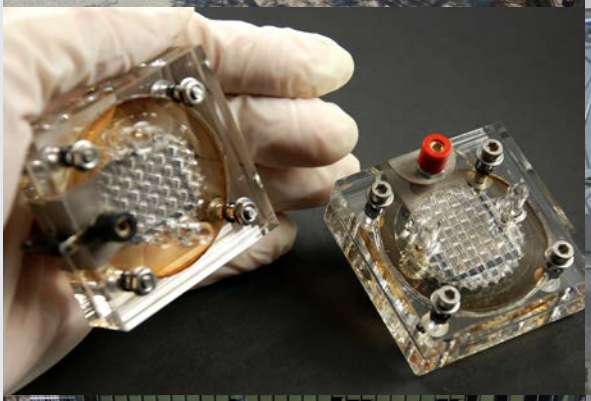
U.S. DEPARTMENT OF
ENERGY

*Office of*
ENERGY EFFICIENCY &
RENEWABLE ENERGY

# Fuel Cell Technologies Market Report

October 2017





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# Acronyms

| | |
|---|---|
| **ARPA-E** | Advanced Research Projects Agency – Energy (DOE) |
| **CHP** | Combined heat and power |
| **DMFC** | Direct Methanol Fuel Cell |
| **DOE** | U.S. Department of Energy |
| **EERE** | Office of Energy Efficiency and Renewable Energy (DOE) |
| **FCEV** | Fuel cell electric vehicle |
| **FCH-JU** | Fuel Cells and Hydrogen Joint Undertaking (Europe) |
| **FC-PAD** | Fuel Cell Consortium for Performance and Durability |
| **FCTO** | Fuel Cell Technologies Office (DOE) |
| **FTA** | U.S. Federal Transit Administration |
| **HyMARC** | Hydrogen Materials—Advanced Research Consortium |
| **LANL** | Los Alamos National Laboratory (DOE) |
| **LBL** | Lawrence Berkeley National Laboratory (DOE) |
| **LLNL** | Lawrence Livermore National Laboratory (DOE) |
| **MCFC** | Molten carbonate fuel cell |
| **MoU** | Memorandum of Understanding |
| **NASA** | National Aeronautics and Space Administration |
| **NREL** | National Renewable Energy Laboratory (DOE) |
| **ORNL** | Oak Ridge National Laboratory (DOE) |
| **OTC** | Over-the-counter |
| **PAFC** | Phosphoric acid fuel cell |
| **PE** | Private equity |
| **PEM** | Polymer electrolyte membrane |
| **PIPE** | Private investment in public equities |
| **PNNL** | Pacific Northwest National Laboratory (DOE) |
| **PPA** | Power purchase agreement |
| **R&D** | Research and Development |
| **RD&D** | Research, development and demonstration |
| **SARTA** | Stark Area Regional Transit Authority (Ohio) |
| **SBIR** | Small Business Innovation Research |
| **SNL** | Sandia National Laboratories (DOE) |
| **SOEC** | Solid oxide electrolysis cell |
| **SOFC** | Solid oxide fuel cell |
| **SRNL** | Savannah River National Laboratory (DOE) |
| **STTR** | Small Business Technology Transfer |
| **VC** | Venture capital |

# Measures

**kg** Kilogram
**kW** Kilowatt
**kWh** Kilowatt-hour
**MPa** Megapascal
**mph** Miles per hour
**MW** Megawatt
**MWh** Megawatt-hour

# Currency Exchange Rates

This report uses U.S. Internal Revenue Service 2016 yearly average exchange rates to convert foreign currencies to U.S. dollars using the following rates.

**2016 Average Exchange Rates for Converting Foreign Currencies into U.S. Dollars**

| Country | Currency | Symbol | Rate |
|---|---|---|---|
| Australia | Dollar | $ | 1.400 |
| Canada | Dollar | $ | 1.379 |
| China | Yuan | ¥ | 6.910 |
| Euro Zone | Euro | € | 0.940 |
| Japan | Yen | ¥ | 113.138 |
| Norway | Krone | kr | 8.745 |
| South Korea | Won | ₩ | 1211.121 |
| United Kingdom | Pound | £ | 0.770 |

Source: U.S. Internal Revenue Service

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# Introduction

The Fuel Cell Technologies Market Report examines global fuel cell and hydrogen activities during 2016, covering business and financial activities, federal programs, and aspects of the various market sectors for fuel cells which include transportation, stationary power, and portable power. The report also examines 2016 activities related to hydrogen production, power-to-gas, energy storage, and components used by fuel cell and hydrogen technologies.

For fuel cells and hydrogen, 2016 was a notable year on many fronts. Fuel cells and hydrogen continued to expand in existing markets and made inroads into new areas. Ongoing research, development, and demonstration (RD&D) projects examined additional uses for fuel cells and hydrogen, such as ground support equipment, drayage trucks, and energy storage.

A major development was the introduction of the third commercial fuel cell electric vehicle (FCEV), the Honda Clarity Fuel Cell, with sales starting in March in Japan and in December in California, the U.K., and Denmark. The Clarity Fuel Cell joins two other commercial FCEVs, the Toyota Mirai and Hyundai Tucson Fuel Cell, which have cumulatively sold or leased more than 1,000 units in the U.S. and nearly 3,000 worldwide through late 2016.[1]

Toyota and Air Liquide also announced plans for the first U.S. retail hydrogen stations to be located outside of California, to be sited in Connecticut, New York, and Massachusetts.

Hydrogen infrastructure continued to grow in 2016, with 92 new hydrogen refueling stations opened worldwide in 2016, and 83 being retail hydrogen stations that are accessible by customers.[2] Almost half of these new hydrogen stations were opened in Japan (45), followed by California (20), with these two comprising 70 percent of the new hydrogen stations opened in 2016.

Sales and deployments continued to grow in the material handling market, with more than 14,000 fuel cell forklifts in operation globally at the end of 2016, compared to more than 10,000 at the end of 2015.

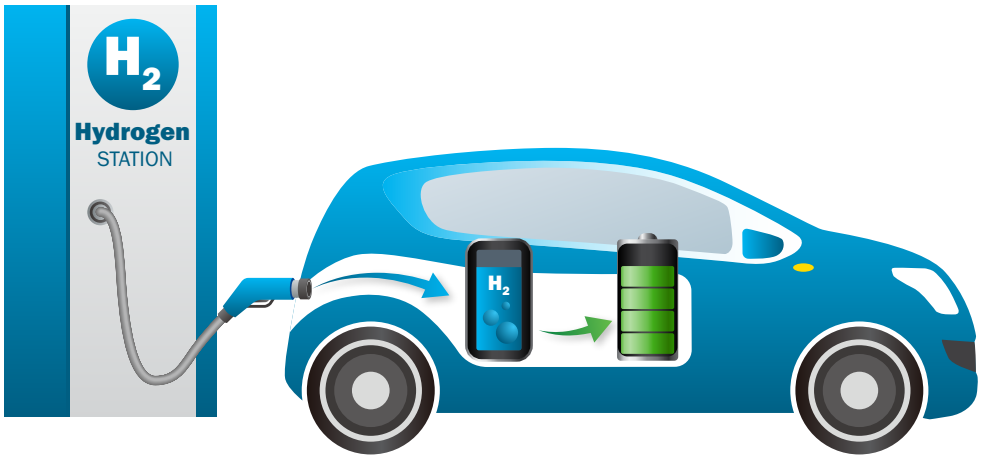
Sales also expanded to Europe, with several major companies purchasing fuel cells to power material handling equipment used in warehouse operations.

Fuel cells also began to expand into new applications during the year, including passenger trains; drayage trucks, long-haul trucks, and delivery vans; and carbon capture from natural gas-fired power generation and oil sands sites.

New policy actions during the year targeted growth in the number of FCEVs and hydrogen fueling stations. These actions—in the U.S., Europe, Japan, South Korea, China, and other countries—include funding for hydrogen stations and fleet vehicles, FCEV incentives, and national targets for FCEV and hydrogen station deployments. In addition, 45 European cities and regions signed a memorandum of understanding (MoU) committing to integrate fuel cells and hydrogen into their path toward a low carbon future.

In the stationary sector, large-scale fuel cell systems continued to see growth in the U.S. as well as internationally. Utilities in Korea ordered more than 120 megawatts (MW) of fuel cell systems in 2016. Big partnerships between fuel cell manufacturers and outside industry helped boost not only financial stakes, but also media and stakeholder focus. This included the strategic alliance of Bloom Energy and Southern Company and FuelCell Energy working with Exxon Mobil on carbon capture technologies.

TRANSPORTATION
# FUEL CELLS




Fuel cells electrochemically combine hydrogen and oxygen to produce electricity, water, and heat. Unlike batteries, fuel cells continuously generate electricity as long as a source of fuel is supplied.

Fuel cells do not burn fuel, making the process quiet, pollution-free, and up to two to three times more efficient than combustion technologies. A fuel cell system can be a truly zero-emission source of electricity when using hydrogen produced from nonpolluting sources.

Many types of fuel cells are currently in operation in a wide range of applications, classified primarily by the kind of electrolyte they employ. These include molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), phosphoric acid fuel cells (PAFC), direct methanol fuel cells (DMFC), and low and high temperature polymer electrolyte membrane (PEM) fuel cells.

**The three main markets for fuel cell technology are stationary power, transportation, and portable power.**

**Stationary power** includes any application in which the fuel cells are operated at a fixed location for primary power, backup power, or combined heat and power (CHP).

**Transportation** applications include motive power for light-duty cars, buses, heavy-duty trucks, specialty vehicles, material handling equipment, and auxiliary power units for off-road vehicles.

**Portable power** applications include fuel cells that are not permanently installed or fuel cells in a portable device.

# 1,000,000

## REACHING THE **MILLION** MILESTONE[1]

In 2016, several companies met and surpassed the million milestone. They announced these industry milestones throughout the year.

In January, Ballard Power Systems announced its fuel cells had powered buses for a combined total of more than 6.2 million miles of revenue service, equivalent to circling the Earth 250 times at the equator.

In February, Plug Power celebrated its one-millionth GenFuel hydrogen forklift refueling.

In October, Hyundai announced that Tucson Fuel Cell drivers accumulated more than 1.5 million miles of driving on California roads and highways.

