2015 ANNUAL REPORT of
The Hydrogen and Fuel Cell Technical Advisory Committee

Hydrogen and Fuel Cells

2015 HTAC ANNUAL REPORT SUMMARY

This Annual Report of the United States (U.S.) Department of Energy (DOE) Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) highlights worldwide advances and challenges with regard to hydrogen and fuel cell commercialization, policy, regulations, standardization, financial climate, and research and development (R&D) during 2015.

Hydrogen and fuel cell technologies continued to advance steadily during 2015. Significant commercial progress and new technical milestones for fuel cell systems and hydrogen production, delivery, and storage were achieved. This growth has come despite the precipitous drop in oil prices that may have slowed interest in alternate fuels. Moreover, the DOE *Hydrogen at Scale* "Big Idea" project this year illustrates even greater potential for hydrogen and fuel cell technologies. These technologies are uniquely valuable in that they can enable dramatic greenhouse gas (GHG) source reductions across many sectors/industries simultaneously. This makes them relevant to achieving the Nation's goal to significantly reduce GHG emissions.

Key highlights from 2015 include:

- Toyota released the Mirai fuel cell electric vehicle (FCEV) to initial customers in the U.S., following up on a late 2014 release in Japan, pledging to make FCEVs a key component of its future vehicle development strategy.
- FuelCell Energy and Beacon Falls Energy Park LLC announced what would be the world's largest stationary fuel cell power plant development in Connecticut, with 63.3 megawatts of ultimate capacity, and construction scheduled for start in 2016.
- Hyundai continued to sell commercial FCEVs in Asia, Europe, and the U.S., with a new FCEV taxi service launched in Paris, France, and announced an autonomous FCEV driving trial in the U.S.
- Honda announced that the 2016 Clarity FCEV is to go on sale in Japan in March 2016, with U.S. (California) and European introductions later in 2016.
- California continues to lead the U.S. in hydrogen fueling infrastructure development, with 12 open stations, 19 additional stations constructed or under construction, and 21 additional stations in planning or permitting at the end of 2015. This compares to the largest deployment of hydrogen fueling stations, in Japan, which has about 45 retail stations as of the end of 2015. Germany, meanwhile, had 20 open retail stations at the end of 2015 and a goal of 400 stations by the end of 2023.[1]
- Hydrogenics announced a broad supply agreement deal with a Chinese consortium that includes Yutang, the largest bus original equipment manufacturer (OEM) in China. The deal covers more than 2,000 vehicles of different types over the next 3–5 years, and includes heavy-duty fuel cells and fueling stations.
- Japan's ENE-FARM project achieved a total of over 140,000 units of stationary fuel cell systems in residential applications.

Despite these encouraging steps, key challenges for the hydrogen and fuel cell industry remain. Individual sectors have their specific challenges, including:

- Evidence suggests that the U.S. is not on track to meet the 2020 goals for hydrogen FCEVs and refueling infrastructure set by the U.S. Energy Policy Act of 2005 (EPACT) Title VIII. It is, therefore, important that an explicit plan, *including measurable progress milestones,* be provided in 2016–2017 that outlines how this will be successfully achieved.
- Developing a sufficient and robust hydrogen refueling structure for FCEVs is an ongoing challenge, given unfavorable economics, until the vehicle market further develops.
- Stationary fuel cell costs remain somewhat high compared to other forms of distributed power generation, at about $4,000–$7,000 per kilowatt, but offer higher operational efficiency and lower onsite emissions than combustion-based generators.

Overall, 2015 was an important and encouraging year for hydrogen and fuel cell system developments. Much progress is being made, but greater momentum is needed for these technologies to provide the larger benefits of which they are capable in 2020 and beyond. More specifically, with continued investment in critical infrastructure and R&D, hydrogen and fuel cells can create additional energy diversity leading to greater energy security and economic resilience.

Overall, hydrogen and fuel cell industries continued to progress at a steady rate in 2015, with growing installations and research and development (R&D) progress around the world. The year was marked by the achievement of key market development milestones in the transportation, stationary, backup, and materials handling sectors. Noteworthy events in 2015 in the United States included a Fuel Cell and Hydrogen Energy Policy Forum on Capitol Hill on May 5, and the celebration of National Hydrogen and Fuel Cell Day on October 8. At the Policy Forum, Congressman Charlie Dent (R-PA), Co-Chair of the House Hydrogen and Fuel Cell Caucus, remarked that:

> "Hydrogen fuel cell technology is developing rapidly and holds the promise of benefiting both consumers and the environment. Continued research and development will lead to greater efficiencies in production and practical applications. We owe it to future generations to invest now in this safe, reliable, and virtually unlimited source of clean energy."[2]

Caucus Co-Chair Congressman John Larson (D-CT) added:

> "Hydrogen and fuel cell energy technology is providing businesses and consumers with clean, reliable, domestic power that can be used in a variety of applications. Fuel cells represent the best of American ingenuity and manufacturing. Along with the continued collaboration with the Department of Energy, this industry will continue to grow and support American jobs."[3]

2015 is also a year that is called out in the U.S. Energy Policy Act of 2005 (EPACT), Title VIII, as a milestone that includes the following goals:

1) "To enable a commitment by automakers no later than year 2015 to offer safe, affordable, and technically viable hydrogen fuel cell vehicles in the mass consumer market and to enable production, delivery, and acceptance by consumers of model year 2020 hydrogen fuel cell and other hydrogen-powered vehicles that will have, when compared to light duty vehicles in model year 2005: 1) fuel economy that is substantially higher; 2) substantially lower emissions of air pollutants; and 3) equivalent or improved vehicle fuel system crash integrity and occupant protection;" and
2) "To enable a commitment not later than 2015 that will lead to infrastructure by 2020 that will provide: 1) safe and convenient refueling; 2) improved overall efficiency; 3) widespread availability of hydrogen from domestic energy sources; and 4) hydrogen for fuel cells, internal combustion engines, and other energy conversion devices for portable, stationary, micro, critical needs facilities, and transportation applications."

Considerable progress has been made toward these goals since 2005, and the 2015 commitments have been partially met. Efforts such as H2USA have brought industry and government together in important ways toward achieving these goals. FCEVs by two manufacturers have now been fully safety certified and commercialized, with a third expected in 2016 and more in the 2018–2020 timeframe. However, this progress has been mostly driven by state-level zero-emission vehicle (ZEV) programs. Federal support does not appear to be adequate to spur the developments that are necessary for the 2020 goals of EPACT 2005.

