

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

July 15, 2013

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 the State of 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.

Fuel cell and hydrogen technologies can help achieve the Administration's key energy initiatives, including the potential to double advanced energy technology exports, increased deployment of CHP by 50% by 2020, and developing advanced electric drive vehicles in pursuit of both climate and energy security goals. HTAC also supports the new clean energy manufacturing initiative, which is of substantial value to the fuel cell and hydrogen energy industry.

The Committee is pleased to report to you that within its statutory independence, the working relationship with the Fuel Cell Technologies Office is productive, functional, and cooperative. The Office remains key to addressing the Department's ongoing efforts on fuel cell durability, costs, advanced research and manufacturing, and infrastructure. The Committee has assessed these efforts with a Subcommittee structure that operates in the mutual interests of both the full Committee and the Program Office.

Critical also to the Committee's functioning has been the Department's leadership and its interests, both from EERE and the Secretary. We have completed a productive year, having had significant and helpful interactions with both Assistant Secretary Danielson and your predecessor, Secretary Chu, along with other senior Department leaders. We look forward, via this letter and subsequent communications, to an ongoing and mutually beneficial new relationship with you and are most anxious to tell you our story and keep you abreast of our concerns.

This Annual Report may be the most important to date not only because of the progress made over the past year, but also because it highlights the fragility of the economic support for future developments in the hydrogen and fuel cell field. It also flags the international competitive threats to a sustained U.S. leadership position in hydrogen fuel cell technology and in the emerging industry more broadly.

For clarity this letter covers highlights of the Annual Report in summary, which we believe warrant your attention, and then also summarizes key concerns, which we believe we have a duty to bring directly to you. We conclude with recommendations for your consideration. We also hope that you have the opportunity to look through the entire Annual Report and will enjoy doing so.

Highlights of 2012:

- The growth in applications and volumes of hydrogen fuel cell products, both stationary and mobile, is happening to a far greater extent than is commonly known or reported. Such growth is critical for sustained economic support, especially from private sources.
- Department leadership was more visibly involved and verbally supportive than in the past. We are hopeful that under your leadership these efforts will expand even further.
- Natural gas production expansion bodes well for future hydrogen supplies.
- Commercial activities in material handling and power systems have exceeded expectations and rapid development is happening because of market pull, from what we observe, as well as technology push. This is truly significant considering where we have been.
- Pre-commercial activities, such as transportation, renewable hydrogen from bio-gas, wind and solar, and energy storage continue, but not perhaps at the pace in the United States that the Committee believes will sustain our nation's leadership over time. As has always been the case, the pre-commercial depends upon public support and collaborative agreements, which have become more difficult over the past year.
- Research and development funding for the Program Office has dropped by 50%. Progress thus continues, but at a reduced rate.
- Hydrogen fuel cells for transportation were included in the National Petroleum Council's major report of 2012: *Advancing Technology for America's Transportation Future*. FCEVs produce zero tailpipe emissions and significantly reduce life-cycle GHG emissions, making them a critical part of our portfolio to address climate pollution.
- Work continues on creating policy and on setting codes and standards. This is a critical part of the overall hydrogen infrastructure efforts and thus the Program Office continues to pay attention to developments in these areas.
- Finally, the financial climate is fragile and warrants ongoing attention from the public and private sectors if we are to both progress and hold a leadership position in the world. As a natural outgrowth there has been some consolidation among companies; helpfully, there have also been some amazingly high valuations of companies in the public marketplace.

Concerns:

- A recent public announcement in Japan describes the creation of a task force of public- and private-sector participants to secure "Japanese dominance" of hydrogen fuel cell vehicles in the years ahead. The U.S. leadership position is under serious challenge by

both Japan and Germany from the Committee's perspective and the experience of recent years.

- Increased attention to the hydrogen fueling infrastructure is ever more important to maintaining the interest and financial commitment of the U.S. and global auto company leaders. There are more indications that Germany and Japan have made infrastructure progress beyond what has been happening in the United States. These initiatives influence where the future suppliers to the auto companies focus their product development and manufacturing efforts. We stand to lose the leadership position not only in first market mover advantage of auto sales volumes, but also in terms of establishing the manufacturing base for components, parts, and finished products.
- The journey will nonetheless remain a long haul and we should keep that in mind as we pursue opportunities and tackle challenges. Market uptake in both vehicle and stationary hydrogen fuel cell markets is not immediate and returns on investments remain a future promise.
- The language chosen surrounding hydrogen fuel cells and technology by the Department's leadership is extremely important to both the public- and private-sector perceptions of the industry. Words, actions, and consistent funding have profound impact to enable increased support and more rapid progress.
- A recent reorganization and priority setting within the Department has had the unintended consequence of appearing to separate hydrogen fuel cell program development for transportation from stationary power generation. The consequence is a lack of clarity on where and how stationary hydrogen fuel cell program activity is being managed, and there is a risk that others perceive this outcome as signaling a diminished interest in or support for hydrogen and fuel cells in power generation.
- The risk of diminished funding by Congress and the Department will have a real impact in the coming years that may simply not be recoverable on an internationally competitive basis.

