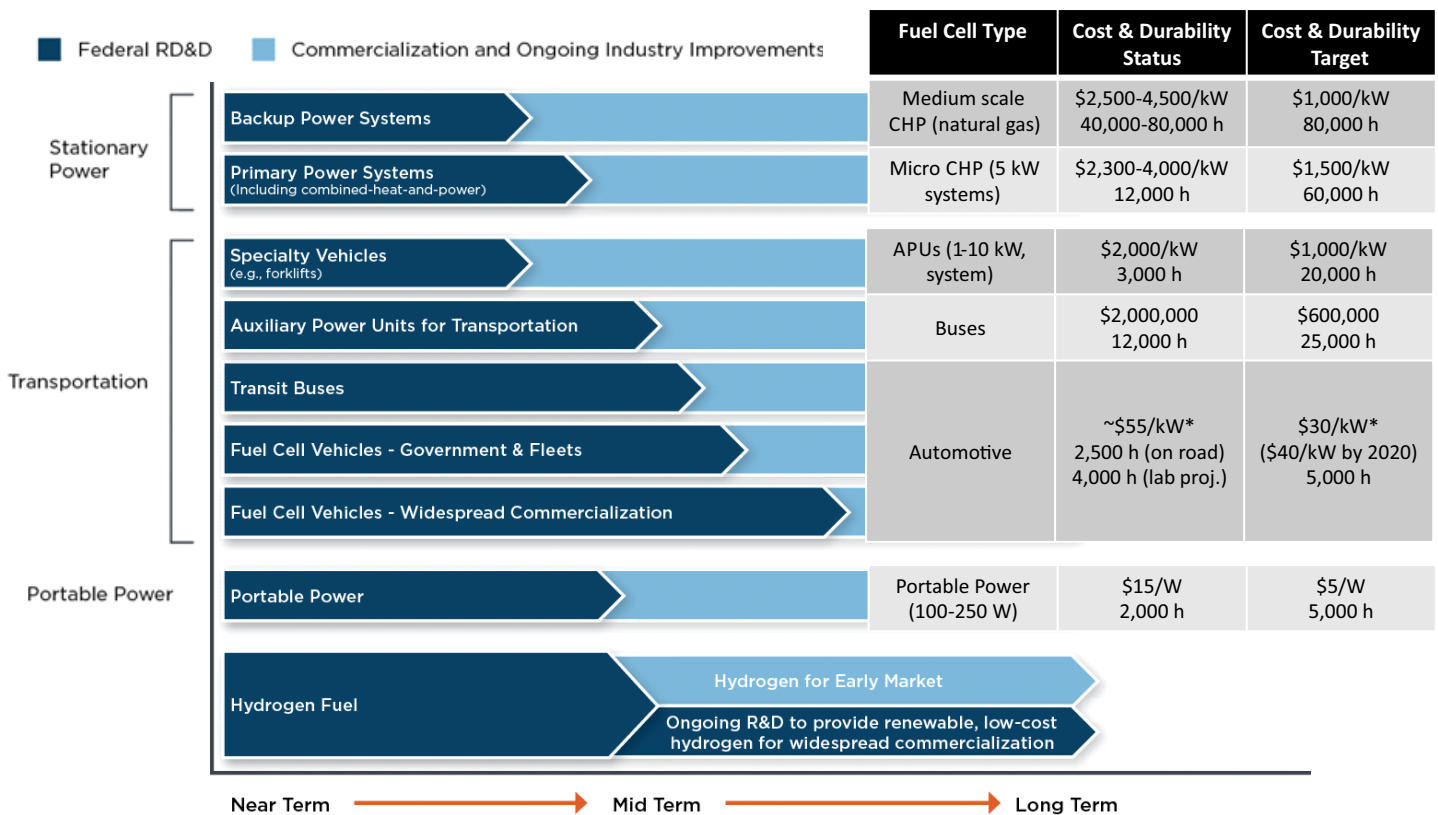
- Hess Oil refocused on its core business and put its Nuvera fuel cell and hydrogen production/dispensing business up for sale; at year-end a deal had yet to be completed.
- BASF decided to exit its high-temperature fuel cell membrane business, closing its New Jersey operation. The technology was acquired by Advent Energy and moved to Connecticut, with the encouragement of \$1 million from Connecticut Innovations.
- Wartsila spun off its solid oxide fuel cell activities into a new company, Convion Oy.
- The ambitious Ecoisland Partnership on the Isle of Wight went into voluntary liquidation due to lack of funding, though elements of the project are likely to continue under separate funding arrangements.
- Financial transactions during the early part of the year were done at very modest values.
  - FCE re-acquired the remaining shares of the solid oxide fuel cell company Versa Power Systems, owned by other investors, for \$3.3 million.
  - The French company McPhy acquired Italian electrolyzer company PIEL for \$13.3 million.
  - Cummins Inc. made a strategic investment in ReliOn, the Spokane-based PEM fuel cell company, for an undisclosed amount.
  - Struggling UK-based solid oxide fuel cell manufacturer Ceres Power signed an agreement with Korean boiler-maker KD Navian.
- Early stage and venture-backed companies often found it very difficult to raise capital and, when they did, the amounts were generally modest and valuations relatively punitive.
  - Point Source Power, a start-up company that had licensed Lawrence Berkeley National Laboratory solid oxide fuel cell technology, was unable to complete a modest crowd source funding effort.
  - ACAL Energy, a UK company, raised bridge financing from existing investors but its efforts to raise capital from new investors had not been successful by the end of the year.