It is unrealistic to expect FCEVs and hydrogen fueling infrastructure to become available at the same time all across the country; analysis concludes that a more regional approach is appropriate. However, it also appears that greater momentum is needed to reach the 2020 goals, particularly since achieving greater manufacturing scale is required for necessary cost reductions. It is thus important that an explicit plan, *including measurable progress milestones,* be provided in 2016–2017 for how to successfully achieve the 2020 EPACT Title VIII goals, with commensurate funding commitments.

With regard to key metrics of commercial progress, a 2015 industry assessment report, *E4Tech,* reports that the size of the global hydrogen and fuel cell technology market (in total megawatt [MW] terms) expanded by over 80% from the prior year. This represents the greatest expansion in fuel cell markets in any calendar year. The report estimates 340 MW of total shipments across sectors in 2015 compared with 180 MW in 2014. A substantial increase in the average size of units is driving much of this increase. Asia stands out as deploying about two-thirds of total units and about half the total global capacity. Meanwhile, North American deployments are relatively steady in numbers of shipments, but with an almost doubling of total capacity in MW in 2015, and deployments in Europe were almost tripled from 2014 levels in MW terms.[4]

Significant Challenges Remain

Despite this progress, fuel cell and hydrogen R&D programs are still developing technologies to address ongoing technical, commercial, and logistical challenges. Major technical improvements have been realized in recent years in reducing costs and improving system durability, but cost targets are not yet achieved in key markets. Achieving cost competitiveness will require a combination of increased production volume and additional efforts to reduce costs of both fuel cell stacks and "balance of plant" components. However, achieving complete cost parity may not be necessary because some types of fuel cell systems can serve multiple applications (for example, primary power and also backup power with onsite fuel storage).

Challenges for Fuel Cell Power Systems

Hydrogen fuel cell systems are of two fairly distinct classes, and each has different performance and long-term durability issues. The first class of fuel cells—relatively low-temperature (i.e., 80–200 °C) proton exchange membrane and phosphoric acid systems—are dependent on noble-metal catalysts including platinum, and are sensitive to impurities in fuel quality (especially sulfur compounds and carbon monoxide). The second class of fuel cells—high-temperature molten carbonate and solid oxide systems (500–1,000 °C)—require less expensive catalyst materials but more expensive bipolar plate and inter-cell sealing materials to withstand the higher temperatures. Fuel impurities are somewhat less of a concern, but sulfur compounds are still a key issue. In addition to hydrogen, the high-temperature systems can run directly on hydrocarbon fuels such as pipeline natural gas that then break down into hydrogen/carbon monoxide "syngas" within the system.

Key challenges for low-temperature fuel cells include further reducing the amount (or changing the type) of precious metal catalyst required for good performance while maintaining durability requirements, and continuing to improve system integration and driving down balance-of-plant system costs. For high-temperature systems, concerns include overall system durability, such as maintaining the integrity of inter-cell seals over time, tolerance for thermal cycling (e.g., due to shutdown for maintenance events), and further refinement of system design to optimize for "electricity only" versus "combined heat and power" applications. Hybridization of high-temperature fuel cell systems with a gas-turbine generator for increased overall efficiency is an active area of development with additional system integration challenges.

Remaining challenges include:

- Improved system integration and balance-of-plant cost reductions
- Further validation of system durability, especially for stationary markets with long runtime requirements
- Improved integration of fuel cell systems and fuel supply options, such as for longer run-time of fuel cell backup power systems through onsite reforming of liquid fuels
- Better strategies for the limited ability of stationary high-temperature fuel cells to dynamically change output to match changing electric loads

Challenges for Hydrogen Production, Storage, and Distribution

For hydrogen production and storage, key challenges relate to electrolytic production of hydrogen with good system durability over time, and the potential for increased efficiency of hydrogen production from renewable energy sources using various thermo-chemical and photo-electrochemical means. Hydrogen storage remains an ongoing challenge, with high-pressure composite storage vessels being the dominant means of vehicle-based storage (but relatively heavy and expensive), and with other options possible in the future such as organic and metal hydride and ammonia-based storage, and cryogenic gas/liquid combined systems. Hydrogen distribution for vehicle fueling applications has experienced significant progress but challenges remain, including the relatively high costs of hydrogen fueling station equipment, siting and permitting of fueling stations, and fueling station reliability.

Key remaining challenges for hydrogen production, storage, and distribution include:

- Improved membrane electrode assembly integration for hydrogen crossover reduction/mitigation and combination of membrane and catalyst advances for electrolyzers
- Development and validation of value propositions and systems solutions for renewable energy to hydrogen for power, fuel, and grid-stabilization
- Improved hydrogen storage solutions that are lightweight, compact, safe, energy efficient, and fully reversible
- Cost of hydrogen fuel infrastructure and difficulties with station siting/permitting and reliability

More generally, hydrogen and fuel cell technologies are now competing in a world of low-cost fossil fuels, due to major expansion of production in the U.S. and weakening of OPEC power to reduce output to boost prices of crude oil. As of late 2015, oil prices were below $35 per barrel, their lowest price in real terms since 2009 when prices quickly rebounded after a precipitous fall from over $130 per barrel in 2008. However, there also has been strong growth recently in renewable energy supplies, and increased adoption of carbon emissions regulations, zero emissions standards, and renewable portfolio standards worldwide. These developments have significantly helped to support the growth of hydrogen and fuel cell systems by increasing interest levels due to their relatively efficient, clean, and quiet operation.

HTAC Activities In 2015

Key HTAC activities in 2015 include that the Committee:

- Published the 2014 HTAC Annual Report and HTAC's associated letter to the Secretary of Energy, Dr. Ernest Moniz in July 2015. The Secretary, in a September 2015 response letter to the HTAC Chair, highlighted the ongoing challenges with hydrogen and fuel cell system commercialization, but also noted significant market and DOE successes. His letter noted that DOE was responsible for "more than 515 U.S. patents, 40 commercial technologies in the market related to hydrogen and fuel cells, and another 65 technologies we anticipate to be commercial in the next three-to-five years." The Secretary also noted the potential of hydrogen for cross-cutting applications for grid energy storage as well as fuel for vehicles and stationary applications.
- Released a Manufacturing Sub-Committee report highlighting progress in fuel cell manufacturing systems and key remaining challenges and bottlenecks. In particular, the report points out specific potential public-private initiatives that could help fuel cell development and commercialization, including the use of advanced

manufacturing techniques. Some recommendations have already been acted upon, such as highlighting the use of backup power fuel cell technology and collaboration in China as part of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) conference in Wuhan, China on May 29, 2015. The report also cited the need for greater standardization and concentration of the stationary supply chain in order to achieve the next level of cost competitiveness and market growth, especially for U.S. fuel cell exports.