The Committee has worked hard for many years to provide a mature, pragmatic set of useful recommendations to the Secretary as part of its Annual Reporting process. We are thus delighted to offer you our recommendations for your consideration. And we welcome the opportunity to discuss these suggestions further with you.

Recommendations:

- Please include the importance of hydrogen and fuel cell technology and the progress being made in your formal and informal remarks to multiple audiences. The impact of your messages is significant and your voice amplifies the importance of the efforts underway.
- We feel that it is important for you to recognize publicly the reality of international competition and the potential that it will permanently erode the U.S. leadership position in the market for fuel cells.
- We suggest you make positive efforts to support the rollout of a retail infrastructure for hydrogen fueling by intermediating with the multiple interested parties. A special

conference in the coming months to review and discuss infrastructure issues and opportunities could be an extraordinary opportunity to learn, decide, and lead the next steps to progress and success. Such an event could also build upon and reinforce the efforts of H2USA and important state initiatives such as those developing in California, Hawaii, and the Northeast.

- We would be pleased if you would request a review of both the work of HTAC and its Subcommittees later this year or early next year, where you and your leadership team will hear and see firsthand how this committee of citizen volunteers, a well-functioning group of energy technology and energy policy experts, is helping to shape the nation's transportation and technology future in support of the ongoing efforts of the Program Office.
- Despite the challenging funding environment, please include this work among your funded priorities.

We look forward to continuing our service to you, your leadership team, and the Program Office. It is a pleasure to serve our nation by virtue of our contributions while serving on this Committee. Any feedback you might have, as well as the opportunity to discuss our findings with you, 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

2012 ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee

Hydrogen and Fuel Cell Technical Development and Commercialization Activity

Introduction: Advances and Remaining Challenges

Hydrogen and fuel cell technologies continued to advance rapidly in 2012. New technical milestones for fuel cells, hydrogen production, delivery, and storage were achieved. A range of fuel cell and hydrogen technologies in material handling, transportation, and backup and stationary power applications moved toward commercialization.

Worldwide fuel cell shipments reached 100 MW in 2011 and were projected to reach 176 MW in 2012.¹

Deployments that numbered in the hundreds just a few years ago now are numbered in the thousands or tens of thousands:

- Tens of thousands of small-scale fuel cell combined heat and power systems were installed in homes in Japan.
- Thousands of new fuel cell forklifts went into service in the United States. Fuel cell stationary power applications multiplied, with megawatt-scale systems installed around the world.
- The largest ever (58.8 MW) fuel cell power plant is being planned for construction in South Korea.
- Fuel cell bus fleets were demonstrated in the United States, United Kingdom, Germany, and Japan, with bus fuel cell durability of 12,000 hours demonstrated in one commercial test in California.
- The first commercial passenger vehicle introductions are anticipated in the 2015–2017 timeframe.
- Fueling infrastructure deployment programs are under way in Germany, Scandinavia, Japan, South Korea, and California.
- Renewable hydrogen demonstration projects were initiated in North America, Europe, and Asia, spurred in the United States by renewable portfolio regulations. These included hydrogen storage systems for

intermittent renewables like wind, solar and a tri-generation system that produces power and heat plus hydrogen for vehicles from renewable biogas.

- Several key studies highlight the capacity of hydrogen fuel cells to enable low-carbon power grid solutions and a zero-emission vehicle fleet.

It is important to note that many challenges need to be addressed before hydrogen fuel cell (HFC) technologies can be considered fully commercial. Cost is a major obstacle as is the challenge of matching commercial vehicle sales with infrastructure deployment.

The Department of Energy (DOE) supports highly targeted research and development (R&D) to address these challenges. Critical areas being addressed by DOE's Fuel Cell Technologies Office (FCTO) include fuel cell durability and cost reduction, advanced manufacturing, improvements in hydrogen storage and production technologies, and mechanisms to achieve cost-effective hydrogen distribution and dispensing infrastructure. The FCTO Market Transformation Program has made a measurable contribution to cost reduction and system improvement through end user experience. Research on large scale solid oxide fuel cell systems (SOFC) is under way in the Office of Fossil Energy, which manages the Solid State Energy Conversion Alliance (SECA).

The 2012 progress and achievements documented in this report are important and exciting steps along the pathway to widespread commercial readiness, but substantial work remains before the technologies can become fully seated as sustainable energy and power options.



Indoor fueling of a material handling pallet jack. *Photo courtesy of Air Products and Chemicals, Inc.*

In 2012, Energy Secretary Chu acknowledged the excellent technical progress being made by the FCTO and industry. He participated in a number of hydrogen and fuel cell activities and discussions, including a roundtable with auto executives at the Detroit auto show and the launching of HTAC's subcommittee, the Hydrogen Production Expert Panel, to identify challenges and recommendations for the DOE. He also observed that increasing availability and attractive pricing of natural gas

is helping make hydrogen a more attractive option for the transportation sector. The Secretary remarked on the emerging potential for hydrogen as an enabler for renewable energy generation and recognized the substantial commitment the auto industry has made worldwide to move HFC technology toward commercial viability in passenger vehicles. The views of the Secretary and the DOE leadership team are closely monitored by industry and by the financial community.