- The financial climate in the latter part of the year became more favorable, at least for public fuel cell companies, leading to a number of more attractive deals.
  - Air Liquide made a \$6.5 million structured investment in Plug Power (PLUG), and then late in the year Plug's stock price escalated and continued to rise into 2014, apparently on the strength of large order announcements.
  - Ballard (BLDP), Hydrogenics (HYGS), and Fuel Cell Energy (FCEL) saw significant upward movement in their stock prices and took advantage with secondary stock offerings. The market capitalization of all these companies, though materially improved, remained at a small fraction of invested capital and stock prices were still far short of the values at the time of their initial public offerings more than a decade ago.

A bright spot in the financial picture was Bloom Energy, a company commercializing solid oxide fuel cells. While the rest of the hydrogen fuel cell market struggled, Bloom raised an additional \$130 million, bringing its total invested capital to a reported \$1.1 billion. The company also signed a major joint venture with Japanese telecom/internet giant SoftBank Group. Bloom is reportedly considering a public offering, which, if successful, could well pull the rest of the companies in the industry up with it.

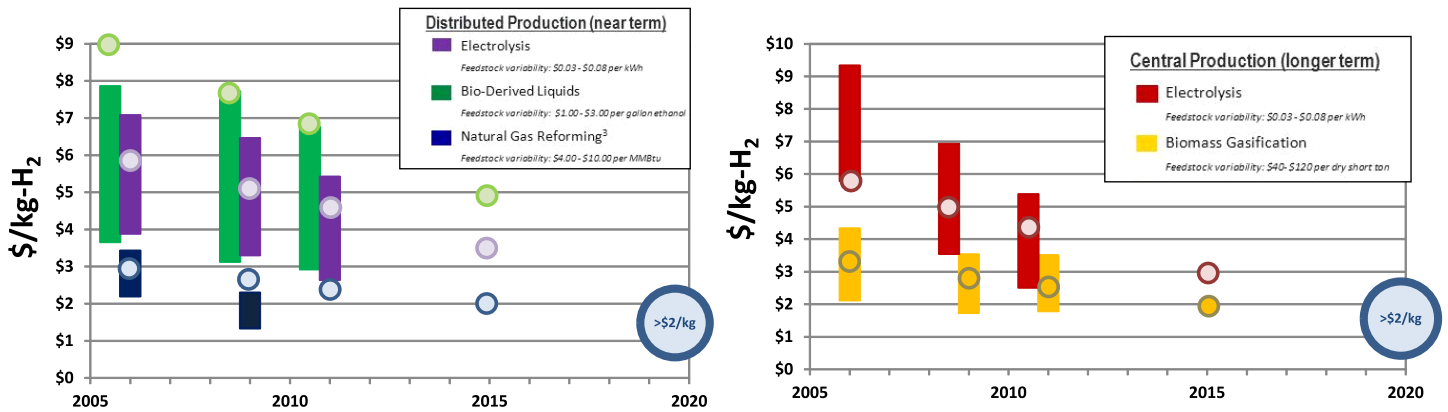
## Research and Development

Research and development activities provide important support for efforts to commercialize hydrogen fuel and fuel cells. Some advances are being made towards meeting key targets established by DOE, despite relatively low funding levels for the DOE fuel cell program in recent years. The current status against DOE cost and durability targets for fuel cells is illustrated in Figure 7, while projected high volume hydrogen production costs are illustrated in Figure 8. A number of metrics can be



**Figure 7: Department of Energy cost and durability status and targets for fuel cells.**

Source: U.S. Department of Energy, Fuel Cell Technologies Office.