- Distributed a financial analysis of H_2 infrastructure that highlighted the key station capital cost, operation and maintenance costs, and profit margins needed to make hydrogen refueling infrastructure investments attractive to private investors. The report suggests that station costs somewhat lower than today's costs are needed, along with high levels of station utilization and relatively low and predictable station maintenance costs.[5]

Commercialization Initiatives

Fuel cells continue to make significant inroads into an array of commercial sectors, further highlighting the broad potential impact of these technologies. Key sectors include stationary power markets (i.e., primary and backup power), transportation markets (e.g., cars, buses, trucks, and forklifts), electricity grid-support applications, military applications, underwater vehicles, and small electronics. Hydrogen as an industrial chemical also has broad impact for ammonia production, metal and semiconductor processing, and refining of petrochemicals.

Fuel Cells for Stationary Applications

Fuel cells continue to make steady inroads into stationary power markets. Approximately 200 MW of stationary fuel cell systems were shipped in 2015, compared with about 150 MW in 2014.[6] Details include:

- Doosan announced an agreement to supply 70 fuel cell power plants for Korea Hydro and the city of Busan for a total of 30.8 MW, with installation expected by 2017.[7]
- Installations of Japan's ENE-FARM residential fuel cell systems increased to approximately 140,000 units.[8]
- SOLIDpower began selling its "mCHP EnGen™-2500" 2.5 kilowatt (kW) solid-oxide fuel cell (SOFC) system in Europe along with its 1.5 kW BlueGen units.[9]
- In a noteworthy international development, Implats Platinum mine announced plans to install a 1.8 MW Fuji Electric fuel cell power plant at its mine in South Africa. The ultimate plan calls for up to 22 MW of fuel cell power to make the mine independent of the local power grid.[10]

Fuel Cells for Passenger Cars

2015 was a milestone year for fuel cells for passenger cars, with key commitments for vehicle commercialization and hydrogen infrastructure development. Key developments include:

- In May 2015, Toyota announced that eight California dealers would sell or lease the 2016 Mirai FCEV for initial U.S. introduction. Order requests were opened in summer 2015, with the first deliveries beginning in fall 2015. U.S. sales volume is expected to be approximately 3,000 units through 2017.[11]
- Toyota plans to continue the commercial rollout of Mirai vehicles on Oahu in Hawaii, for late 2016 or early 2017, in conjunction with the first commercial hydrogen fueling station in Hawaii.
- Hyundai continued to lease its Tucson FCEVs in Asia and Southern California, and has partnered with an electric taxi service in Paris called STEP (Société du Taxi Electrique Parisien) to employ five Tucson FCEVs in commercial taxi service.
- Hyundai also announced that it had been granted permission by the State of Nevada to test fully autonomous FCEVs in the U.S., the first automaker to receive this clearance.[12]
- Honda announced the production version of the 2016 Clarity Fuel Cell that will go on-sale in Japan in March 2016 for a retail price of 7.66 million yen (about $67,000), with U.S. and European introductions later in 2016.[13]
- A consortium of Ford, Nissan, and Daimler aims to start releasing commercial FCEVs using common componentry in 2017, General Motors is pursuing fuel cell technology independently and in connection with Honda, and BMW is pursuing FCEV development with a 2020 target date.[14]
- Three Daimler F-Cell vehicle customers drove over 1,000 miles each in a three-day road rally between Southern and Northern California, taking advantage of a new hydrogen fueling station in Coalinga along the I-5 highway corridor. The event was supported by Mercedes Benz Research and Development North America and intended to highlight the growing level of fueling infrastructure in California.[15]

Source: Toyota.com

Source: HyundaiUSA.com

Source: Honda.com

Figure 1: Toyota 2016 Mirai, Hyundai 2016 Tucson, and Honda 2016 Clarity Fuel Cell Electric Vehicles

Fuel Cells for Buses

Fuel cell buses continued to make excellent progress in performance. Separate bus trial programs in the U.S. and England both established over 20,000 hours of fuel cell system durability for buses in regular fare service. In addition:

- Ballard Power Systems announced a partnership to develop fuel cell buses in China. The deal is for 33 buses for a value of about $10 million. The project will employ Ballard's FCvelocity®-HD7 modules and partnerships with Chinese electric vehicle companies to deploy the buses in the cities of Rugao (Nantong) and Yunfu (Guangdong) starting in 2016.[16]
- Ballard Power Systems also announced a Strategic Collaboration Agreement with Xiamen King Long United Automotive Industry Co., Ltd. ("King Long") to design and deploy fuel cell buses.[17]
- Ballard Power Systems reported that the highest-mileage fuel cell bus in the Transport for London (TfL) fleet reached 20,000 hours of operation since being placed in service in 2010. The overall fleet of eight fuel cell buses has achieved over 690,000 kilometers (428,000 miles) of operation. TfL recently agreed with Ballard to operate the buses for an additional five years, through 2020.[18]
- In late 2015, Hydrogenics announced a broad supply agreement deal with a Chinese consortium, including Yutang, the largest bus OEM in China. The deal covers more than 2,000 vehicles of different types over the next 3–5 years, and includes heavy-duty fuel cells, fueling stations, and assessments for converting surplus wind and other renewable electricity sources to hydrogen using Hydrogenics' Power-to-Gas energy storage technology.[19]

Source: Transport for London

Source: Leslie Eudy/NREL

Figure 2: Fuel Cell Buses in California and London have Achieved 20,000+ Hours of Accumulated Operation in 2015

Fuel Cells for Other Vehicles

- US Hybrid announced a project in conjunction with the Port of Houston to develop and test three fuel cell powered drayage trucks with a 200-mile driving range and 60 mile per hour top speed. The $7.6 million program will involve converting Class 8 Navistar International ProStar cab tractors; additional partners include the U.S. DOE, Gas Technology Institute, Environmental Defense Fund, and University of Texas.[20]
- Intelligent Energy announced a fuel cell range extender for drones, expected to be unveiled at the 2016 Consumer Electronics Show in Las Vegas, NV.