Commercial Deployments

There was strong growth in commercial use of HFC technologies in 2012 both in the United States and worldwide. Highlights of developments in material handling equipment and power systems, based on three key reports released in 2012, are described in this section.²

Material Handling Equipment

Hydrogen-powered fuel cell forklifts offer many advantages for the material handling industry. Fuel cell forklifts only need refueling once or twice daily (depending on use), refuel rapidly, and do not experience the decreased performance battery units suffer as the state of charge declines or in cold environments. Some purchasers of fuel cell systems have been able to eliminate battery charging and storage facilities. Fuel cell forklifts achieve overall productivity gains, depending on fleet size and operation. In 2012, the U.S. materials handling industry operated more than 4,000 fuel cell forklifts in a total of 36 warehouse locations nationwide. This is an order of magnitude increase from 2008 when only a few hundred fuel cell units were in use.³

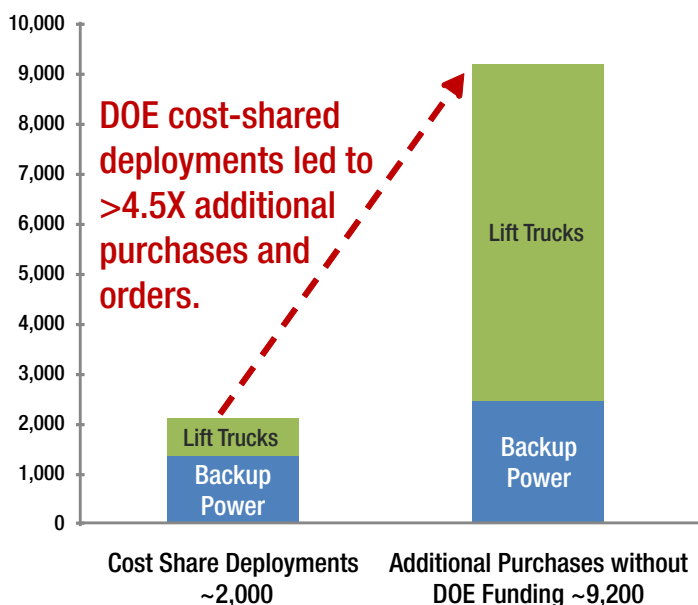


Figure 1. Early market deployments of approximately 2,000 fuel cells have led to more than 9,000 additional purchases by major companies (including Coca-Cola, Sprint, Sysco, FedEx, and others) with no additional DOE funding.

- Collectively, several materials handling sites currently dispense 75,000 hydrogen refills per year, adding to the experience base for launching light duty passenger vehicle infrastructure.⁴
- DOE support played an important role in initiating successful forklift and backup power markets in the United States. Thousands of additional forklift purchases were made after the DOE cost share ended, as shown in Figure 1.⁵

Power Systems

Fuel cell power system production increased rapidly in 2012, finding applications in backup power, assured power, and combined heat and power market segments.⁶ Reliability appears to be a key sales point, since many systems operate off-grid or are configured to maintain power when the grid fails.

- More than 32 MW of stationary fuel cell power systems were purchased for U.S. facilities in 2012. Six purchasers employ fuel cells to help provide reliable power to major data centers and communications hubs.
- Major companies placed repeat fuel cell orders after experiencing operational benefits and financial savings. AT&T now has more than 17 MW installed or on order for 28 sites in Connecticut and California.⁷ Walmart has installations at 26 stores in California. Both companies are operating solid oxide fuel cells (SOFC) from Bloom Energy.
- A PureCell stationary fuel cell system at Mohegan Sun Resort & Casino in Uncasville, Connecticut, achieved a record durability milestone of 90,000 hours by operating for 10 years on the original phosphoric acid stack and fuel processor. This is double the system's expected life.
- Stationary baseload and backup power fuel cell systems by Alteryg, Ballard Power Systems, Bloom Energy, ReliOn, and UTC Power maintained power for Caribbean and Northeastern U.S. customers throughout Hurricane Sandy and during the aftermath.
- A total of about 40,000 residential fuel cell combined heat and power systems have been installed in Japanese homes as of the end of 2012 under the Ene-Farm program.⁸
- FuelCell Energy announced a 121.8 MW order with Korean partner POSCO, representing the largest fuel cell order ever received. UTC Power announced a total of 10 MW of fuel cell sales through Korean distributor Samsung. South Korea's rapidly growing market is driven by a new Renewable Portfolio Standard, power

grid reliability concerns, and a pledge to roll-out 230 MW of fuel cells that will offset planned nuclear plant closures. South Korea has expressed a strategic interest in developing a domestic fuel cell industry.

Pre-Commercial and Technology Demonstration Activities

Field testing, demonstrations, and early commercial deployment are under way in a wide range of market segments worldwide. The following summary, which is by no means exhaustive, focuses on significant pre-commercial and demonstration activities under way or in the final planning stages in 2012. Sectors include transportation (including passenger cars, buses, and fueling stations), renewable hydrogen, and hydrogen energy storage.