**Figure 8: Predicted high-volume hydrogen production costs via distributed and central production (status in vertical bars, targets in circles, 2007 dollars).**

Source: U.S. Department of Energy, Fuel Cell Technologies Office Program Record #14011, Hydrogen Cost Target Calculation, June 2014, [http://www.hydrogen.energy.gov/pdfs/14011\\_b2\\_cost\\_target\\_calculation.pdf](http://www.hydrogen.energy.gov/pdfs/14011_b2_cost_target_calculation.pdf).

used to assess progress in R&D, including patents and publications.

- After many years of leading clean technology innovation, the number of patents issued for fuel cell technologies dropped slightly in 2013.
  - The top five companies for fuel cell patents were GM, Honda, Toyota, Samsung, and UTC Power (now ClearEdge).
  - There is speculation that the decline in issued patents for fuel cell technologies is a consequence of decreased DOE investment in fuel cell and hydrogen R&D. As illustrated in Figure 9, DOE funding for 2013 was down from levels in 2012 and was substantially below the high point in 2007 of almost \$330 million in funding provided under the DOE Hydrogen Fuel Initiative, including \$63.4 million in the Solid State Energy Conversion Alliance (SECA) Program. Conversely, the European Union, Japan, and California made significant new financial commitments for research, demonstration, and infrastructure deployment.
- The number of new R&D papers published this year indicates that this field of inquiry is still very robust.
  - More than 260 papers describing the results of fuel cell research and development were published. Topics ranged from new electrocatalytic and membrane materials to advanced cell architectures.

- With regard to hydrogen production, nearly 860 relevant papers were published describing many new catalytic materials for the conversion of feedstocks including water, hydrocarbons, and biomass.

## Continuing Challenges

While deployment of fuel cells in various applications has been increasing, there remain several technical challenges that hinder more widespread acceptance and implementation. There is the continuing challenge of decreased funding for fuel cell and hydrogen R&D, but perhaps more of an issue is that progress toward reaching the goals set by DOE has stalled over the past few years in automotive fuel cells, hydrogen production, hydrogen storage, and stationary power. Of course, it is important to re-evaluate whether the goals remain appropriate; DOE is undertaking such a task, but the following key areas have shown little or no change from their status in 2011:

- The automotive fuel cell cost goal is \$30 per kW and the projected cost at 500,000 units per year has remained at approximately \$55 per kW since 2010.
- The automotive fuel cell durability goal is 5,000 hours and the status measured in NREL field tests is 2,500 hours, although industry has signaled informally that system tests have demonstrated up to 7,000 hours and ACAL Energy has published single cell performance of more than 10,000 hours.

Funding (\$ in thousands)							Funding (\$ in millions)			
Office of Energy Efficiency and Renewable Energy	FY 2012	FY 2013		FY 2014		FY 2015	Other DOE Offices	FY2012	FY 2013	FY 2014
Key Activity	Approp.	Request	Enacted (C.R.)	Request	Enacted	Request				
Fuel Cell R&D	43,634	36,899	41,266	37,500	33,383	33,000	Basic Science	27	26	~\$25
Hydrogen Fuel R&D	33,824	26,177	31,682	38,500	36,545	36,283	Fossil Energy, SECA	25	23.8	\$25
Manufacturing R&D	1,944	1,939	1,899	4,000	3,000	3,000	ARPA-E	2	2	~\$30
Systems Analysis	3,000	2,922	2,838	3,000	3,000	3,000	Total	\$54	\$52	~\$80
Technology Validation	8,986	4,992	8,514	6,000	6,000	6,000	<b>Total FY14 Budget: &gt;\$172M</b>			
Safety, Codes and Standards	6,938	4,921	6,808	7,000	7,000	7,000				
Market Transformation	3,000	0	2,838	3,000	3,000	3,000				
Education	0	0	0	0	0	0				
NREL Site-wide Facilities Support	0	0	0	1,000	1,000	1,700				
SBIR/STTR	2,298	2,150	2,139	TBD	TBD	TBD				
Total	\$103,624	\$80,000	\$97,984	\$100,000	\$92,928	\$92,983				

**Figure 9. Recent Department of Energy funding for hydrogen and fuel cells R&D.** Source: U.S. Department of Energy, Fuel Cell Technologies Office.