Hydrogen Production and Distribution

Key milestones in hydrogen production and distribution include progress in building hydrogen refueling infrastructure in California, and the announcement by Proton Onsite that the company has achieved over 1 billion cell hours of PEM electrolysis operation in the field. Furthermore:

- California's aggressive hydrogen infrastructure development effort continued, with 12 fueling stations open, an additional 19 currently constructed or under construction, and 21 more in various stages of planning and permitting. This progress represents steady movement toward a planned initial network of 100 stations by 2024.[21]
- Toyota and Air Liquide announced plans to develop a hydrogen fueling network in the Northeastern U.S.[22]
- Japan currently has the largest deployment of hydrogen fueling stations, with about 45 operating retail stations as of the end of 2015. This includes 4–5 mobile refuelers along with the other permanent stations.
- Germany continued hydrogen station development efforts, with 20 stations operational at the end of 2015. By 2023, a network of 400 stations is envisioned, with a station sited every 90 kilometers along the autobahn network, and with a total investment of approximately $455 million. The effort is led by a consortium of six companies that include Air Liquide, Daimler, Linde, OMV, Shell, and Total.[23]
- Air Liquide announced on December 1, 2015, that it had installed the first commercial hydrogen station in Paris, France. The opening coincided with the COP21 international climate chance conference.
- The Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) announced €16 million in funding for large scale electrolysis: a 6 MW PEM electrolysis demonstration (€12 million) and a 3 MW alkaline electrolysis demonstration (€4 million).

- Air Products and Chemicals Inc. announced hydrogen deliveries using higher-pressure hydrogen gen trailers, capable of delivering hydrogen fuel at pressures of up to 500 bar (7000 psi).[24]

Figure 3: Hydrogen Delivery System
Source: Air Products and Chemicals, Inc.

Fuel Cells for Material Handling

- Plug Power Inc. launched the model 3340 GenDrive fuel-cell unit for its production forklifts. Plug Power has produced more than 9,000 GenDrive units with over 107 million hours of runtime.[25]
- NACCO (Hyster-Yale) acquired Nuvera's technology for its own forklift vehicles, creating additional competition in this sector.

Fuel Cells for Backup Power Applications

- Ballard Power Systems announced shipment of its 3,000th ElectraGen™ backup system. The company reports over 50 million operating hours and over 1 million hours of backup to critical telecom sites.[26]
- Ballard Power Systems also reported the sale of 100 fuel cell backup power units in India in April 2015, in conjunction with Reliance Jio Infocomm Limited (RJIL) for 100 ElectraGen™-ME fuel cell backup power systems.[27]
- Altergy Systems reported that it has surpassed over 32 million hours of operation from its fleet of PEM Freedom Power™ fuel cell backup units, with more than 8.3 MW of installations around the world.[28]
- Intelligent Energy announced a deal with GTL Limited for £1.2 billion ($1.8 billion) over ten years to supply hydrogen fuel cell backup power units to 27,400 telecom towers in India.[29]

Hydrogen for Grid Support Applications

- Germany announced continued efforts to explore "power-to-gas" concepts using hydrogen technologies, with several ongoing investigations by consortia groups using both power-to-hydrogen and power-to-methane systems. In one recent development, in what is being called the "the world's most modern power-to-gas plant," a new 800 kW power-to-hydrogen project in the Hamburg/Reitbrook district was inaugurated in October 2015. The €13 million project (half supported by the German government) converts wind power to hydrogen that is then fed into the Hamburg gas grid. The project is led by German regional energy provider E.on Hanse, with partners Hydrogenics GmbH, SolviCore GmbH, Deutsches Zentrum fuer Luft-und Raumfahrt, and the Fraunhof Institute for solar energy systems.[30]

Figure 4: Fuel Cell Powered Forklifts by Plug Power Inc.
Source: Plug Power Inc.

- Proton Onsite will provide its 7 kW and 60 kW electrolyzers for the first power-to-gas project in the U.S. The project will be performed in collaboration with SoCal Gas, and take place at the University of California campus in Irvine, California.[31]

Policy, Regulations, Codes and Standards

Policy and Regulations

Noteworthy policy developments include:

- The 30% U.S. Investment Tax Credit (ITC) for stationary fuel cell systems is now set to sunset at the end of 2016, based on the December 2015 omnibus budget bill. If allowed to expire, this is expected to slow the pace of installation of fuel cell systems that otherwise would benefit from this program.
- The Fuel Cell Motor Vehicle Tax Credit of up to $8,000 on light-duty FCEVs is also set to expire at the end of 2016, after only a two-year prior extension from 2014.[32] Expiration of the credit just as major automakers are moving to bring FCVs to market would be unfortunate, and the industry is hopeful for an extension of this program.
- On December 4, 2015, President Obama signed the Fixing America's Surface Transportation (FAST) Act, the first long-term transportation bill in a decade, which provides authorizations for FY 2016 through FY 2020. This bill includes a Section 1413, "National electric vehicle charging and hydrogen, propane, and natural gas fueling corridors." The language instructs the Secretary of Transportation to designate alternative fueling corridors for electric, natural gas, and hydrogen vehicles, and identify

the near- and long-term need for, and location of, these fueling spots at strategic locations along national highways.

- Stationary fuel cell systems continue to qualify for capital cost support under the California Self-Generation Incentive Program (SGIP). The initial incentive of $1,650 per installed kW (which began in 2009) has declined to a current level of $1,490 per installed kW, with an additional incentive of $1,310 per kW if biogas is used as the fuel source.[33]
- FCEVs receive a $5,000 purchase incentive under the California Clean Vehicle Rebate Project.[34]

Codes and Standards

Codes and standards for hydrogen and fuel cell systems continue to evolve to fill in gaps due to technology evolution and to keep up with the latest industry practices. Key codes and standards developments include:

- *NFPA 2: Hydrogen Technologies, Edition 2016* was released as a vital document for the fuel cell and hydrogen industry, providing fundamental safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas (GH_2) form or cryogenic liquid (LH_2) form.
- SAE J2601, with the latest revision finalized in 2014, is now being promoted as a worldwide standard for hydrogen refueling, including fuel flow rate, temperature, end pressure, and other aspects. The SAE J2719 standard, which specifies hydrogen fuel quality standards for vehicle applications, was updated in late 2015.
- The "H2TOOLS" portal was unveiled at H2TOOLS.ORG as a central location for information on hydrogen safety, best practices, lessons learned, and supportive resources. The site, sponsored by DOE, includes a collection of resources for education and training and forums for exchanging information among key groups such as project developers, safety officials, and incident first responders.

Financial Climate

The financial climate for hydrogen and fuel cell technologies improved somewhat, with steadily increasing demonstration of technology performance and reliability, and a generally favorable market environment with low interest rates for capital investments. However, a bankruptcy filing by ClearEdge Power and relatively steady (rather than increasing) valuations for most fuel cell companies signaled some continuing struggles for the industry.