Hydrogen station operator TrueZero reached two million miles of powering fuel cell vehicles on California roadways in October, achieving this just two months after achieving the first million miles, which took nine months.

# Industry Trends and Data

In 2016, approximately 62,000 fuel cell systems were shipped worldwide (Figure 1), up slightly from 2015 (60,000). More significantly, the total MW grew substantially from 300 MW in 2015 to 500 MW in 2016 (Figure 2).

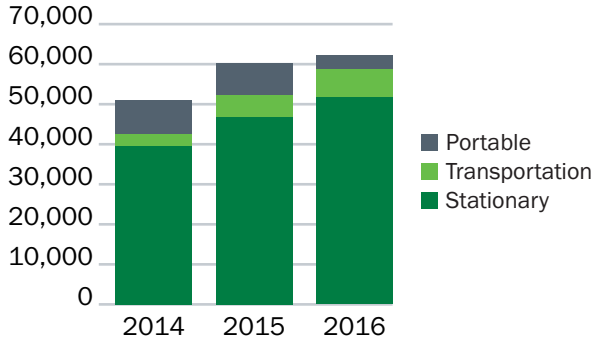



Figure 1: Fuel Cells Shipped Worldwide by Application
Source: U.S. Department of Energy
Fuel Cell Technologies Office, E4 Tech

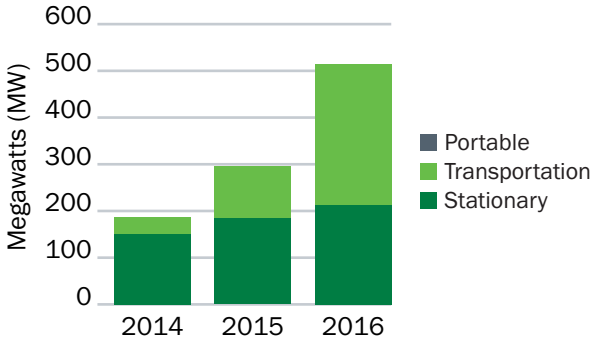



Figure 2: Megawatts of Fuel Cells Shipped Worldwide by Application
Source: U.S. Department of Energy
Fuel Cell Technologies Office, E4 Tech

The largest increase—nearly triple—in MWs occurred in the transportation sector, and that growth can be attributed to the introduction and expansion of fuel cell light-duty vehicles from Japan and Korea to new regions around the world. There was also the inclusion of Honda's fuel cell vehicle to the marketplace. Other transportation applications such as buses and material handling also contributed to the increase in MW shipped. In 2016, China emerged as a leading customer for fuel cell buses, with more than 30 either deployed or ordered throughout the year, with potential for more via announced partnerships with fuel cell manufacturers.

The small increase in stationary fuel cell shipments show sustained activity in Asia, a combination of large-scale units from Korea and smaller, residential fuel cell systems from Japan.

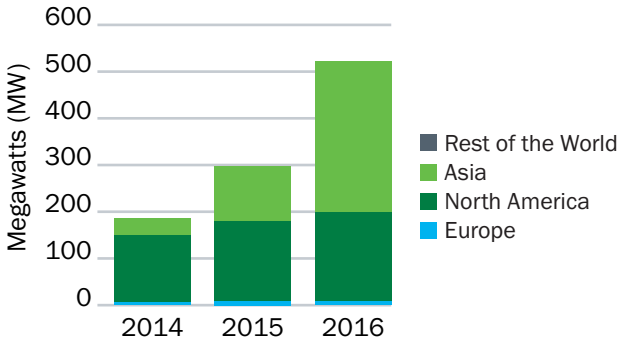



Figure 3: Megawatts of Fuel Cells Shipped Worldwide by Region of Manufacture
Source: U.S. Department of Energy
Fuel Cell Technologies Office, E4 Tech

# Business and Financial Activities

This section provides information regarding the financial activities of fuel cell and hydrogen companies. It includes mergers and acquisitions, company expansions, and industry investment, and provides an overview and analysis of venture capital (VC), private equity (PE), and other investment activity, including equity and stock offerings to raise capital.

This section also includes fuel cell company revenues, cost of revenue, and other key data for selected publicly traded fuel cell companies that have fuel cells as their primary business. The focus is on public companies because many private companies do not release financial information.

## Revenues, Assets, and Research and Development Expenses

Fuel cell companies derive revenue from the sale of fuel cells and related equipment (such as hydrogen generators), support and maintenance contracts, and contract research and development (R&D).

Tables 1 through 3 provide financial data for select public companies. These companies were chosen because fuel cells are their primary product, and because they are publicly traded on major stock exchanges and thus must report detailed data.

Table 1 shows gross revenue and cost of revenue for select fuel cell companies over the past three years. Gross revenue is money generated by all of a company's operations during a specific period, before deductions for expenses. Cost of revenue is the total operating expenses directly related to the goods sold and services provided, such as selling and marketing activities associated with a sale.

R&D expenditures are shown in Table 2 and Table 3 shows each company's total assets and liabilities.

**Gross Revenue and Cost of Revenue for Select Public Fuel Cell Companies (Thousands US$ except where noted)**

| Companies | 2016 | | 2015 | | 2014 | |
|---|---|---|---|---|---|---|
| | Gross Revenue | Cost of Revenue | Gross Revenue | Cost of Revenue | Gross Revenue | Cost of Revenue |
| Ballard Power Systems (Canada) | 85,270 | 61,086 | 56,463 | 46,489 | 68,721 | 58,475 |
| FuelCell Energy[1] (U.S.) | 108,252 | 108,609 | 163,077 | 150,301 | 180,293 | 166,567 |
| Hydrogenics Corp. (Canada) | 28,990 | 22,995 | 35,864 | 29,893 | 45,548 | 34,334 |
| Plug Power (U.S.) | 85,928 | 81,982 | 103,288 | 113,178 | 64,230 | 69,092 |
| Ceres Power[2, 3] (U.K.) | 1,113 | 14,026 | 324 | 12,476 | 1,224 | 10,128 |
| SFC Energy AG4 (Germany) | 44,040 | 30,794 | 47,310 | 34,083 | 53,631 | 37,970 |

[1] Year ends October 31 [2] Year ends June 30 [3] £ Thousands 4 € Thousands
Source: Annual reports and investor presentations[3]

Table 1: Gross Revenue and Cost of Revenue for Select Public Fuel Cell Companies

The following discussion provides additional details regarding revenue drivers for select companies in 2016:

Ballard Power Systems' 2016 revenue grew by $28.8 million over 2015, due to growth in the company's Heavy-Duty Motive and Technology Solution markets, and from the Portable Power market. Ballard's cost of revenue grew by $14.6 million compared to 2015.[4]

For the fiscal year ending October 31, 2016, FuelCell Energy's revenue decreased by $54.8 million compared to 2015. The decline is attributed primarily to lower revenue from its partner, POSCO Energy, due to transitioning of POSCO kit and module sales to a royalty based model. FuelCell Energy's total cost of revenue for the year decreased by $41.7 million compared to the same period in 2015.[5]

Hydrogenics' 2016 revenue decreased by $6.9 million from revenue reported in 2015, attributed to a decline in electrolyzer sales for energy storage and industrial applications and the delivery of certain significant projects in 2015 that were not repeated in 2016. This was partially offset by higher sales to the Chinese mobility market and increased shipments to Europe for commuter rail fuel cell systems. Hydrogenics' total cost of revenue for 2016 was $6.9 million lower compared to 2015.[6]

Plug Power's 2016 revenue decreased by $17.4 million compared to 2015, driven by a decrease in sales of fuel cell systems and related infrastructure ($38 million) and partially offset by increases in revenue from services performed on fuel cell systems and related infrastructure ($6.4 million), power purchase agreements (PPAs) ($8 million), and fuel delivered to customers ($5.8 million). Total cost of revenue for 2016 decreased by $31.2 million compared to 2015.[7]

Ceres Power's 2016 revenue increased by £0.79 million ($1.02 million) over 2015 revenue, with £586,000 ($761,000) derived from Europe (deferred revenue from work completed for British Gas) and £527,000 ($684,000) from Asia. The 2016 cost of revenue increased by £1.5 million ($1.9 million) compared to 2015.[8]

SFC Energy's revenue decreased by €3.3 million ($3.5 million) due to low sales to the Oil & Gas segment. The company reports that positive sales performance in the Security and Industry segment was not able to fully offset this effect. The cost of revenue decreased by €3.3 million ($3.5 million) compared to 2015.[9]

| R&D Expenditures for Select Public Fuel Cell Companies (Thousands US$, unless footnoted) | | | |
|---|---|---|---|
| **Companies** | **2016** | **2015** | **2014** |
| **Ballard Power Systems (Canada)** | 19,827 | 16,206 | 14,294 |
| **FuelCell Energy[1] (U.S.)** | 20,846 | 17,442 | 18,240 |
| **Hydrogenics Corp. (Canada)** | 3,576 | 4,070 | 3,284 |
| **Plug Power (U.S.)** | 21,177 | 14,948 | 6,469 |
| **Ceres Power[2, 3] (U.K.)** | 10,588 | 9,146 | 7,138 |
| **SFC Energy AG[4] (Germany)** | 4,148 | 5,806 | 4,530 |

[1] Period ending October 31 [2] Period ending June 30 [3] £ Thousands [4] € Thousands
Source: Annual reports and investor presentations[10]

Table 2: R&D Expenditures for Select Public Fuel Cell Companies

| Total Assets and Liabilities for Select Public Fuel Cell Companies (Thousands US$, unless footnoted) | | | | | | |
|---|---|---|---|---|---|---|
| Companies | 2016 | | 2015 | | 2014 | |
| | Assets | Liabilities | Assets | Liabilities | Assets | Liabilities |
| Ballard Power Systems (Canada) | 183,446 | 61,903 | 161,331 | 49,717 | 127,949 | 48,715 |
| FuelCell Energy[1] (U.S.) | 342,137 | 167,884 | 277,231 | 122,620 | 280,636 | 122,330 |
| Hydrogenics Corp. (Canada) | 49,273 | 38,891 | 59,368 | 39,120 | 47,555 | 32,079 |
| Plug Power (U.S.) | 240,832 | 146,122 | 209,456 | 83,567 | 204,181 | 44,715 |
| Ceres Power[2, 3] (U.K.) | 10,081 | 3,103 | 20,685 | 4,084 | 10,084 | 3,726 |
| SFC Energy AG[4] (Germany) | 33,793 | 20,454 | 35,889 | 19,331 | 47,256 | 19,667 |

[1] Period ending October 31 [2] Period ending June 30 [3] £ Thousands [4] € Thousands
Source: Annual reports and investor presentations[11]

Table 3: Total Assets and Liabilities for Select Public Fuel Cell Companies

## Investment

Disclosed cumulative global investment in fuel cell companies—VC, PE, over-the-counter (OTC) and private investment in public equities (PIPE)—totaled $355.8 million for the period between 2014 and 2016. Figure 4 provides a breakdown by quarter and by investment type. Figure 5 shows the publically disclosed total investment in U.S. fuel cell companies.