- The hydrogen production cost goal is less than \$4 per gasoline gallon equivalent, and the current status is reported by DOE to be \$4–9 per gasoline gallon equivalent. Industrial gas companies have indicated in public presentations that hydrogen can be dispensed to the consumer at \$8/kg today for a fully loaded 150-200 kg/day station with high-pressure hydrogen delivered by tube trailer from a nearby large-scale production facility. This achieves parity with a 30 miles-per-gallon gasoline vehicle at \$4/gasoline gallon. The dispensed price can be as low as \$6/kg when hydrogen can be delivered by pipeline from nearby large-scale production facilities, which is equivalent to \$3/gasoline gallon.
- Hydrogen storage performance for pressurized tanks remains about 50 percent below the goal of 2.3 kWh per liter or 2.5 kWh per kilogram. Stationary power status on both cost and durability is unchanged from 2011 and remains a factor of 3.5 times more costly than the goal.
- One performance measure that already meets the DOE goal is automotive driving range. While unchanged from 2011, it exceeds the target of more than 300 miles. At least one vehicle OEM reported achieving ranges of more than 400 miles.

A final continuing challenge is the lack of understanding and appreciation of hydrogen and fuel cell technologies and applications among many stakeholders, especially in the early adopter regions. A focused and dedicated

explanation of the status and potential for hydrogen and fuel cells is warranted, as infrastructure and market growth will depend upon their acceptance by the public. This lack of awareness and knowledge could jeopardize the early successes and importance of this undertaking.

## Reports

A number of reports on hydrogen and fuel cells were published in 2013.

- A report from the Institute of Gas Engineers and Managers in the UK affirms the importance of hydrogen in reducing carbon dioxide emissions and increasing the useful output of renewables.
- “The Business Case for Fuel Cells,” a report prepared by Fuel Cells 2000 with DOE support, summarizes the purchases of fuel cells for stationary (32 MW) and materials handling (1,100) applications in 2012.
- The National Research Council published *Transitions to Alternative Vehicles and Fuels*, a report that examines the current capability and estimated future performance and costs of alternative vehicles and non-petroleum-based fuel technology. The report analyzes scenarios that combine various fuel and vehicle pathways, identifies barriers to implementation, and suggests policies to achieve goals for reducing petroleum use and greenhouse gas emissions.
- The California Fuel Cell Partnership published “A California Road Map,” which details plans for the roll-out of fuel cell buses.

- Navigant Research released a white paper on “The Fuel Cell and Hydrogen Industries: 10 Trends to Watch in 2013 and Beyond.”
- UK H<sub>2</sub>Mobility published a Phase 1 Report evaluating the potential of FCEVs to “decarbonise road transport, create new economic opportunities, diversify national energy supply, and reduce significantly the local environmental impacts of road transport.”
- The HTAC commissioned development of a report on hydrogen and renewables integration.

## Conclusions

During 2013, there was significant expansion in the deployment of fuel cells, in particular for stationary and materials handling applications. Of particular note is the

successful Ene-Farm deployment in Japan. The fact that automotive companies, in several cases via partnerships, are preparing to offer FCEVs to the public suggests that cost and performance are moving into acceptable ranges. These activities have stimulated the climate for fuel cell financing, encouraged the establishment of new policies and codes, and caused a refocus in R&D investment.

Despite a number of positive signals, challenges remain. Technical progress in key areas has been steady during the past few years, but DOE investments have decreased. Given these recent developments and the substantial but as yet unrealized potential of hydrogen and fuel cell technologies, it is clear that further market development support is needed to assure the continued positive trajectory of commercialization of these systems.

*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. For more information see [http://www.hydrogen.energy.gov/advisory\\_htac.html](http://www.hydrogen.energy.gov/advisory_htac.html)*