Key finance and partnership developments in 2015 included:

- FuelCell Energy announced a $30 million deal with PNC Energy Capital, LLC, to finance fuel cell projects, including a 1.4 MW fuel cell plant for the University of California, Irvine Medical Center. The financing allows the company the option to retain project ownership, leading to greater ultimate revenues over time.[35]
- Constellation and Bloom Energy announced an agreement to develop 40 MW of Bloom Energy fuel cell projects for commercial and public sector customers in California, Connecticut, New Jersey, and New York.[36]
- FuelCell Energy and E.on Hanse announced a program to offer decentralized combined heat and power solutions with MW and multi-MW Direct FuelCell® power plants to its existing and prospective customer base.[37]
- On January 6, 2015, Toyota announced that it would allow royalty-free use of about 5,680 patent licenses related to fuel cell stacks, and an additional 3,350 patents concerning fuel-cell system control technology through the initial market introduction period of FCEVs. About 290 of these items will be related to high-pressure hydrogen storage tanks.[38]

U.S. government support for hydrogen and fuel cell technology development efforts remained relatively constant from recent years, with $105.5 million requested in FY 2017 for the Fuel Cell Technologies Office, slightly more than in FY 2016 (see Figure 5). However, this is approximately half the historical peak funding level of over $200 million.

As shown in Figure 6, the current budget for fuel cell technologies is approximately 4.9% of the DOE Energy Efficiency and Renewable Energy (EERE) FY 2015 budget request of $2.3 billion.

Research and Development

Research and development activities around hydrogen and fuel cell technologies continued at a steady pace in industrial, government lab, and university settings. Key activities included:

- The Hydrogen Station Equipment Performance (HyStEP) device was completed as a station field testing and commissioning device.[39] The device was developed and validated by DOE, Sandia National Laboratories, and the National Renewable Energy Laboratory, and delivered to California for field-testing of station fueling performance at retail hydrogen stations. CARB is now taking on HyStEP project management.
- FuelCell Energy initiated a new DOE-funded project for a combined "reformer-electrolyzer-purifier" (REP) for hydrogen production, based on its molten carbonate fuel cell technology, and with the potential for high production efficiency. The system utilizes a waste heat source to assist with the first partial reforming step, and then produces high-purity hydrogen from further full reformation, water-gas shift, and electrolysis steps.[40]
- FuelCell Energy is pursuing additional "tri-generation" opportunities based on its successful installation in Fountain Valley, California. The site is producing power and waste heat for local use at the Orange County Sanitation District's wastewater treatment plant, along with

Key Activity	FY 14 Approp.	FY 15 Approp.	FY 16 Approp.	FY17 Request
Fuel Cell R&D	33,383	33,000	35,000	35,000
Hydrogen Fuel R&D[1]	36,545	35,200	41,050	44,500
Manufacturing R&D	3,000	3,000	3,000	3,000
Systems Analysis	3,000	3,000	3,000	3,000
Technology Validation	6,000	11,000	7,000	7,000
Safety, Codes and Standards	7,000	7,000	7,000	10,000
Market Transformation	3,000	3,000	3,000	3,000
Technology Acceleration	0	0	0	13,000[2]
NREL Site-wide Facilities Support	1,000	1,800	1,900	N/A
Total	**92,928**	**97,000**	**100,950**	**105,500**

Other DOE Offices	FY 14 Approp.	FY 15 Approp.	FY 16 Approp.
Basic Energy Sciences	19,922	18,499	18,499[3]
Fossil Energy (SECA)	25,000	30,000	30,000
ARPA-E (FC-related)	33,000	0	TBD
Total	**77,922**	**48,499**	**48,499**

[1] Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

[2] Combines Manufacturing R&D, Technology Validation, Market Transformation

[3] Estimated FC-related BES funding (based on FY15)

FY 2016 DOE Total: ~$150M

Figure 5. Recent DOE Funding for Hydrogen and Fuel Cells R&D
Source: U.S. DOE, Fuel Cell Technologies Office

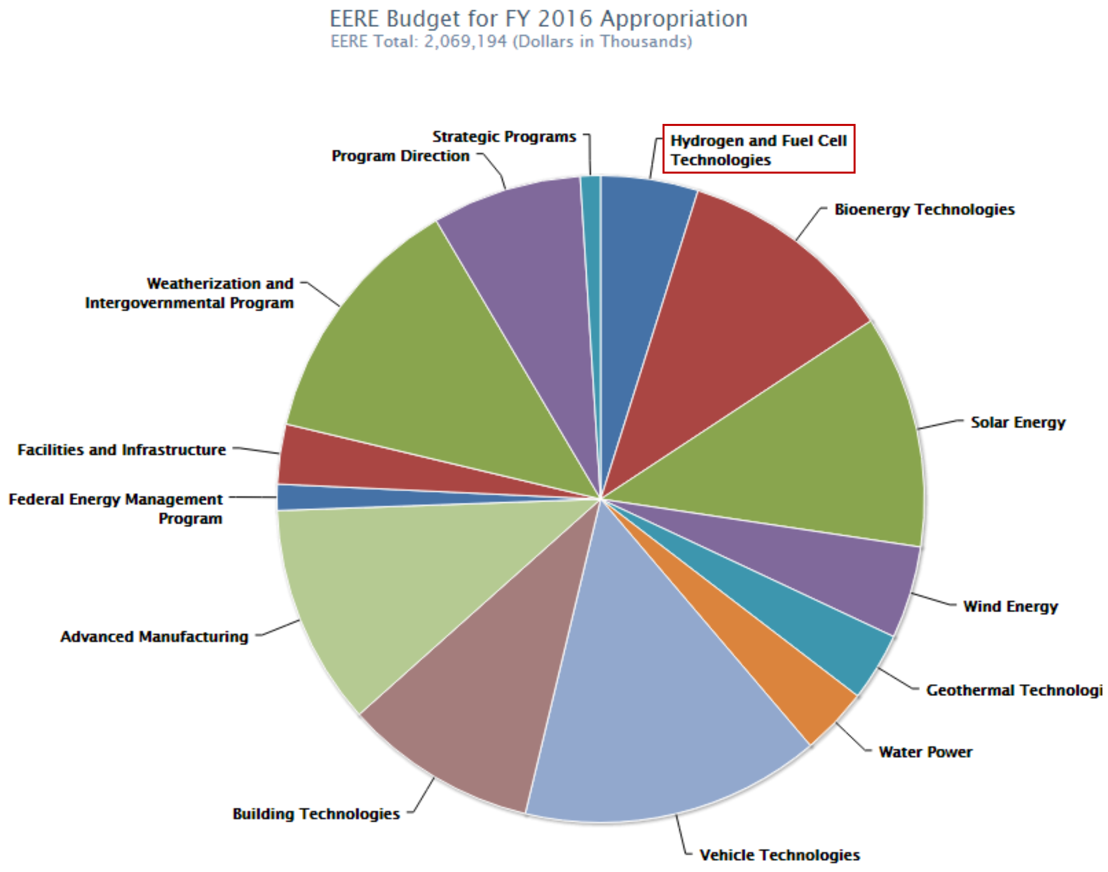

Figure 6: DOE EERE Funding Allocations across Program Areas
Source: U.S. DOE, http://www5.eere.energy.gov/office_eere/program_budget_formulation.php

hydrogen for FCEV refueling, based on the use of low-carbon biogas as a feedstock. A 1.2 MW FCE molten carbonate system can co-produce up to 800 kg per day of hydrogen that can then be purified for vehicle applications.