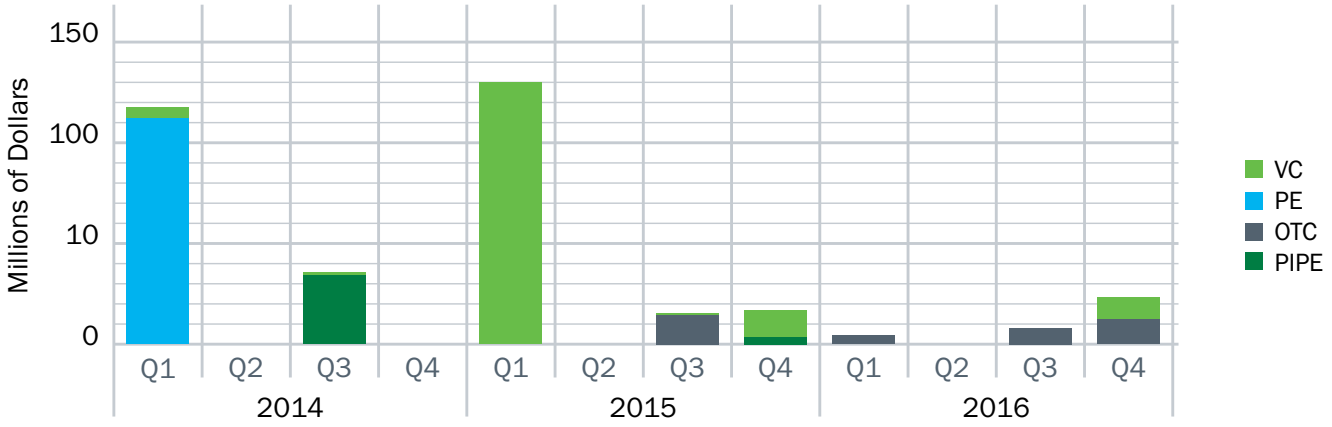



Figure 4: Worldwide Venture Capital, Private Equity, Over-the-Counter, and Private Investment in Public Equities Investments in Fuel Cell Companies (2014-2016)
Source: Fuel Cell and Hydrogen Energy Association using data from Bloomberg New Energy Finance. Data provided by Bloomberg New Energy Finance includes only disclosed and completed deals.

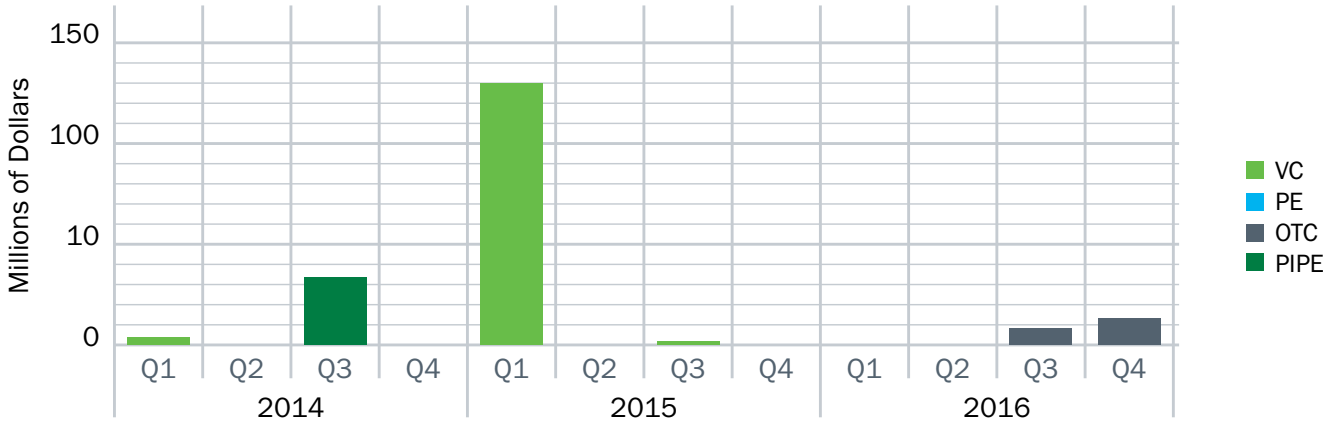



Figure 5: U.S. Venture Capital, Private Equity, Over-the-Counter, and Private Investment in Public Equities Investments in Fuel Cell Companies (2014-2016)
Source: Fuel Cell and Hydrogen Energy Association using data from Bloomberg New Energy Finance. Data provided by Bloomberg New Energy Finance includes only disclosed and completed deals.

In 2016, publicly disclosed venture capital investment in fuel cell companies included the following:[12]

Electro Power Systems (Italy/France) received €10 million ($10.9 million) in venture capital investment from three investors: Intesa Sanpaolo (Italy) through its subsidiary Medio-Credito Italiano SpA, Unicredit Group (Italy) and Banca Sella (Italy).

Symbio FCell SA (France) received an undisclosed amount of venture capital investment from three investors: ENGIE SA (France), Michelin (France), and a private investor.

Publicly disclosed OTC investment in fuel cell companies during 2016 included £3.6 million (US$5.1 million) raised by AFC Energy (U.K.), $13 million raised by Plug Power (U.S.), and $8.6 million raised by FuelCell Energy (U.S.).[13]

Over-the-counter investment in hydrogen-related companies included CA$1.5 million (US$1.1 million) raised by dynaCERT Inc. (Canada), and £2.1 million ($3.1 million) raised by ITM Power PLC (U.K.).[14]

In addition, several companies acquired funding by entering into long-term credit agreements or loan facilities (Table 4).[15]

| Examples of 2016 Loan Activity | | |
|---|---|---|
| **Company** | **Net Proceeds** | **Details** |
| **FuelCell Energy** | Up to $25 million | Long-term loan facility with Hercules Capital.[16] |
| **Hydrogenics** | $9 million | Credit agreement with Export Development Canada for a five year term loan.[17] |
| **Intelligent Energy** | $39 million | £30 million (US$39 million) fundraising through the issue of 13.0% Senior Secured Convertible Loan Notes 2019, secured from the Company's largest shareholder, Meditor European Master Fund Limited.[18] |
| **Plug Power** | $30 million | Loan facility with a specialty finance company.[19] |
| | Up to $40 million | Long-term loan facility with Hercules Capital.[20] |
| | $25 million | Senior loan with the NY Green Bank.[21] |

Table 4: 2016 Loan Activity

## Mergers, Acquisitions, Partnerships and Collaborations

In 2016, several fuel cell and hydrogen companies grew their business activities through mergers, acquisitions, and joint ventures:

Ceres Power signed a joint development license agreement to develop and launch a multi-kW CHP product using its SteelCell technology with a leading global original equipment manufacturer (OEM).[22]

Chung-Hsin Electric & Machinery Manufacturing Corporation (Taiwan) purchased certain assets of the Ballard Power Systems (Canada) methanol telecom backup business, including intellectual property rights and physical assets. Ballard retained its direct hydrogen fuel cell backup power system assets.[23]

Douglas Acquisitions (California) acquired Quantum Fuel Systems Technologies (California), a manufacturer of natural gas and hydrogen tanks.[24]

Fuji Electric (Japan) announced it would acquire a 70 percent stake in N2telligence (Germany).[25]

Mitsui & Co. will take a 25 percent stake in carbon fiber maker Hexagon Composites via private placement of new shares and buying outstanding stock.[26]

Industrial gas companies Linde AG (Germany) and Praxair (Connecticut) merged in an all-stock transaction. The combined company is named Linde.[27]

MicroOrganic (New York), a developer of microbial fuel cells, acquired the assets of microbial fuel cell company, Arbsource LLC (Arizona).[28]

In addition, a number of companies signed joint development or distribution agreements. These are highlighted in Table 5.

| Examples of 2016 Fuel Cell and Hydrogen Business Collaborations | |
|---|---|
| **Companies** | **Details** |
| **Arcola Energy, IMS ECUBES** | Joint venture to develop hydrogen and fuel cell energy and mobility solutions for Europe and South Asia.[29] |
| **Ballard Power Systems, Toyota Tsusho Corp.** | Toyota Tsusho Corporation will be a distributor of Ballard fuel cell products in Japan through 2020.[30] |
| **Ballard Power Systems, Zhongshan Broad-Ocean Motor Co., Ltd.** | Announced a strategic collaboration for activities in China, including market development activities and product development for fuel cell vehicles, including buses and commercial vehicles, and potential license and local assembly of Ballard fuel cell modules by Broad-Ocean in selected Chinese cities.[31] |
| **Ceres Power, Honda R&D Co. Ltd.** | Ceres Power Holdings PLC signed a new joint development agreement with Honda R&D Co. Ltd. to develop SOFC stacks using Ceres Power's Steel Cell technology.[32] |
| **PowerCell Sweden AB, Swiss Hydrogen SA** | The companies are cooperating to market and sell fuel cell systems based on PowerCell's stacks for mobile and stationary applications.[33] |
| **US Hybrid, Sumitomo Corp.** | Collaboration to expand fuel cell stack production capacity for commercial production of fuel cell engine and integrated vehicle technologies.[34] |

Table 5: Examples of Business Collaborations

# Federal Activities

The federal government provides funding for a range of fuel cell and RD&D activities conducted at U.S. universities and private industry.