Transportation

Fuel cell electric vehicles (FCEVs) advanced toward commercialization with several of the largest automakers announcing or affirming commercialization timetables and manufacturing investments. Multiple original equipment manufacturers (OEMs) signed collaborative development and manufacturing agreements, but a viable hydrogen infrastructure is still required for consumer acceptance.⁹ By the end of 2011, 215 hydrogen refueling stations were in operation, located in Europe (85), North America (80), Asia Pacific (47), and the rest of the world (3). Unfortunately, few of these stations are open to the public.

Several public stations opened in 2012, but deployment has been slower than anticipated. Germany, California, and Japan separately announced progress toward a total of more than 200 additional stations by 2016.¹⁰

Fuel Cell Passenger Cars

Hydrogen FCEV developers continue to make progress toward technical and cost objectives. The business case remains challenged by marginal hydrogen fueling infrastructure progress and relatively low conventional fuel prices. Without sufficient infrastructure growth, the first commercial vehicle deployments risk prolonged production cycles that may prevent OEMs from quickly iterating upon designs and rapidly realizing scale economies. In response, some automakers are establishing new collaborations that are targeted at mitigating these risks and delivering the following advantages:

- Distributing development costs across multiple OEMs.
- Standardizing components to reduce material costs and help develop the supply base.

- Establishing additional FCEV market participants to help drive early volume increases and support growth of infrastructure.
- Driving the development and adoption of common codes and standards across the industry.



Chevrolet Equinox Fuel Cell Vehicle on Test in Hawaii. *Photo courtesy of General Motors.*

In 2012, several major automakers reaffirmed their commitment to introducing thousands of fuel cell passenger cars within the next few years.

- In January 2013, two major partnerships were announced to develop mass-produced, affordable FCEVs. Toyota and BMW agreed to collaborate on FCEV technology. One week later, Ford, Daimler, and Nissan announced a similar development project, with the purpose of achieving “affordable, mass-market fuel cell electric vehicles,” with an initial production target of 100,000 vehicles. Daimler had previously announced its intent to commercialize in 2014. Analysts accepted the new timetable as a practical response to the lack of fueling infrastructure and the need for scale economies to lower costs.¹¹
- European Hydrogen Road Tour 2012 was held in September–October of 2012.¹² Seven vehicles, from Daimler, Honda, Hyundai, and Toyota, participated. The tour began in Hamburg stopping at the Paris Motor Show and culminating in Copenhagen. In Paris, each of the companies affirmed its intention to launch commercial hydrogen FCEVs within the next few years. Hyundai announced an initial production target of 1,000 of its ix35 hydrogen FCEV by 2015, with production of another 10,000 vehicles after 2015.¹³
- Honda’s President and CEO, Takano Ito, detailed the company’s plans to release next-generation FCEVs “...sequentially in Japan, the U.S. and Europe starting in 2015.”
- Toyota announced an improved stack, to be used in a fuel cell Prius, scheduled for launch around 2015. The company plans a production launch in 2014. Cars will be marketed in Japan, the United States, and Europe. A Toyota spokesman said that if the car were series

produced now it would cost just under €100,000; costs must come down by 30%–40% to make it marketable.

Automotive fuel cell technology continued to advance.

- GM's FCEV fleet accumulated more than 2.6 million total miles. Multiple vehicles are in excess of 80,000 miles after more than five years of operation. The fleet logged more than 18,000 successful cold start events. These vehicles have been refueled with more than 64,000 kg of hydrogen and their operation has offset over 1,100 tons of vehicle CO₂ emissions. In October, GM announced plans to consolidate its fuel cell development centers into the Global Powertrain Headquarters in Pontiac, Michigan. GM will invest in a new fuel cell development laboratory at this facility.
- The FCTO updated the projected high-volume manufacturing cost of automotive fuel cells, which in 2012 was estimated to be \$47/kW (Figure 2).¹⁴ This represents a 36% reduction since 2008 and more than 80% since 2002.

Fuel Cell Buses

- The European Fuel Cells and Hydrogen Joint Undertaking completed a study to evaluate alternative powertrains for clean buses and their potential to reduce emissions from the transportation sector. McKinsey & Company facilitated the study, comparing emissions, performance, and economic impact from 2012–2030. The report highlights fuel cell powertrains as the best long-term alternative for achieving EU objectives.¹⁵