Important areas for additional R&D include:

- Additional reductions in catalyst material costs for membrane electrode assemblies (MEAs) for low-temperature fuel cell and electrolyzer systems, while maintaining durability over time
- Better system integration and reduced components costs for lowered balance-of-plant costs
- Improvements in manufacturing processes and yield rates for electrolyzer and fuel cell system manufacturing
- Reduced component costs, improved compressors, and improved metering/metrology for hydrogen refueling stations
- Improved systems for continuous monitoring of impurities and contaminants in hydrogen and reformate gas streams, with lowered costs

Figure 7 presents the current cost and durability status and targets for various fuel cell market sectors.

Studies and Reports

Several key reports were released in 2015. These include:

- The DOE's *Fuel Cell Technologies Market Report 2014*[41]
- The DOE's *State of the States: Fuel Cells in America 2015*, 6th edition[42]
- The *2015 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*, California Air Resources Board, July 2015[43]
- An annual joint report by CEC and ARB on "Time and Cost Needed to Attain 100 Hydrogen Fueling Stations in California," December 2015[44]
- The California Hydrogen Business Council's report *Power-to-Gas: The Case for Hydrogen*[45]
- The Fuel Cell and Hydrogen Energy Association (FCHEA) 2014 *State Policy Activity Wrap-up: Fuel Cells & Hydrogen*[46]
- FCHEA's *Business Case for Fuel Cells 2015* report[47]
- E4Tech's *Fuel Cell Industry Review 2015* report[48]

NREL and other labs under the direction of DOE have been exploring concepts for hydrogen used in large-scale, in an expanded array of industrial and power-sector markets. Figure 8 depicts how hydrogen and fuel cells can be provided at-scale to impact these sectors.

Fuel Cell Type	Cost & Durability Status[a]	Cost & Durability Target[a]
Backup Power (Direct Hydrogen)	$6,100/kW[b] 8,000 hours (h)	$1,000/kW 10,000 h
Medium Scale CHP (natural gas)	$4,500/kW[c] 40,000—80,000 h	$1,000/kW 80,000 h
APUs (1-10 kW, system)	$2,100/kW 3,000 h	$1,000/kW 20,000 h
Buses	$800,000 +20,000 h	$600,000 25,000 h
Automotive	~$53/kW 3,900 h (on road)[d]	$30/kW ($40/kW by 2020) 8,000 h
Portable Power (100-200 W)	$15/W 2,000 h	$5/W 5,000 h

a. Unless otherwise noted, all data is from the U.S. DOE, Fuel Cell Technologies Office, *Multi-Year Research, Development, and Demonstration Plan*, http://energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22, June 2016; equipment cost.

b. http://www.nrel.gov/hydrogen/images/cdp_lab_15.jpg

c. DOE Hydrogen and Fuel Cells Program Record 11014, "Medium-Scale CHP Fuel Cell System Targets," https://www.hydrogen.energy.gov/pdfs/11014_medium_scale_chp_target.pdf.

d. DOE Hydrogen and Fuel Cells Program Record 15014, "On-Road Fuel Cell Stack Durability," https://www.hydrogen.energy.gov/pdfs/15014_fuel_cell_stack_durability.pdf -high-volume modeled cost.

Figure 7: Cost and Durability Status and Targets for Various Fuel Cell Market Sectors

Initial analysis shows that pursuit of these concepts could greatly reduce greenhouse gas (GHG) emissions by displacing the use of fossil fuels, if implemented in large scale in this multi-faced manner.[49] An example of this type of concept is in Arezzo, Italy, where a network of underground pipelines provides hydrogen fuel for metallurgy and other purposes.[50]

Conclusions

The overall outlook for hydrogen and fuel cell technologies is promising. Recent years have seen a proliferation of commercial and research developments and also noteworthy progress in stationary and backup power, transportation fuel, and grid-support applications. Hydrogen and fuel cell technologies are recognized as important solutions for achieving international goals to reduce GHG emissions for climate stabilization per the landmark Climate Accords, signed in Paris in December 2015.[51]

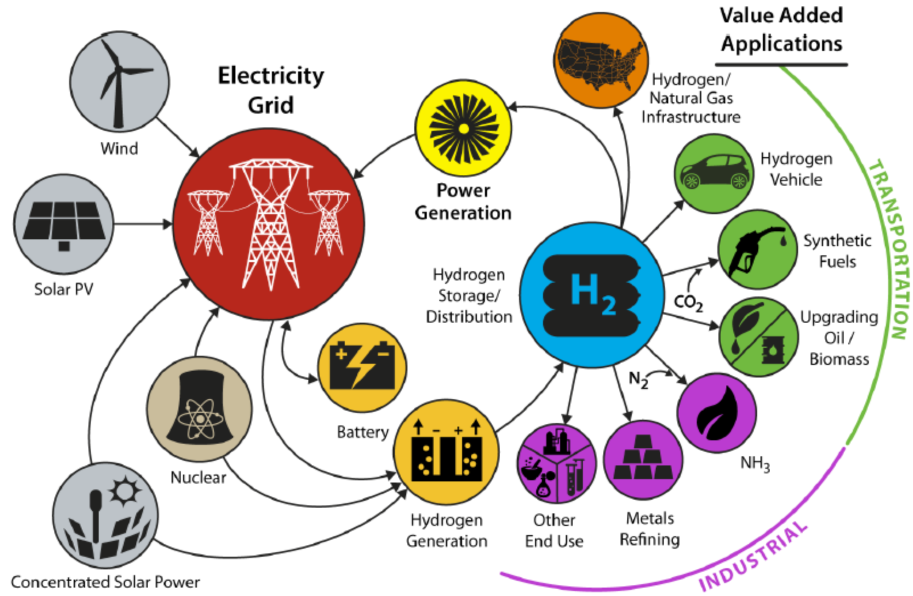

Figure 8: Conceptual Diagram for Hydrogen at Scale

Source: Pivovar et al, DOE National Lab Big Idea available in 2016 AMR Proceedings at https://www.hydrogen.energy.gov/pdfs/review16/2016_amr_h2_at_scale.pdf