## U.S. Department of Energy

The U.S. Department of Energy's (DOE) Fuel Cell Technologies Office (FCTO) in the Office of Energy Efficiency and Renewable Energy covers a comprehensive portfolio of activities that focuses on applied research, development, and innovation to advance hydrogen and fuel cells for transportation and diverse applications. The national laboratories – Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), National Energy Technology Laboratory (NETL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Sandia National Laboratories (SNL), and Savannah River National Laboratory (SRNL) – also work to advance hydrogen and fuel cell technologies.

In 2016, DOE supported a number of early stage R&D activities to provide innovation of hydrogen and fuel cell technologies across diverse applications.

DOE and Hyundai extended a FCEV loan program to its second phase (2016-2017).[35] Hyundai has provided a Tucson FCEV to DOE for daily use, data collection, and validation of existing hydrogen infrastructure. Phase one of the program (2013-2015) was focused in the Southern California region where the earliest hydrogen infrastructure existed; phase two expands the program's reach to Northern California, Washington D.C., Michigan, and Denver, Colorado.

DOE and the U.S. Department of Interior's National Park Service officially opened a new technology demonstration hydrogen station in Washington, D.C. in July, developed as part of a $1.4 million DOE-funded award to Proton OnSite in 2012.[36] The station, located on Park Service property, produces about 30 kg of hydrogen daily for FCEVs used by federal agencies and for demonstration.

NREL received a 2015 Tucson Fuel Cell vehicle from Hyundai through a one-year Cooperative Research and Development Agreement (CRADA) and a B-Class F-CELL on loan from Mercedes-Benz to support a one-year Technical Services Agreement.[37] NREL will evaluate the interaction of the vehicles' high-pressure hydrogen storage systems with NREL's hydrogen fueling system equipment and the lab's new state-of-the-art hydrogen fueling station.

SNL made the Hydrogen Risk Assessment Models (HyRAM) available, a software toolkit to assess the safety of hydrogen fueling and storage infrastructure.[38]

DOE's Federal Energy Management Program (FEMP) and FCTO partnered to develop training modules on hydrogen and fuel cell technologies, including safety and outreach modules, as part of FEMP's training program.[39]

DOE and Virginia Clean Cities at James Madison University launched the Hydrogen and Fuel Cell Nexus website in July.[40]

DOE's EERE established three collaborative research consortia, each comprising of a core team of DOE national laboratories, with plans to add industry and university partners.[41]

Led by LANL, the Fuel Cell Consortium for Performance and Durability (FC-PAD) focuses on improving fuel cell performance and durability, decreasing the amount of platinum required and increasing the performance and durability of transportation fuel cells.

The Hydrogen Materials - Advanced Research Consortium (HyMARC), with a core team comprised of SNL, LLNL, and LBL will work to improve onboard automotive hydrogen storage systems by lowering costs and increasing the storage capacity.

The HydroGEN Advanced Water Splitting Materials Consortium (HydroGEN), with six national labs (NREL, SNL, LBL, INL, LLNL, and SRNL) accelerates the development of viable pathways for hydrogen production from renewable energy sources.[42]

NREL and the Fraunhofer Institute for Solar Energy Systems ISE (Germany) signed an MoU for close collaboration on research, focusing on: electrolysis, including cell, stack, and system R&D and characterization; hydrogen infrastructure R&D; analysis and modeling for grid-scale implementation of hydrogen systems; field validation, performance data collection and evaluation of hydrogen systems; and accelerated stack and system evaluation, testing, and deployment.[43]

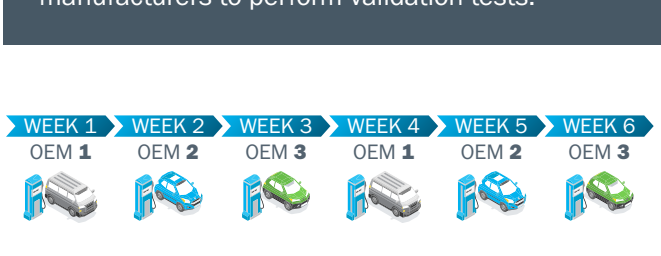
In 2016, DOE awarded funds to support a variety of fuel cell and hydrogen early stage research. These funds were made available through several DOE programs, initiatives and consortiums, including:

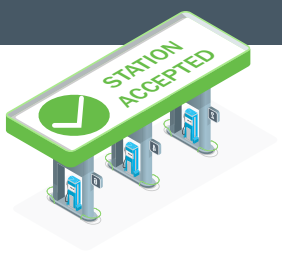
- Advanced Research Projects Agency-Energy (ARPA-E) Integration and Optimization of Novel Ion-Conducting Solids (IONICS) Program
- ARPA-E Renewable Energy to Fuels Through Utilization of Energy-Dense Liquids (REFUEL) Program
- Binational Industrial Research and Development (BIRD) Energy Grant
- EERE Program
- Office of Fossil Energy SOFC Program
- FC-PAD
- H2 Refuel H-Prize
- HyMARC
- Small Business Innovation Research (SBIR) Program
- Small Business Technology Transfer (STTR) Program
- Small Business Vouchers Pilot Program
- Technology Commercialization Fund (TCF)
- 2016 Climate Action Champion Initiative

Details on individual funding awards are provided in the Appendix.

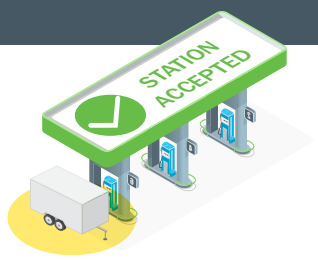
## HyStep Device Enables Faster Hydrogen Station Validation

DOE, NREL, SNL, and industry partners Air Liquide, Boyd Hydrogen, the California Air Resources Board, and Toyota, were selected as 2016 recipients of a Federal Laboratory Consortium Far West Region Award for their outstanding partnership in designing, building, and deploying the Hydrogen Station Equipment Performance (HyStEP) Device. HyStEP measures the performance of hydrogen fueling station dispensers, with respect to the required fueling protocol standard, and eliminates the need for individual automotive manufacturers to perform validation tests.




**PROBLEM:**
Each OEM performs verhicle test fills




**SOLUTION:**
Hystep is a vehicle surrogate; operated by a testing agency

## U.S. Department of Transportation

In April, the U.S. Department of Transportation Federal Transit Administration (DOT FTA) provided funding awards to two transit agencies through the Low and No-Emission (LoNo) Vehicle Deployment Program. The awards include:

- $1.5 million to SunLine Transit Agency (California) to construct a state-of-the-art maintenance facility for SunLine's 20 zero-emission buses, including three fuel cell buses, and to provide an interactive learning center for transit agency staff on new technology bus maintenance.
- $4.0 million to the Stark Area Regional Transit Authority (SARTA) (Ohio) for three American Fuel Cell Buses (AFCBs). This will add to SARTA's existing fleet of five AFCBs.

The Federal Highway Administration (FHWA) unveiled the National Alternative Fuel and Electric Charging Network comprised of a network of 55 fueling corridors spanning 35 states.[44] The initial designated hydrogen highways are located in 10 states: California, Colorado, Connecticut, Florida, Illinois, Missouri, New York, Tennessee, Texas, and Wisconsin (figure 3).

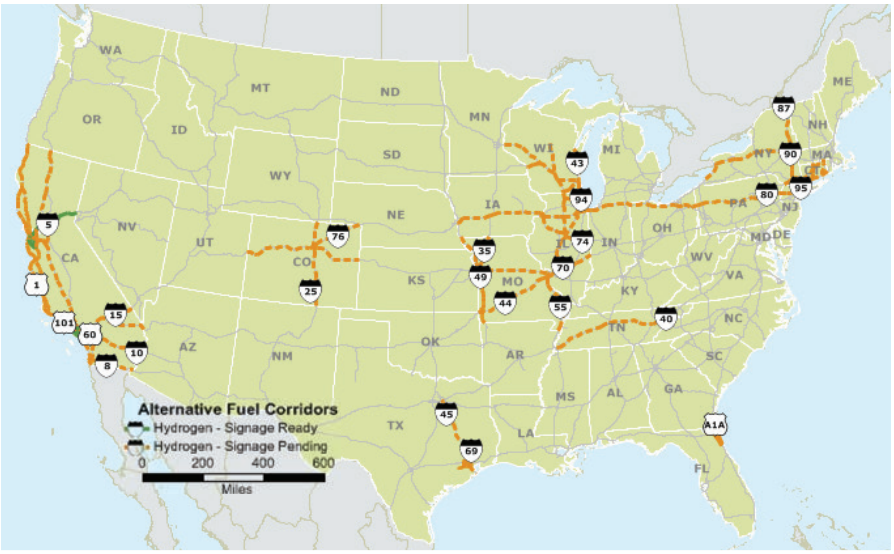



Figure 6: The Federal Highway Administration's Hydrogen Refueling Map, Part of the National Alternative Fuel and Electric Charging Network

## U.S. Department of Defense

The U.S. Department of Defense awarded $3.46 million in SBIR funding to four fuel cell projects, supporting research on SOFCs, microbiological fuel cells, and reformers. These awards, from the U.S. Air Force, Army, and Navy, are detailed in the Appendix.

In October, the Army Tank Automotive Research, Development and Engineering Center (TARDEC) and General Motors unveiled the ZH2 hydrogen fuel cell electric vehicle prototype.[45]

## National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA), under its Transformative Aeronautics Concepts Program, is funding FUELEAP: Fostering Ultra-Efficient Low-Emitting Aviation Power to examine if a new kind of fuel cell can be used to generate power for an electrically-propelled general aviation-sized aircraft.[46]

NASA also awarded almost $1 million in SBIR funding to three fuel cell projects – two focusing on SOFCs and the third on advanced lightweight fuel cell to power unmanned aerial systems. Details are provided in the Appendix.

## National Science Foundation

The National Science Foundation awarded $2.2 million in SBIR funding to two projects, one focusing on PEM fuel cells and the other on electrolysis/hydrogen energy storage. The awards are summarized in the Appendix.

# Transportation

The transport section focuses on light duty FCEVs, and also covers news related to fuel cell buses and trucks, material handling equipment, locomotives and trams, and specialty vehicles.