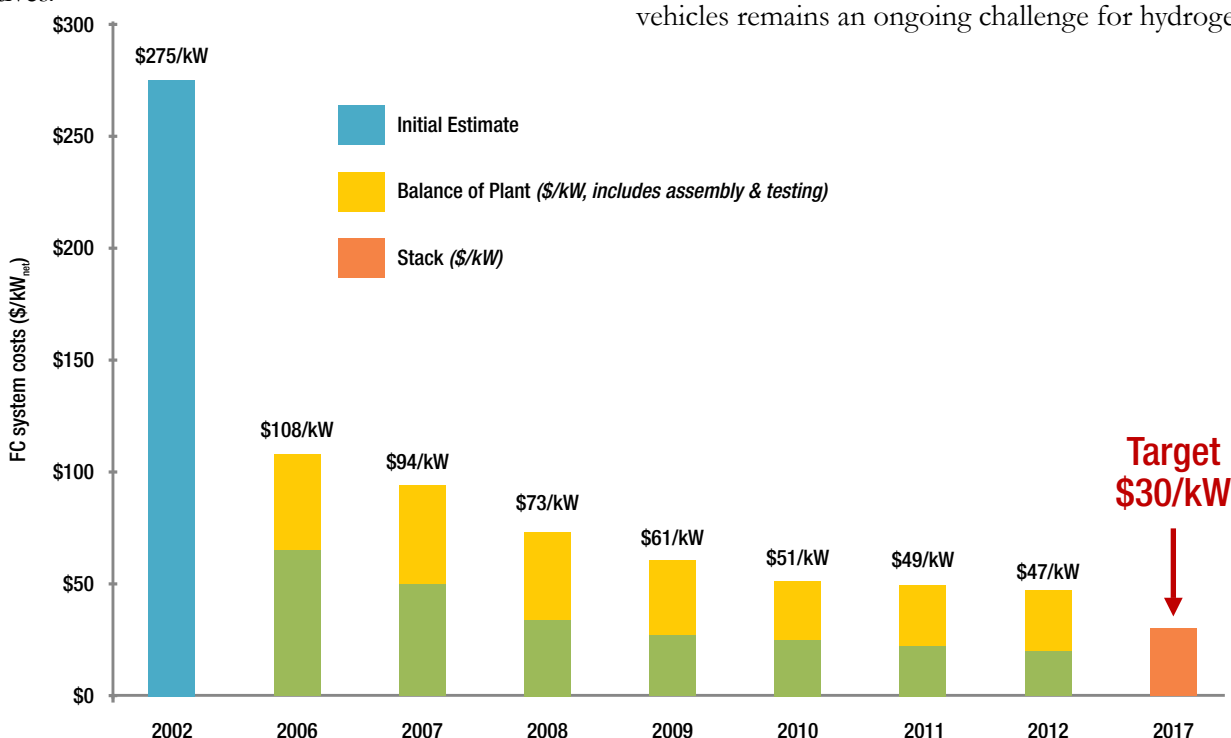


Figure 2. Projected cost for 80 kW automotive fuel cell system, based on projections to high-volume manufacturing (500,000 units/year).

- A UTC Power PureMotion PEM system established a world record for transit bus fuel cell durability, surpassing 12,000 commercial operating hours on its original stack.
- Fuel cell buses began operation in Flint, Michigan, and Cleveland, Ohio, in 2012 with good initial results reported.
- London's fleet of fuel cell buses, which have been servicing the RV1 Riverside route since early 2011, passed milestones of 100,000 miles of service and 1,000 hydrogen refuelings.
- CT TRANSIT, which operates three fuel cell buses, became the first transit agency in the United States to also use fuel cells for heat and power at its headquarters in Hartford, Connecticut.
- Daimler's next-generation Citaro fuel cell hybrid buses boast 25% greater range, 35% higher fuel cell efficiency, and 50% greater durability than its previous generation bus. It also uses 50% less hydrogen per mile, according to the company.¹⁶
- Ballard Power signed agreements to provide 25 fuel cell power plants for buses in Brazil and 21 for buses to be deployed in several European cities.¹⁷ Ballard also received a contract to provide 12 fuel cell power plants for buses to Tata Motors.¹⁸

Infrastructure Planning and Financing

Coordinating the deployment of fueling stations and vehicles remains an ongoing challenge for hydrogen

FCEVs. Progress was made through several new governmental funding commitments and comprehensive plans.

- The German Transport Ministry announced a \$50 million investment to expand its existing 15-station network to 50 stations by 2015. These fueling stations will support up to 5,000 FCEVs by 2015.¹⁹
- In Japan, the Ministry of Trade, Economy, and Industry proposed in April to nearly double Japan's fuel cell R&D program. The proposal includes funds for a program to deploy 100 fueling stations that would support the initial FCEV sales in Tokyo, Kyushu, Chubu, and Kansai.²⁰
- The California Fuel Cell Partnership released "A California Road Map: Bringing Hydrogen Fuel Cell Vehicles to the Golden State." It projects that a total of 68 California stations are needed to support the first 50,000 FCEVs.²¹ Early in 2013, Governor Brown endorsed the 68-station target in establishing a state-level goal of 1.5 million zero emission vehicles by 2025.
- Denmark's *Energy Plan 2020* aims to install a national hydrogen refueling network by 2015 and offers purchase incentives for FCEVs. This program is part of a national strategy to become energy independent by 2050. Denmark expects to lease 16 Hyundai ix35 FCEVs early in 2013.²²
- In the United Kingdom (UK), the H2 Mobility project was launched early in the year to prepare for the roll out of FCEVs in the UK over the next several years.²³