While hydrogen and fuel cell technology solutions may not be the most economical in each application they can serve, they have the potential to simultaneously serve more value streams than the competing technologies in each application. These value streams include:

- Transportation applications: FCEVs offer the clean operation and rapid acceleration of other electric vehicles, but with faster refueling and longer driving ranges.
- Electric grid support: fuel cell systems offer clean power in areas where local air quality is an issue, and can also provide various grades of waste heat and enhanced power reliability for host sites.
- Energy storage: Hydrogen can provide long-term energy storage, potentially helping to maximize the benefits of renewable energy systems.
- Natural gas system support: power-to-hydrogen and power-to-methane can utilize stranded intermittent renewable energy to supplement local natural gas-based fuel supplies.
- Industrial applications: hydrogen is already widely used in industrial settings, but there are additional opportunities to expand the use of hydrogen for chemical manufacture, ammonia production, metals production and processing, enhancement of liquid fuels, and to take advantage of hydrogen produced as a co-product of industrial processes such as chlor-alkali production.

Concepts such as these point to a much larger potential role for hydrogen and fuel cell technologies in the future. However to achieve this, continued government support for these emerging technologies is still critically needed until they become more mature and established.

In this regard, the sunset of the 30% ITC for fuel cell system installation at the end of 2016 is expected to have a dampening effect on the market commercialization of stationary fuel cell systems. The Fuel Cell Motor Vehicle Tax Credit of up to $8,000 on light-duty FCEVs is also set to expire at the end of 2016, after only a two-year prior extension. FCEVs and stationary fuel cell systems are only beginning to make inroads into major markets, and the potential for sudden expiration of these credits represents a significant risk to continued market development. Extending both of these complementary programs to promote the further introduction of fuel cell systems while their costs are steadily declining should be considered.

In conclusion, 2015 was a milestone year for hydrogen and fuel cell systems in the U.S. Much progress is being made, but greater momentum is needed for these technologies to provide the larger benefits they are capable of in 2020 and beyond. An explicit plan including measurable progress milestones should be provided in 2016–2017 for how the 2020 EPACT Title VIII goals will be successfully achieved, with commensurate funding commitments including those identified through the 2015 FAST Act.

Endnotes

[1] Green Car Congress, October 13, 2015, "New JV pushes hydrogen infrastructure expansion in Germany; ~400 stations by 2023; $455M investment," http://www.greencarcongress.com/2015/10/20151013-h2.html.
[2] Fuel Cell Works article on Capitol Hill Briefing Highlights Fuel Cell and Hydrogen Technologies, May 2015, https://fuelcellsworks.com/archives/2015/05/06/capitol-hill-briefing-highlights-fuel-cell-and-hydrogen-technologies/
[3] Fuel Cell Works article on Capitol Hill Briefing Highlights Fuel Cell and Hydrogen Technologies, May 2015, https://fuelcellsworks.com/archives/2015/05/06/capitol-hill-briefing-highlights-fuel-cell-and-hydrogen-technologies/
[4] E4Tech, "The Fuel Cell Industry Review 2015," http://www.e4tech.com/now-available-the-fuel-cell-industry-review-2015.
[5] Shaw, R.W.; A Venture Capitalist's Look at H2 Station Economics. HTAC Meeting October 2015, https://www.hydrogen.energy.gov/pdfs/htac_oct15_04_shaw.pdf
[6] E4Tech, "The Fuel Cell Industry Review 2015," http://www.e4tech.com/now-available-the-fuel-cell-industry-review-2015
[7] Doosan Fuel Cell America, "Doosan Fuel Cell Wins Contract to Supply 70 Power Units to Korea," http://www.doosan.com/en/media/news.do.
[8] E4Tech, "The Fuel Cell Industry Review 2015," http://www.e4tech.com/now-available-the-fuel-cell-industry-review-2015
[9] Bertoldi, M., "SolidPOWER update," *Fuel Cell Seminar*, Los Angeles, CA, November 18, 2015.
[10] Mining Weekly, "Implats surges ahead with platinum fuel cell power," April 1, 2015, http://www.miningweekly.com/article/implats-surges-ahead-with-platinum-fuel-cell-power-2015-04-01.
[11] "Toyota Mirai: Coming This Fall to Showrooms Near…?" Toyota news release, May 6, 2015.
[12] Automotive World, "Hyundai Motor to Test Fully-Autonomous Fuel Cell Vehicle in the US," December 14, 2015, http://www.automotiveworld.com/news-releases/hyundai-motor-test-fully-autonomous-fuel-cell-vehicle-us.
[13] Honda, "Honda Exhibits World Premiere of CLARITY FUEL CELL, Planned Production Model of its All-new Fuel Cell Vehicle, at 44th Tokyo Motor Show 2015," http://world.honda.com/news/2015/4151028eng.html.
[14] "GM and Honda may jointly manufacture fuel cells," January 20, 2016, http://finance.yahoo.com/news/gm-honda-may-build-hydrogen-161118604.html;_ylt=A0LEVxji759WVlEAFJBXNyoA;_ylu=X3oDMTExZzQ0YmY1BGNvbG8DYmYxBHBvcwMxBHZ0aWQDVUlDMV8xBHNlYwNzYw--
[15] "Nearly 1,000 fuel cell electric miles: Crossing California on Hydrogen," October 27, 2015, http://media.daimler.com/dcmedia/0-921-656547-1-1859369-1-0-0-0-0-1-12759-614216-0-0-0-0-0-0-0.html?TS=1452110099115
[16] Ballard Power Systems, "Ballard Inks $10 Million Deal to Power 33 Clean Energy Buses in China," June 8, 2015, http://www.ballard.com/about-ballard/newsroom/news-releases/news06081501.aspx
[17] Ballard Power Systems, "Ballard Inks Strategic Cooperation Agreement With King Long For Fuel Cell Buses," November 9, 2015, http://www.ballard.com/about-ballard/newsroom/news-releases/news11091501.aspx
[18] Ballard Power Systems, "Transport for London Fuel Cell Bus Achieves 20,000 Hours of Operation," November 30, 2015, http://www.ballard.com/about-ballard/newsroom/fuel-cell-market-updates/2015/TfL_Mileage.aspx
[19] Globe Newswire, "Hydrogenics Signs Broad Supply Agreements With Chinese Vehicle Integrators," November 16, 2015, https://globenewswire.com/news-release/2015/11/16/787420/10156334/en/Hydrogenics-Signs-Broad-Supply-Agreements-With-Chinese-Vehicle-Integrators.html.
[20] Fleets and Fuels, "U.S. Hybrid Fuel Cell Trucks for Houston," July 21, 2015, http://www.fleetsandfuels.com/fuels/hydrogen/2015/07/us-hybrid-fuel-cell-trucks-for-houston/
[21] California Energy Commission and California Air Resources Board, "Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California," http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf.
[22] Air Liquide, "Toyota plan Northeastern US hydrogen fuel network," *Fuel Cells Bulletin* **2014**(12): 8–9.
[23] Nixon, T., "Germans get ahead with hydrogen filling stations," February 25, 2015, http://www.energylivenews.com/2015/02/25/germans-get-ahead-with-hydrogen-filling-stations/.
[24] Air Products and Chemicals, "Supporting a Growing UK Hydrogen Infrastructure: Air Products' High Pressure Tube Trailer Fleet Expansion and Permanent Fuelling Station Installation ," August 4, 2014, http://www.airproducts.com/Company/news-center/2014/08/0804-air-products-high-pressure-tube-trailer-fleet-expansion-and-permanent-fueling-station.aspx
[25] "Plug Power Launches GenDrive 3340 Designed Around Plug Power Stack for Increased Reliability," November 18, 2015, http://www.plugpower.com/news/.
[26] Ballard Power Systems, "Delivery of the 3,000th ElectraGenTM System," 2015, http://www.ballard.com/landing-pages/Featured_Deployment.aspx.
[27] Ballard Power Systems, "Ballard Receives Initial 100 Unit Order From Reliance Jio Infocomm For Backup Power Systems In India," April 29, 2015, http://www.ballard.com/about-ballard/newsroom/news-releases/news04291501.aspx.
[28] Altergy Systems, "Altergy's New Freedom Power™ Nacelle Breaks Price Barrier Associated with Fuel Cells," March 24, 2015, http://www.altergy.com/altergys-new-freedom-power-nacelle-breaks-price-barrier-associated-with-fuel-cells/.