## Light-Duty Vehicles

The Honda Clarity Fuel Cell became available to select customers in 2016, bringing the number of commercial FCEVs to three, with models also available from Hyundai (Tucson Fuel Cell/ix35 Fuel Cell) and Toyota (Mirai). Toyota and Hyundai also discussed their next-generation FCEV models, slated for introduction in 2018 (Hyundai) and 2020 (Toyota). Details on the automakers' activities and plans are presented in Tables 6, 7, and 8.

Although initial light-duty FCEV production is currently limited, it is expected to increase and expand in the next few years as hydrogen fueling infrastructure grows.

| Honda's Key Activities and Announcements – 2016 | |
|---|---|
| March | Sales of the Clarity Fuel Cell started in Japan. Honda's Power Exporter also went on sale, allowing the Clarity FCEV to provide seven days' worth of power to an average Japanese home.[47] Showed the first U.S. spec version of the Clarity Fuel Cell at the New York Auto Show. The Clarity's fuel cell stack is 33 percent more compact, with a 60 percent increase in power density.[48] |
| April | Announced the Clarity Fuel Cell will be joined by two additional variants, the Clarity Electric and Clarity Plug-in Hybrid, based on the same platform underpinning the Clarity Fuel Cell.[49] |
| May | Opened the "Packaged Smart Hydrogen Station (SHS)" at its Tokyo headquarters. The SHS uses a high-pressure water electrolysis system and 20-kW of solar power generation to produce up to 1.5 kg of hydrogen daily at a pressure of 40 MPa, without using a compressor. The private station can store about 19 kg of hydrogen.[50] |
| October | The Clarity Fuel Cell received an Environmental Protection Agency (EPA) driving range rating of 366 miles and combined fuel economy rating of 68 miles per gallon of gasoline-equivalent.[51] |
| November | Delivered the first Clarity Fuel Cell vehicles in Europe.[52] |
| December | Began deliveries of the 2017 Clarity Fuel Cell to Southern California customers.[53] |

Table 6: Honda Activities and Announcements

| Hyundai's Key Activities and Announcements – 2016 | |
|---|---|
| **February** | Announced it will have 22 new alternative fuel cars by 2020. Two of the models will be FCEVs.[54] |
| **May** | Began Tucson Fuel Cell deliveries to northern California customers.[55]<br>Announced plans to launch a next-generation FCEV in early 2018.[56] |
| **June** | Delivered 50 ix35 FCEVs to The Linde Group in Munich, Germany, to BeeZero, the world's first fuel cell car sharing service.[57]<br>Signed a MoU with Air Liquide to accelerate the deployment of hydrogen infrastructure and FCEVs in Korea and Europe.[58]<br>The ix35 FCEV, undertook the longest FCEV road trip across Europe, covering more than 1,500 miles and using only existing fuel cell station infrastructure to travel from Bergen, Norway, to Bolzano, Italy.[59] |
| **July** | Extended a FCEV loan program with DOE to its second phase.[60] |
| **September** | Announced fuel cell taxi and car-sharing businesses in South Korea. A pilot taxi business debuted in Ulsan in 2016 and Hyundai will expand it to five cities and 100 fuel cell taxis by 2018. Hyundai also has partnered with J'car (South Korea) for a car sharing business comprised of both fuel cell and battery vehicles.[61]<br>Revealed the H350 Fuel Cell Concept light commercial vehicle at the 2016 Internationale Automobil-Ausstellung (IAA) Motor Show in Germany.[62] |
| **November** | Signed a MoU with the Paris-based fuel cell taxi fleet Société du Taxi Electrique Parisien (STEP) to supply 60 additional Hyundai ix35 FCEVs to its existing fleet of five.[63] |

Table 7: Hyundai Activities and Announcements

| Toyota's Key Activities and Announcements – 2016 | |
|---|---|
| **January** | Showed the FCV Plus concept vehicle at the 2016 Consumer Electronics Show. The FCV Plus is capable of generating electricity from hydrogen stored outside the vehicle.[64] |
| **April** | Stated the company will introduce a new model FCEV with a lower cost before the 2020 Tokyo Olympics.[65]<br>Toyota and partner Air Liquide announced the initial four locations of the 12 public hydrogen fueling stations planned for the northeastern U.S. (Hartford, Connecticut; Braintree, Massachusetts; Mansfield, Massachusetts; and Bronx, New York).[66] |
| **July** | Announced a project to produce hydrogen from solar power at Toyota Motor Kyushu's Miyata Plant to fuel a stationary fuel cell and forklifts. Toyota plans full adoption of hydrogen power at the Mirai plant in Toyota, Aichi Prefecture, by 2020.[67] |
| **September** | Reduced the Mirai's California lease price for 2017 model and lowered the down payment on the three-year lease. The purchase price of the car remains the same.[68]<br>Added stationary hydrogen-powered fuel cells to the energy management facility at its Honsha Plant in Toyota City, Aichi Prefecture, Japan.[69] |
| **October** | Won the inaugural e-Rallye Monte Carlo, a car race for zero-emission vehicles, using a Mirai FCEV entered by Toyota France.[70] |
| **November** | Announced the expansion of R&D facilities at Toyota Motor Engineering & Manufacturing (China) Co., Ltd. Toyota plans FCEV demonstration tests in China and will conduct research for the introduction of electric vehicles into the China market.[71] |

Table 8.: Toyota Activities and Announcements

Other major automakers have also discussed their fuel cell activities and plans for their commercial FCEV rollout. Table 9 highlights 2016 announcements and activities by these automakers.

| Examples of Activities and Announcements by Other Automakers – 2016 | |
|---|---|
| **Audi** | Debuted the h-tron Quattro concept FCEV at the North American International Auto Show in Detroit, which includes the fifth generation of fuel cell technology from Audi and Volkswagen.[72]<br>Announced it will lead Volkswagen Group's FCEV development efforts.[73]<br>Received regulatory permission to purchase excess renewable energy to power the electrolytic production of hydrogen at its Werlte, Germany, plant.[74]<br>Issued purchase orders to Ballard Power Systems to accelerate certain key development activities under the current long-term HyMotion Technology Solutions program that Volkswagen Group has with Ballard.[75] |
| **BMW** | Stated the company will enter the fuel cell market early in the next decade, starting with very small production runs.[76] |
| **Daimler** | Confirmed it will offer a new production FCEV in 2017, the GLC F-Cell, which includes a battery that recharges via a wall plug. The vehicle features a fuel cell stack co-developed with Ford.[77] |
| **GM** | Revealed the Chevrolet Colorado ZH2 FCEV, developed with the U.S. Army Tank Automotive Research, Development and Engineering Center. The vehicle is built on a stretched midsize pickup chassis with a specially modified suspension that helps the vehicle navigate rough terrain. The Colorado ZH2 features an Exportable Power Take-Off unit that allows the fuel cell to power activity away from the vehicle. In 2017, the vehicle will be turned over to the Army for a year of field testing.[78] |
| **GreenGT** | The Green GT H2 fuel cell-powered race car completed laps of the Le Mans circuit during a break in the official qualifying session. The car's two 200-kW fuel cells were provided by Symbio FCell.[79] |
| **Kia** | Confirmed that the company is developing a FCEV.[80] |
| **Nissan** | Showed a prototype vehicle in Brazil equipped with a SOFC-powered system that runs on bio-ethanol. Nissan says the technology may be ready for vehicles in 2020.[81]<br>Nissan Motor Manufacturing, Ceres Power and M-Solv formed a consortium to develop a compact, on-board SOFC stack for electric vehicle range extension.[82] |
| **Pininfarina** | Revealed its H2 Speed hydrogen-powered sports car concept at the Geneva Motor Show. Pininfarina plans to build a limited run of 10 vehicles.[83] |
| **RiverSimple** | Unveiled its production-ready Rasa prototype FCEV two-seat vehicle that has an 8.5-kW fuel cell stack and a 1.5-kg tank of hydrogen. RiverSimple is partnering with Monmouthshire County Council (Wales) for a 12-month trial of the Rasa.[84] |

Table 9: Activities and Announcements by Other Automakers

Several European fuel cell manufacturers announced vehicle-related projects and sales.

PowerCell Sweden supplied its S3 fuel cell system to Coop (Switzerland) for use in a distribution truck and received an order for its S2 fuel cell stack from a Chinese company for use as a hydrogen-based Range Extender for electrified passenger cars.[85, 86]

SFC Energy announced that Volkswagen uses its EFOY Pro fuel cell, which supplies energy for more than five days, to power video systems on board its Amarok Pickup vehicle.[87]

Arcola Energy sold or leased 32 of Renault's Kangoo ZE-H2 electric vans, equipped with a Symbio FCell fuel cell range extender, to U.K. customers.[88]

With FCEVs now commercially available from three major automakers, and more FCEVs planned by these and other automakers, national and state governments are implementing policies and funding programs that will bring FCEVs to their roadways and develop hydrogen fueling stations to support them. Table 10 highlights recent policies and funding.