Stations and Operation

- The Fountain Valley Renewable Energy Tri-generation Station—the world's first facility capable of co-producing hydrogen, heat, and power from digester gas—began operation at a wastewater treatment plant in California. During its initial run, it achieved an efficiency of 54% when co-producing hydrogen and power and 70% when including cogenerated heat.
- A Danish firm, H2 Logic, reported performance data on several 700 bar refueling stations in Oslo, Norway, showing availability of 96% and refueling times consistently less than four minutes.²⁴
- Europe's largest hydrogen station, capable of delivering 750 kg of hydrogen per day, opened in Hamburg, Germany. The station will deliver fuel for 20 fuel cell buses and make hydrogen available for fuel cell cars. Half of the hydrogen is produced on site via water electrolysis using renewable energy and the other half is delivered. The local power company, Vattenfall, and

the German Federal Ministry of Transport shared the €10 million cost.

Renewable Hydrogen

There was growing development of renewable hydrogen in 2012. Hydrogen can be produced renewably from biomass using various methods or from renewable electricity such as geothermal, wind, or solar power via electrolysis.



Personal FCEV fueling with 100% renewable hydrogen. *Photo courtesy of Air Products and Chemicals, Inc.*

- In October 2012, Toyota Motor Sales, USA, Inc. activated a 1.1 MW Ballard PEM fuel cell, capable of meeting approximately half of the peak electricity needs of its six headquarters buildings. The hydrogen supplied by Air Products is sourced through the purchase of landfill-generated renewable bio-gas and delivered via pipeline.²⁵
- Enertrag, one of Europe's largest wind energy producers, installed a wind-powered hydrogen production facility that helps stabilize power production by three wind turbines. The facility also provides hydrogen for Total fueling stations in Hamburg and Berlin as part of the Clean Energy Partnership Program.²⁶ More than 50 FCEVs are operating in Berlin.
- Honda unveiled a solar-powered hydrogen production unit for the home, producing 1.5 kg/day of hydrogen at 350 bar (5,000 psi) using its high-pressure electrolyzer capable of achieving 5,000 psi pressure without a separate compressor.²⁷
- Aloha Motor Company in Hawaii opened the first off-grid solar-powered hydrogen refueling station in Honolulu. The electrolyzer was supplied by an Italian firm, Acta SPA.²⁸
- Apple is constructing a 4.8 MW fuel cell power plant at its Maiden, North Carolina data center.²⁹ The center is designed to be 100% renewable, with 60% of its power generated on-site from the fuel cell and solar plants

and 40% procured from local and regional renewable sources.

- The MYRTE project, located on the French island of Corsica, combines 560 kW of solar power with electrolyzers, hydrogen storage, and fuel cells. The project is a partnership between the French Nuclear and Alternative Energies Commission, energy company AREVA, and the University of Corsica.

Hydrogen Energy Storage

Hydrogen is being used as a storage mechanism for renewable electricity in several projects worldwide.

- Hydrogenics will supply electrolyzers to German utility E.ON for a 2 MW project to store hydrogen produced using surplus renewable energy (largely wind) in the gas pipeline system.³⁰
- A consortium of seven European partners launched the \$30 million INGRID storage project to develop and demonstrate a 39 MWh grid-connected renewable energy storage system using hydrogen.³¹
- AREVA won a project to install its Greenergy Box renewable energy storage system at the city of La Croix-Valmar in France.³²
- Hydrogenics signed an agreement with the Japanese firm Iwatani Corporation to pursue a broad range of utility-scale energy storage projects in Japan.³³

Research & Analysis

DOE funding for R&D in hydrogen and fuel cells declined by about 50% between FY 2009 and FY 2011 in both the FCTO and SECA. DOE's new ARPA-E program has funded long-term research into biological hydrogen production but the Department's overall investment in the sector remains substantially below its peak. In the areas still supported by DOE, progress continues, and several of the past year's highlights are summarized below.



OCS Energy Park producing heat, power, and hydrogen from anaerobic digester gas. *Photo courtesy of Air Products and Chemicals, Inc.*

Research

Research has led to advances toward key technical milestones for fuel cells, hydrogen production, delivery, and storage and identified key areas of additional R&D needs.³⁴

- Progress continued in key areas of hydrogen production, including biomass gasification, reforming of bio-derived liquids, electrolysis, solar-thermochemical hydrogen production, photoelectrochemical hydrogen production, and biological hydrogen production.
- Hydrogen delivery research continued to focus on reducing the cost and increasing the energy efficiency of hydrogen delivery, including work on higher pressure compressed gas equipment. Lighter weight, higher pressure, and higher payload composite tube trailers are commercial today, as a result of previous R&D.
- A novel hydrogen storage materials development project validated hydrogen excess uptake in a metal organic framework (MOF) material synthesized by Northwestern University (NU-100). The validated excess capacity of approximately 8 weight-percent at 50 bar and 77 K for the NU-100 MOF is among the highest confirmed to date.
- Another hydrogen storage project achieved a 30% improvement in hydrogen weight-percent uptake when normalized to surface area through boron incorporation into porous carbon (University of Missouri).
- The Clean Energy Patent Growth Index shows growth in fuel cell patents along with other clean energy technologies.³⁵ Over the years, about 35 new technologies that received DOE support have entered the market.³⁶

Analysis

Several analytic studies of sustainable energy futures identified potential major roles for hydrogen.