[29]" Intelligent Energy announces milestone £1.2 billion deal to provide efficient, economical and clean power to over 27,400 telecom towers in India," October 1, 2015, http://www.intelligent-energy.com/news-and-events/company-news/2015/10/01/intelligent-energy-announces-milestone-12-billion-deal-to-provide-efficient-economical-and-clean-power-to-over-27400-telecom-towers-in-india/

[30] Hamburg News, "The World's Most Modern Power-to-Gas Plant," October 15, 2015, http://www.hamburg-news.hamburg/en/cluster/renewable-energy/power-gas-plant-inaugurated-hamburg/

[31] Proton Onsite, "Proton OnSite Delivers Electrolyzer for First Power to Gas Project in the U.S.," April 13, 2015, http://protononsite.com/company/in-the-news.html.

[32] Fuel Cell Motor Vehicle Tax Credit, http://www.afdc.energy.gov/laws/350

[33] California Public Utilities Commission, Self-Generation Incentive Program, http://www.cpuc.ca.gov/sgip

[34] California Air Resources Board, "Clean Vehicle Rebate Project," http://www.arb.ca.gov/msprog/aqip/cvrp.htm

[35] "FuelCell Energy Announces Project Finance Facility with PNC Energy Capital," December 15, 2015, http://fcel.client.shareholder.com/releasedetail.cfm?ReleaseID=947038.

[36] Business Wire, "Constellation and Bloom Energy to Develop 40 Megawatts of Fuel Cell Projects for Commercial and Public Sector Customers in Four States," August 12, 2015, http://www.businesswire.com/news/home/20150812005259/en/Constellation-Bloom-Energy-Develop-40-Megawatts-Fuel#.Vctf_vlVhBc

[37] Globe Newswire, "FuelCell Energy Announces Project Development Agreement With E.ON Connecting Energies GmbH and First European Megawatt Stationary Fuel Cell Power Plant Sale in Europe," July 30, 2015, https://globenewswire.com/news-release/2015/07/30/756337/0/en/FuelCell-Energy-Announces-Project-Development-Agreement-With-E-ON-Connecting-Energies-GmbH-and-First-European-Megawatt-Stationary-Fuel-Cell-Power-Plant-Sale-in-Europe.html

[38] Phys.org, "Toyota to give away fuel-cell patents to boost industry," January 6, 2015, http://phys.org/news/2015-01-toyota-fuel-cell-patents-boost-industry.html.

[39] "Development of the Hydrogen Station Equipment Performance (HyStEP) Device." Terry Johnson, Sandia National Laboratory, June 11, 2015, Project TV026 (presentation).

[40] Jahnke, F., "Reformer-Electrolyzer-Purifier (REP) for Production of Low Cost Hydrogen," *Fuel Cell Seminar*, Los Angeles, CA, November 19, 2015.

[41] U.S. DOE, "Fuel Cell Technologies Market Report 2014," http://energy.gov/sites/prod/files/2015/10/f27/fcto_2014_market_report.pdf.

[42] U.S. DOE, "State of the States: Fuel Cells in America 2015, 6th Edition," December, 2015, http://energy.gov/sites/prod/files/2015/12/f27/fcto_state_of_states_2015.pdf.

[43] California Energy Commission and California Air Resources Board, December 2015, http://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2015.pdf.

[44] California Energy Commission and California Air Resources Board, "Joint Agency Staff Report on Assembly Bill 8: Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California," http://www.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf.

[45] California Hydrogen Business Council, October 8, 2015, https://californiahydrogen.org/sites/default/files/CHBC%20Hydrogen%20Energy%20Storage%20White%20Paper%20FINAL.pdf

[46] Fuel Cell & Hydrogen Energy Association, 2015, http://www.fchea.org/s/2015StatesH2FCWrapUp.pdf.

[47] Fuel Cell and Hydrogen Energy Associations, "Business Case for Fuel Cells 2015," 2015, http://www.fchea.org/reports/.

[48] E4Tech, "The Fuel Cell Industry Review 2015," http://www.e4tech.com/now-available-the-fuel-cell-industry-review-2015.

[49] National Renewable Energy Laboratory, Department of Energy Lab Big Idea Summit, April 2016.

[50] ABO Newsletter, "Arezzo, a town that runs on hydrogen," January 27, 2015, http://www.abo.net/oilportal/articles/view.do?locale=&contentId=2374558

[51] United Nations Framework Convention on Climate Change, The Paris Agreement, http://bigpicture.unfccc.int/#content-the-paris-agreement