| Examples of Policies Supporting FCEVs and Hydrogen Infrastructure Development – 2016 | |
|---|---|
| **U.S.** | California added funding to the Clean Vehicle Rebate Project, which includes rebates for the purchase or lease of FCEVs and increased clean vehicle rebate funding for low income consumers.<br>Connecticut raised its FCEV rebate incentive.<br>New York implemented a Zero Emission Vehicle (ZEV) rebate program that includes FCEVs.<br>Colorado implemented rules regarding hydrogen fueling to ready for implementation.<br>Nebraska launched a vehicle rebate program that includes incentives for FCEVs.<br>Pennsylvania announced a funding opportunity that includes hydrogen-powered vehicles and refueling infrastructure.<br>Washington exempted clean alternative fuel vehicles, including hydrogen powered vehicles, from sales and use taxes.[88b] |
| **Europe** | The U.K. Fuel Cell Electric Vehicle Fleet Support Scheme was launched, allowing local authorities, health trusts, police, fire departments, and private companies to bid for funding to add FCEVs to their fleets.[89]<br>The U.K. announced a £35 million (US$45 million) investment to encourage the use of ultra-low-emissions cars and motorbikes that includes £2 million (US$2.6 million) to encourage businesses to adopt FCEVs.[90]<br>The six-year, €100 million (US$106 million), pan-European H2ME 2 project was launched, adding 1,230 FCEVs and 20 hydrogen refueling stations to the European network to test the ability of electrolyzer-based hydrogen refueling stations to help balance the electrical grid.[91]<br>The three-year INSPIRE program will validate the next generation of automotive fuel cell stack technology, supported by a €7.0 million (US$7.4 million) grant from Europe's Fuel Cells and Hydrogen Joint Undertaking (FCH JU).[92] |
| **Asia** | Japan's Ministry of Trade and Industry announced a plan calling for 40,000 FCEVs by 2020, 200,000 by 2025, and 800,000 by 2030; 160 hydrogen stations by fiscal year (FY) 2020 and 320 by FY 2025; and research and development to reduce fuel cell costs to reduce the prices of FCEVs. The plan also calls for the government to relax regulations to permit self-service hydrogen stations, allowing station operators to generate a profit without relying on government subsidies.[93]<br>South Korea's government announced a goal to export 14,000 hydrogen-fueled light-duty vehicles by 2020, with another 10,000 units targeted for buses and taxis. The government plans to increase subsidies and tax incentives for hydrogen vehicles and has set a goal of 100 hydrogen fueling stations in operation by 2020.[94]<br>The United Nations Development Program, China's Ministry of Science and Technology and Ministry of Finance, and several Chinese provincial governments launched a project to use FCEVs for passenger transport, logistics, and mail services.[95]<br>China's central economic planning agency released a draft of a carbon credit plan proposal to encourage Chinese automakers to produce green vehicles, including FCEVs.[96]<br>The Chinese city of Wuhan set up a 200 million yuan (US$28.9 million) fund to develop an automotive FCEV industry.[97] |

Table 10. Policies Supporting Fuel Cell Vehicles and Hydrogen Infrastructure Development

## Buses

Fuel cell bus technology is maturing beyond the demonstration phase, with Hyundai, New Flyer, Toyota, and Wrightbus announcing plans to put fuel cell buses into commercial production (Table 11). A number of fuel cell bus projects were announced worldwide, including deployments in the U.S., Europe, and China.

| Examples of Fuel Cell Bus Commercialization Plans – 2016 | |
|---|---|
| **Hyundai** | Will introduce buses with platforms designed specifically for fuel cells at the end of 2017.[98] Korea's Finance Minister announced the government intends to replace about 26,000 compressed natural gas (CNG) buses nationwide with Hyundai fuel cell buses, replacing 2,000 annually. Existing stations will be allowed to set up hydrogen fuel pumps.[99] |
| **New Flyer of America** | Will offer the Xcelsior® XHE60 heavy-duty, articulated fuel cell transit bus to customers in the U.S. and Canada following evaluation at the Federal Transit Administration's Altoona, Pennsylvania, testing center and completion of a 22-month demonstration with California's AC Transit.[100] |
| **Toyota** | Will sell fuel cell buses under the Toyota brand from early 2017. More than 100 Toyota FC Buses will be placed in service ahead of the Tokyo 2020 Olympic and Paralympic Games. The FC Bus has an external power supply capability that can be used as a power source during disasters.[101] |
| **Wrightbus** | Plans to begin full-scale production of its fuel cell bus in 2017, offering both single- and double-decker models.[102] |

Table 11: Fuel Cell Bus Commercialization Plans

Fuel cell bus deployments grew, with more buses serving transit riders in California, Michigan, and Ohio. Table 12 summarizes these and other fuel cell bus projects and deployments at transit agencies worldwide.

| Examples of Fuel Cell Bus Development and Deployment Announcements – 2016 | |
|---|---|
| **Flint Mass Transportation Authority (MTA) – Michigan** | MTA unveiled a Proterra fuel cell bus in October that will operate in a one-year pilot program. The bus is the result of a collaborative partnership under FTA's National Fuel Cell Bus Program.[103] |
| **Orange County Transportation Authority (OCTA) – California** | OCTA's first fuel cell bus went into service in May. The bus has a Ballard FCveloCity® fuel cell module to provide primary power and will initially fuel at the University of California, Irvine. Funding for the project was provided by FTA's National Fuel Cell Bus Program.[104] |
| **Stark Area Regional Transit Agency (SARTA) – Ohio** | The first of 10 fuel cell buses was unveiled by SARTA in April. The initial bus will operate for 12 months at Ohio State University's Columbus campus and the university's Center for Automotive Research will collect data on the vehicle's performance in everyday use. The second of the 10 buses will be delivered to SARTA following federally-mandated testing of new buses at FTA's Altoona testing facility. All 10 buses will join SARTA's fleet in 2017 and 2018, making SARTA the third largest operator of fuel cell buses in the United States and the largest outside of California.[105] |
| **Rotterdamse Elektrische Tram (RET) – The Netherlands** | Rotterdam's public transport agency, RET, signed a contract with Belgian bus manufacturer Van Hool for two fuel cell buses.[106] |

| | |
|---|---|
| **Transport for London and Birmingham City Council – U.K.** | In July, Birmingham City Council and Transport for London jointly won £2.8 million (US$3.6 million) from the government's low emission bus scheme for 42 fuel cell buses.[107] London's mayor announced in November that the city would deploy the world's first hydrogen double-decker bus in 2017. At least 20 additional hydrogen buses will be delivered as part of a £10 million (US$12.9 million) project partly funded by the European Union (EU), with Transport for London providing at least £5 million (US$6.4 million) in funding.[108] |
| **U.K.** | Arcola Energy and its partners received a £150,000 (US$194,800) competitive award from the Niche Vehicle Network to assist in the development a range-extended fuel cell bus.[109] |
| **Rigas Satiksme – Latvia and other European locations** | Ballard announced a long-term sales agreement with Solaris Bus & Coach for fuel cell modules to support deployment of Solaris fuel cell buses in Europe. An initial order was placed for 10 FCveloCity®-HD fuel cell modules, with deliveries to start in 2017. The 85-kW fuel cell modules will be deployed as range extenders in Solaris Trollino model low-floor trolley buses that will be operated by Rigas Satiksme, the transport operator in Riga, Latvia.[110] |
| **City of Yunfu, China** | Ballard announced the commissioning and deployment of 10 fuel cell-powered buses in Yunfu, China.[111] |
| **Shenzhen UpPower Technology Co., Ltd – China** | Ballard received a purchase order from bus systems integrator UpPowerTech for the supply of 10 FCveloCity®-MD 30-kW fuel cell power modules for buses that will be operated in Nanning, China. |
| **Foshan Sanshui Guohong Public Transit Co. Ltd. – China** | Ballard announced the deployment of 12 fuel cell-powered buses in Foshan, China, operated by Foshan Sanshui Guohong Public Transit Co. Ltd.[112] |
| **China** | Hydrogenics announced a strategic partnership agreement with SinoHytec, a Chinese vehicle propulsion technology company, for the delivery of fuel cells in China. The agreement includes fuel cell power module co-development and supply of power systems to be integrated into buses and trucks from several leading Chinese vehicle manufacturers.[113]<br>Hydrogenics also received an order from one of its integrator partners in China for fuel cells to power buses throughout a number of major metropolitan areas.[114] |

Table 12. Fuel Cell Bus Deployment and Development Announcements

In addition, fuel cell buses are showing improved fuel economy over diesel buses. An analysis by the DOE found fuel cell economy to be 1.4 times higher than diesel.[115] The Aberdeen, Scotland, Hydrogen Bus Project reported that its 10-bus fleet is almost four times more fuel efficient than diesel buses.[116]

## Trucks

Several major truck manufacturers - Kenworth, Peterbilt, and Scania - are participating in fuel cell projects.

Kenworth was awarded funding for two low emissions projects, one hybrid-electric and the other fuel cell, to be deployed in Kenworth T680 Day Cabs used as drayage tractors in Southern California ports. The fuel cell project is funded at $1.9 million by the DOE's EERE, with California's South Coast Air Quality Management District (SCAQMD) as the prime applicant.[117]

Truck manufacturer Scania and Norway's largest convenience goods wholesaler, Asko, through a research project partly funded by the Norwegian government, will test three, nine-ton, three-axle distribution trucks equipped with a fuel cell powertrain.[118]

Canada's Loop Energy received a CAD$7.5 million ($US5.4 million) award in March from Sustainable Development Technology Canada to install its eFlow fuel cell powertrain in a Peterbilt Class 8 truck and will deliver it for customer testing.[119] Loop Energy also announced a collaboration agreement with Hunan CRRC Times Electric Vehicle Co., Ltd.[120]

In addition:

Nikola™ Motor Company unveiled its zero-emission Nikola One™ electric, class-8 semi-truck in December, powered by a custom-built 800-V fuel cell, for the U.S. and Canadian markets.[121]

PowerCell Sweden delivered a prototype, 100-kW PowerCell S3 fuel cell stack to the European transport company for application in a distribution truck.[122]

ULEMCo delivered two converted hydrogen/diesel dual-fuel trash trucks to the Fife Council in Scotland.[123]

## Material Handling Equipment

In 2016, the material handling market expanded outside of the U.S., with sales of several hundred fuel cell to companies for deployment in France:

The Carrefour Group purchased more than 150 Plug Power GenDrive® fuel cell units for class-2 and -3 electric lift trucks at its new distribution center in Vendin-lès-Béthune.[124]

FM Logistic placed an order for GenDrive® units for use on pallet jacks and reach trucks at its logistics facility in Neuville-aux-Bois.[125]

Prelocentre added 40 fuel cell-powered lift trucks at its Saint-Cyr-en-Val facility in 2016 and plans to add 60 more in 2017.[126]

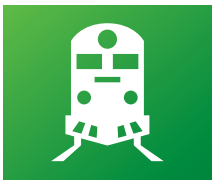
Interest is also growing in China. Plug Power, along with China's Zhangjiagang Furui Special Equipment Co. and a Chinese industrial vehicle manufacturer, are developing new fuel cell applications and fueling solutions for the country's industrial electric vehicle market. Two prototype delivery trucks, equipped with Plug Power's ProGen fuel cell engines, will be delivered in 2017.[127]

Plug Power also reported that a U.S. customer, Newark Farmers Market, placed a third order for 96 next-generation GenDrive® fuel cell units. Newark Farmers Market now operates an all fuel cell truck fleet with 240 GenDrive® units.[128]

Several additional fuel cell material handling projects were also announced in 2016:

Finnish cargo and load-handling company Kalmar and Swedish steel manufacturer SSAB are developing a fuel cell-powered, medium-range forklift truck that will be demonstrated at SSAB's production facility.[129]

Mining company Impala Platinum Limited, working with the University of the Western Cape, unveiled its prototype fuel cell forklift and a refueling station at its Impala Refining Services site outside of Johannesburg, South Africa. An earlier prototype fuel cell forklift has been in operation since October 2015 at the Impala's Base Metals Refinery.[130]



## Rail

Hydrogen-powered rail, or hydrail, became a reality in 2016 when Alstom debuted its Coradia iLint fuel cell-powered train at the InnoTrans 2016 trade show in Berlin. The train provides performance comparable to conventional trains, reaching almost 90 miles per hour (mph), traveling up to 500 miles per tank of hydrogen, and accommodating 300 passengers. Hydrogenics provided the fuel cell system. The first Coradia iLint will begin operation in December 2017 on the regional line in Lower Saxony, Germany. Four additional German states have signed letters of intent with Alstom for 60 trains.[131] In addition, the German state of Schleswig-Holstein announced its plan to electrify its entire rail network by 2025, using hydrail and hydrogen generated from excess off-peak wind turbine energy and other zero-carbon sources.[132]

Ballard Power Systems signed a MoU with Latvian Railways (LDZ) and locomotive manufacturer CZ Loko for production of a fuel cell locomotive, using a rebuilt CME3 shunting locomotive.60 Ballard also supplied its FCveloCity®-HD power module for an urban tram designed and built by Tangshan Railway Vehicle Co. Ltd. for use in China's Hebei Province.[134]

TIG/m Modern Street Railways delivered Oranjestad, Aruba's fourth fuel cell-powered streetcar.[135]

## Other Motive Applications

In 2016, several major companies made announcements about their interest in fuel cell power.

EasyJet, a British airliner, revealed its plan to trial fuel cells to deliver aircraft power while taxiing to and from runways, potentially saving up to 50,000 tonnes of fuel annually.[136]

Royal Caribbean Cruises announced it will begin testing fuel cell technology on an existing Oasis-class ship in 2017 and will run progressively larger fuel cell projects in the next several years. Royal Caribbean's new Icon class of ships will be powered by liquefied natural gas (LNG) and will use fuel cells as a supplemental power source, and two new Icon vessels using LNG and fuel cells will be delivered in 2022 and 2024.[137]

Insitu, a Boeing Company subsidiary, received prototype PEM fuel cell modules from Protonex, a subsidiary of Ballard Power Systems, for use in a hybrid-electric version of its ScanEagle unmanned aerial vehicle (UAV).[138]

PowerCell Sweden received an order from Swiss Hydrogen for two S3 prototype fuel cell stacks for a new ship that will include hydrogen production from solar electricity, hydrogen storage, and two 30-kW fuel cells.[139]

The German Aerospace Center (DLR) and its partners successfully flew a fuel cell-powered, four-seat plane for 10 minutes at Stuttgart Airport. Hydrogenics fuel cells supplied the in-flight power, while batteries were used for take-off and landing.[140]

General Motors, the Office of Naval Research, and the U.S. Naval Research Laboratory announced a cooperative effort to incorporate automotive hydrogen fuel cell systems into the next generation of Navy unmanned undersea vehicles (UUVs).[141]

U.S. Naval Research Laboratory researchers completed the first flight of the Ion Tiger UAV using a new 5-kW fuel cell built in-house.[142]

Two commercial, fuel cell-powered UAV products were also announced in 2016: HYWINGS by H3 Dynamics (Singapore) and H-Drone by Micro Multi Copters Aero Technology (China).[143]

# Hydrogen

This section reviews 2016 announcements about new and planned hydrogen fueling stations worldwide. It also covers activities involving hydrogen production and supply, hydrogen energy storage, and power-to-gas.

## Hydrogen Infrastructure/Supply

More than 40 hydrogen stations were opened worldwide in 2016, with 16 of the new stations located in California. Additionally, a private station was opened in Ohio and a demonstration station was opened in Washington, D.C.

Internationally, Belgium, Denmark, Germany, Japan, South Korea, Sweden, Switzerland, and the U.K. all welcomed new stations. A mobile fueler was also deployed in Australia. Cumulatively, the hydrogen stations were supplied by a dozen different companies.

In addition, plans for more than 160 new hydrogen stations were announced. These stations will be located in California, Connecticut, Massachusetts, New York, France, Japan, Latvia, Norway, Sweden, and the U.K.[144]

Table 13 highlights hydrogen infrastructure and supply announcements in 2016.

| Examples of Hydrogen Infrastructure and Supply Announcements - 2016 | |
|---|---|
| **AGA Industrial Gases** | Opened Sweden's fourth hydrogen station, located in Sandvik.[145] |
| **Air Liquide** | Announced the locations of public hydrogen stations in northeast U.S. – Hartford, Connecticut; Braintree and Mansfield, Massachusetts; and Bronx, New York. The stations, which will open in 2017, are the first of 12 public stations planned by Air Liquide and Toyota Motor Sales USA in the Northeast U.S.[146]<br>Opened a public hydrogen station in Zaventem, Belgium, and opened a public hydrogen refueling station at Hyundai Motor's European headquarters in Offenbach, Germany.[147, 148] |
| **Air Products** | Opened public hydrogen refueling stations in Los Angeles and Santa Monica, California.[149] The company was also selected to convert Shell's Torrance, California, hydrogen station from non-retail to retail status.[150]<br>In Canton, Ohio, deployed a hydrogen fueling station dispensing unit, 9,000 gallon hydrogen tank, and hydrogen compression and storage technologies to support SARTA fuel cell buses.[151]<br>In Japan, with partner Nippon Steel & Sumikin Pipeline & Engineering Co. Ltd. opened their first retail hydrogen fueling station in Tokyo.[152] |
| **Areva H2Gen** | Will build a hydrogen station for the Braley company (France) to support a fleet of Kangoo ZE-H2 light duty vehicles.[153] |
| **FirstElement Fuel** | Opened public hydrogen refueling stations in Campbell, Coalinga, Costa Mesa, Hayward, La Canada Flintridge, Lake Forest, Long Beach, Los Angeles, Mill Valley, San Jose, Santa Barbara, Saratoga, South San Francisco, and Truckee, California.[154] |

| | |
|---|---|
| **H2 Energy AG** | Opened a hydrogen fueling station at the Swiss Federal Laboratories for Materials Science and Technology research campus in Dübendorf. The new pump is used by experimental vehicles and privately-owned FCEVs.[154]<br>Opened a hydrogen station in Hunzenschwil, Switzerland, for retailer Coop that will supply fuel for 12 cars, a truck, and a trailer.[155] |
| **Hyundai Motor Group** | Opened Korea's first integrated station in Gwangju that fuels FCEVs and charges battery vehicles.[156] |
| **Idemitsu Kosan** | Opened a commercial hydrogen station located on the grounds of Narita International Airport in Narita, Japan.[157] |
| **ITM Power** | Opened London's second public access hydrogen station at the Centre of Engineering Manufacturing Excellence, in Rainham, East London. The station uses a solar photovoltaic array to generate renewable hydrogen on-site.[158]<br>Opened a public hydrogen station in London at the National Physical Laboratory, Teddington.[159]<br>Completed a 700 bar upgrade to the M1 Rotherham hydrogen station.[160]<br>Awarded €5.06 million ($5.3 million) to deploy three new dual pressure hydrogen refueling stations to expand the national refueling network in the U.K.[161]<br>Granted planning permission to construct a hydrogen refueling station at the Shell Filling Station, Beaconsfield. The station will be the first in the U.K. to be integrated into the existing fuel forecourt, with the hydrogen dispenser located under the main fuel forecourt canopy.[162]<br>Announced the sale of an integrated hydrogen refueling station with on-site generation to Hydrogène de France, for deployment in France.[163]<br>Signed contracts for the sale of hydrogen fuel at £10/kg (US$12.99/kg), with: Anglo American, Arcola Energy, Arval, Commercial Group, Europcar UK, and Hyundai Motor UK.[164] |
| **Iwatani** | Opened hydrogen stations in Otsu and Kofu, and at Kansai International Airport.[165, 166, 167]<br>Opened a new station in Osaka Morinomiya for both FCEV and fuel cell bus fueling.[168]<br>Launched a mobile hydrogen station in Honmachi.[169]<br>Along with Seven-Eleven Japan Co., Ltd., will open Japan's first hydrogen stations linked to convenience stores, located in Ikegami in Tokyo's Ota-ku and Kariya-shi in Aichi Prefecture.[170]<br>Plans to expand its network of hydrogen stations to roughly 30 by March 2017, spending up to ¥3 billion (US$26.5 million) to build 10 new facilities.[171] |
| **Linde AG** | Unveiled a high-pressure hydrogen refueler located on the back of a Hino heavy truck that will fuel three Toyota Mirais in Australia.[172]<br>Opened a hydrogen station, in partnership with Daimler and Total, at the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) in Ulm, Germany.[173]<br>Opened a hydrogen station, along with Daimler and OMV Deutschland, at an OMV service station Metzingen, Germany.[174]<br>Received an Operations and Maintenance contract for $220,000 from the California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP).[175]<br>Exclusive hydrogen supplier at the 2016 Shell Eco-marathon.[176] |
| **McPhy Energy** | Will deploy a 350 bar refueling station in Rouen, France. The station will open in 2017 and be operated by GNVERT.[176b] |
| **Nel Hydrogen Fueling** | Opened hydrogen stations in Aarhus, Kolding, and Esbjerg, Denmark.[177, 178, 179]<br>Awarded a contract by Uno-X Hydrogen AS to build a hydrogen station in Bergen, Norway.[180]<br>Awarded a contract by SIA Hydrogenis for the delivery of the new dual capability H2Station® for car and bus refueling in Riga, Latvia.[181]<br>Awarded a contract by grocery wholesaler Asko for the delivery of a new solar-powered hydrogen production facility and fueling station in Trondheim, Norway, to fuel Asko forklifts and delivery trucks.[182]<br>Signed an agreement with Mariestad, Sweden, for an H2Station® located in the Gothenburg-Stockholm, Sweden, corridor, completing the last leg in connecting the Scandinavian capitals.[183]<br>Announced a repeat-order for two new CAR-200 hydrogen stations from an undisclosed European customer. Delivery is planned in 2017.[184] |
| **Proton OnSite** | Launched a Washington, D.C., demonstration hydrogen station, developed by the DOE and the U.S. Department of Interior's National Park Service and supported by partners SunHydro and Air Products. The station incorporates electrolysis technology advancements and produces ~30 kg of hydrogen daily.[185] |

| | |
|---|---|
| **Uno-X Hydrogen AS** | Announced an agreement with partner Nel ASA to build a network of 20 hydrogen refueling stations in Norway by 2020.[186]<br>Awarded a grant of NOK 19.8 million (US$2.26 million) from the Norwegian public enterprise Enova SF for a hydrogen production facility and two hydrogen fueling stations in Bergen.[187]<br>Will build a hydrogen station with on-site hydrogen production co-located with Powerhouse Kjørbo, in Sandvika, Norway.[187b] |