- Hydrogen was analyzed as an attractive transportation fuel option in the National Petroleum Council's *Advancing Technology for America's Transportation Future*.
- The International Energy Agency's *Energy Technology Perspectives* report for 2012 envisioned major roles for hydrogen in a low-carbon energy system by 2050.
- DOE's *Transportation Energy Futures Study*, which was partially released toward the end of 2012, sees hydrogen and fuel cells as important zero emissions options.

Evaluation

- A recent report by the National Renewable Energy Laboratory (NREL) analyzed infrastructure costs, concluding that the capital intensities of hydrogen fueling and electric vehicle charging are roughly comparable on a cents-per-mile basis
- NREL also reported on potential cost reductions for early market hydrogen fueling stations, utilizing diverse stakeholder input to NREL's cost calculator.
- The HTAC produced a comprehensive report on hydrogen production technologies.³⁷
- Science reporter Peter Hoffman's new book, *Tomorrow's Energy – Hydrogen, Fuel Cells, and the Prospects for a Cleaner Planet*, (MIT Press) was named an Outstanding Academic Title in Engineering for 2012 by Choice Magazine, published by the Association of College and Research Libraries.

Policy, Regulations, Codes and Standards

In 2012, a high level of activity was focused on developing and revising HFC safety codes and product standards in the United States and internationally.

- The National Hydrogen and Fuel Cell Codes and Standards Coordinating Committee, which is open to private and public sector experts in the field, lists 22 existing standards under active revision and 21 new standards in active development.
- The SAE standard for hydrogen fuel quality (J2719) was fully harmonized and published as an international standard by the International Organization for Standardization (ISO 14687-2) late in 2012.
- Research at Sandia National Laboratories on hydrogen embrittlement testing has resulted in a modification to current test procedures that, according to a DOE update, "...could reduce the time for materials qualification by more than 50%, reducing the effort and cost for screening and deploying material for hydrogen fuel technology."
- Two broad standards under revision by the National Fire Protection Association (NFPA) were in the public comment phase at the end of 2012. NFPA 2, Hydrogen Technologies Code, applies to the production, storage, transfer, and use of hydrogen. NFPA 853 applies to the design, construction, and installation of stationary fuel cell power systems.
- In December 2012, Fuel Cell Today published its *2012 Fuel Cell RCS Review* of regulations, codes and standards, which surveyed codes and standards worldwide.³⁸

- The California Air Resources Board approved rules that are expected to increase the number of zero emission vehicles (ZEV) and near-ZEV vehicles in California to over 1.4 million by 2025. This ruling could help accelerate the market introduction of FCEVs.³⁹

Setbacks

- A small fire at the AC Transit Bus Fueling Depot in Emeryville, CA, apparently was caused by a leak in a pressure relief valve. Little damage was reported, but authorities evacuated nearby buildings and the station was closed for months.⁴⁰
- A planned hydrogen fueling station at San Francisco International Airport apparently will not move forward because of a dispute with the hydrogen supplier over liability.⁴¹
- The operation of a hydrogen fueling station near London's Olympic Park, planned to support fuel cell-powered taxis and buses transporting visitors to the Olympics, was halted due to concerns about potential terrorist attacks. The station was reopened in September.⁴²
- Bloom Energy's proposed 30 MW deal with Delaware Light and Power is under attack in court. The suit alleges that the governor and Public Service Commission unconstitutionally gave Bloom unique financial and regulatory benefits.⁴³

Financial Climate

A pervasive perspective in the financial community is that hydrogen and fuel cell companies—from entrepreneurial start-ups to major corporations—have often over-promised and under-delivered. For several years, financing, particularly for early stage private and small public companies, has been scarce or nonexistent, despite continuing impressive technical and performance advances. Many companies are seriously underfunded. Several early stage companies, however, were successful in raising capital, some at impressively large valuations.

- Intelligent Energy, a UK company, raised £22 million at a £500 million valuation.
- Lilliputian Systems, a developer of SOFCs on a chip, raised \$40 million in financing led by Russian venture fund Rusnano. Lilliputian also announced a partnership with specialty retailer Brookstone.
- ACAL Energy, a UK company developing fuel cells employing a redox reaction instead of platinum at the cathode, was able to raise an additional £2.3 million from existing investors.

- Israeli company CellEra received a \$9.2 million investment to advance its platinum-free membrane technology.
- AFC Energy, the UK alkaline fuel cell company, received a \$13.8 million investment for 15% of the company from Russian fund Ervington Investments Ltd.
- Bloom Energy is reported to have raised an additional \$100 million from venture investors, bringing the total capital raised to date by Bloom to nearly \$1 billion, and valuing the company at \$3 billion.
- Among public fuel cell companies, Plug Power raised \$15.7 million in an underwritten public offering, but also announced layoffs to conserve cash.
- FuelCell Energy raised \$32.1 million in a secondary public offering and received a \$30 million investment from Korean utility POSCO Energy, its largest customer.
- Hydrogenics received a \$5 million investment from Canadian gas company Enbridge, as part of an agreement to develop a power-to-gas hydrogen energy storage system.

An uptick in mergers and acquisitions activity suggests that consolidation in the fuel cell industry is under way.

- FuelCell Energy acquired assets of the German company MTU Onsite Energy, after some years of cooperation between the two companies.
- Korean giant LG acquired Ohio-based Rolls Royce American Fuel Cells.
- Canadian fuel cell company Ballard Power acquired a production line and non-exclusive license to technology from IdaTech, giving Ballard direct access to telecom backup markets in Indonesia and elsewhere.

- A leading German manufacturer of heating systems, the Viessmann Group, acquired a 50% stake in Swiss SOFC manufacturer Hexis.
- Late in the year, it was announced that ClearEdge Power, a small venture-backed PEM fuel cell manufacturer, reached an agreement to purchase UTC Power and its fuel cell assets from United Technologies.

Conclusion

The overall outlook for hydrogen and fuel cell technologies remains promising.

Fuel cell stationary power systems are progressing into commercial use, from small backup power systems to residential combined heat and power systems to megawatt-scale power plants. The market for fuel cell forklifts is sustained by a business case. It appears that early DOE assistance played an important role in launching these technologies into the United States, especially for backup power and material handling.

Fuel cell buses and cars are being demonstrated and a number of automakers announced plans to increase vehicle fleet size into the thousands with introduction in 2015–2017. Unfavorable economics and coordinating the rollout of infrastructure and vehicles remain as key challenges.

Another emerging trend is the role hydrogen can play in enabling renewable energy and other low-carbon energy pathways, as evidenced by the number of renewable hydrogen projects worldwide using hydrogen as a storage medium for renewables. Governments are increasingly identifying hydrogen as an important part of a low-carbon energy future.

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_btac.html

Notes

1. Fuel Cell Today, "The Fuel Cell Industry Review 2012," October 2012, http://www.fuelcelltoday.com/media/1713685/fct_review_2012.pdf. In megawatt terms, 2011 grew 20% versus the previous year to exceed 100 MW for the first time and we anticipate a further 61% growth in megawatts for 2012, totaling 175.8 MW.
2. In December 2012, the U.S. Energy Department released a report, titled *Pathways to Commercial Success: Technologies and Products Supported by the Fuel Cell Technologies Program*, on the commercialization of advanced fuel cell technologies. The report finds that 36 commercial technologies supported by the Department of Energy have entered the global market, and it identifies another 65 emerging technologies. In another 2012 report, *The Business Case for Fuel Cells 2012* (<http://www.fuelcells.org/wp-content/uploads/2012/12/FC-Business-Case-2012.pdf>) Fuel Cells 2000 examined the business case for a wide variety of economically viable fuel cell applications. Finally, Fuel Cells Today issued their 2012 review, a comprehensive look at worldwide fuel cell markets.
3. Fuel Cell Today, "The Fuel Cell Industry Review 2012," October 2012, http://www.fuelcelltoday.com/media/1713685/fct_review_2012.pdf.
4. Ibid.
5. U.S. Department of Energy, *FY12 Annual Progress Report for the DOE Hydrogen and Fuel Cells Program*, (Washington, D.C.: U.S. Department of Energy, December 2012), http://www.hydrogen.energy.gov/annual_progress12.html.
6. This is detailed in the report *The Business Case for Fuel Cells 2012: America's Partner In Power*, released in December 2012, supported by the DOE Fuel Cell Technologies Office and compiled by Fuel Cells 2000, which profiles companies achieving both economic and environmental benefits with fuel cell deployments as part of an overall sustainability plan.
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9. Quoting from the HTAC Infrastructure Subcommittee's report (forthcoming) "The challenge is transitioning to a hydrogen infrastructure while reducing the near term financial risks. To do so, we need: 1) Government leadership and sustained financial support; 2) Energy policies that recognize and define the role of hydrogen in transportation; 3) Sustained incentives that reduce the near term risks for automakers and other system suppliers, fuel suppliers, fueling station owners, and consumers; 4) Nationally, locally and internationally accepted codes and standards that establish safety procedures and product standards and standardize safety reviews and hydrogen purchase; 5) In the automotive sector, assured refueling availability in advance of vehicle introduction."
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12. Scandanavian Hydrogen, "European Hydrogen Road Tour 2012," <http://www.scandinavianhydrogen.org/h2moves/european-hydrogen-road-tour-2012>.
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15. Fuel Cells and Hydrogen Joint Undertaking, "The FCH JU launches its study on urban buses: alternatives power trains for Europe," December 6, 2012, <http://www.fch-ju.eu/news/fch-ju-launches-its-study-urban-buses-alternatives-power-trains-europe>. The Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) completed a study to evaluate alternative powertrains for clean buses and their advantages relative to reducing greenhouse gases and achieving EU targets for reduced transport emissions. McKinsey & Company facilitated the study with participation from more than 40 companies and government organizations.
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