Table 13: Hydrogen Infrastructure and Supply Announcements

Several partnerships were announced during the year to explore hydrogen fueling projects. These include:

A collaboration between Air Products and the National Institute of Clean-and-Low-Carbon Energy (NICE) to jointly explore hydrogen fueling projects in China.[188]

A partnership to supply HyGear's hydrogen generation technology to Plug Power fuel cell customers globally.[189]

Additionally:

Japan's Ministry of the Environment launched a project to deploy renewable hydrogen fueling stations at 100 sites by FY2019, initially at government buildings, then expanding to shopping malls and other locations. The ministry will cover 75 percent of the cost if the FCEVs are used as official vehicles.[190]

Japan's Mitsui Sumitomo Insurance and Aioi Nissay Dowa Insurance Co. began selling a new insurance plan addressing the operational risk of hydrogen stations.[191]

Air Liquide Advanced Technologies U.S. LLC and Air Products signed a license agreement, allowing Air Liquide to use Air Products' patented technology incorporated in the Society of Automotive Engineers (SAE) J2601 hydrogen fueling protocol.[192]

Several new hydrogen fueling products debuted on the market:

Nel ASA – H2Station® CAR-200193

Greenlight Innovation Corp. – a 700- and 350-bar dispenser[194]

Codes and standards organizations published or revised several standards and protocols regarding hydrogen fueling stations, helping to support greater deployment of these stations. These include:

Canadian Standards Association (CSA) standard HGV 4.9, which is the first standard published for an entire hydrogen fueling station, addressing minimum requirements for installation, operation, and maintenance of hydrogen fueling stations for light-duty vehicles.

TS 19880-1 for hydrogen fueling stations, published by the International Organization for Standardization (ISO), recommending minimum design characteristics for safety and, where appropriate, for performance of public and non-public fueling stations that dispense gaseous hydrogen to fuel cell vehicles.

A significant revision was made to SAE J2601 Fueling Protocols for Light Duty and Medium Duty Gaseous Hydrogen Surface Vehicles to incorporate the formula-based protocol, published in Appendix H of SAE J2601_2014 as a development protocol, into the main body of SAE J2601.

CSA/ANSI HGV 4.3 Test methods for hydrogen fueling parameter evaluation, replaces the 2012 edition and establishes the test method, criteria, and apparatus to evaluate a field installed hydrogen fueling station dispensing system as it relates to achieving the protocols specified in SAE J2601 and the SAE J2799 Standard, Hydrogen Surface Vehicle to Station Communications Hardware and Software with light duty vehicle hydrogen storage systems less than 248.6 liters.

## Hydrogen Production

Many projects are planned or under way in 2016 to produce renewable hydrogen for motive and other applications.

Hydrogenics and StratosFuel announced a strategic partnership to build a 2.5-MW Zero Impact Production Hydrogen facility, which will use Hydrogenics' PEM electrolyzers to convert wind and solar energy into renewable hydrogen.[195]

Nel ASA announced a Letter of Intent to establish a joint-venture with a global solar company to develop a solar-driven hydrogen production plant in California.[196]

Toshiba, Tohoku Electric Power, and Iwatani will invest several billion yen to build a hydrogen plant in Japan's Fukushima Prefecture that will produce 900 tons of hydrogen annually, using electrolysis powered by nearby solar and wind resources. The plant will also supply hydrogen for the 2020 Tokyo Olympic and Paralympic Games.[197]

Kanagawa Prefectural Government, the municipal governments of the cities of Yokohama and Kawasaki, and three private sector companies including Toyota, supported by Japan's Ministry of the Environment, launched a project to develop a low-carbon hydrogen supply chain to power forklifts. Hydrogen will be produced via electrolysis using electricity generated at the Yokohama City Wind Power Plant and transported by truck to four sites: a factory, a vegetable and fruit market, and two warehouses.[198]

Toshiba received an order from East Japan Railway Company for its H2One™ system, which will be installed at Musashi-Mizonokuchi Station in Kawasaki City. The system is comprised of a solar photovoltaic generation unit, a storage battery unit, water electrolysis unit, hydrogen tanks, and a fuel cell. Another H2One™ system began operation at the Henn na Hotel, in the Huis Ten Bosch theme park in Nagasaki, Japan.

Kawasaki Heavy Industries and Royal Dutch Shell partnered to produce hydrogen from low-quality brown coal in Australia and ship the liquefied hydrogen in special vessels to Japan. Kawasaki Heavy Industries and Iwatani are partnering with the city of Kobe to establish a hydrogen import terminal to open in 2020.[199]

Neoen and Megawatt Capital are investing AU$55 million (US$39 million) in partnership with Siemens and Hyundai to establish a 1.25-MW hydrogen electrolyzer to produce renewable hydrogen in Australia. The initiative will include a refueling station and an initial fleet of 20 Hyundai FCEVs in Canberra.[200]

Hydrogenics was selected to supply a 1-MW PEM electrolyzer to the Danish HyBalance project, where hydrogen will be produced via wind power and supplied to five Air Liquide hydrogen fueling stations and used to support grid balancing.[201]

Nel ASA announced a Letter of Intent (LOI) with Meløy Energi AS and Meløy Næringsutvikling AS to establish Glomfjord Hydrogen AS for the potential development of a large-scale, low-cost hydrogen production facility in Meløy, Norway, to supply hydrogen to ferries.[202]

PowerCell Sweden and Cortus Energy AB signed a LOI to jointly develop and market electricity from biomass to be used to generate renewable hydrogen for fuel cells.[203]

In addition:

Proton OnSite signed a contract with Guangdong Synergy Hydrogen Power Technology Co. to provide 13, MW-scale PEM electrolyzers to support fuel cell-powered buses in Foshan and Yunfu, China.[204]

ITM Power announced the sale of a 1-MW electrolyzer to ZEAG Energie AG, which will be housed in a specially constructed building at the German Aerospace Center.[205]

Hydrogen Engine Center, Inc. signed a Technology License Agreement granting Malaysia's Off Grid Sdn. Bhd. rights to manufacture certain intellectual properties, including the TINA Renewable Energy Carbon-Free Hydrogen Electrolysis System and H2Gen Electrical Generation Sets, in Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei, Cambodia, Laos, Myanmar, and Vietnam.[206]

Kawasaki Heavy Industries and Obayashi Corp., in conjunction with Kansai Electric Power Co. and the city of Kobe, Japan, will use a mix of 80 percent natural gas and 20 percent hydrogen in specialized 1-MW, turbine-driven power plant to provide power to a 60-acre area housing hotels and the Kobe International Conference Center. Heat from the power generation will be used for hot water at hotels and other facilities.[206b]

## Power-to-Gas and Energy Storage

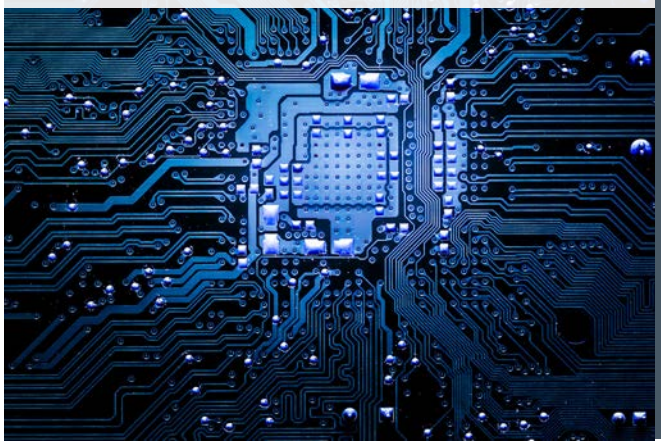
Excess renewable energy produced in off-grid areas can be stored by creating hydrogen, mitigating the intermittencies inherent in sources such as wind and solar power. Hydrogen gas is produced by electrolysis using the excess renewable energy and can be used onsite, stored for later use, or injected into natural gas pipelines. This process is also known as Power-to-Gas (P2G). Table 14 highlights P2G projects announced in 2016.

Also in 2016, the DOE and its national laboratories launched the H2@Scale initiative to assess the potential for widespread production and utilization of hydrogen for diverse applications across sectors and to enable intermittent renewables and grid services, as well as a value stream for baseload plant operations (e.g. nuclear). In addition to workshops and analysis activities, FCTO validated the use of electrolyzers with real time grid simulations and demonstrated sub-second response times.

| Examples of Power-to-Gas (P2G) Demonstration Projects Announced in 2016 | |
|---|---|
| **Australia** | Gas and electricity companies Union Fenosa and ActewAGL Distribution, along with Australian National University, will investigate P2G efficiencies and feasibility for the Australian Capital Territory (ACT) gas network and establish a pilot testing facility to produce renewable hydrogen.[207] |
| **California** | Engineers at the University of California, Irvine, implemented the first hydrogen pipeline injection project in the U.S. using P2G equipment adjacent to the campus's power plant. Southern California Gas Co. provided funding for the project and Proton OnSite supplied the electrolyzer.[208] |
| **California** | A live demonstration of a 50-kW, reversible SOFC system was held at Naval Base Ventura County, in Port Hueneme, California. The system produces, compresses, and stores renewable hydrogen.[209] |
| **Canada** | The Canadian government awarded Hydrogenics CA$2.5 million (US$1.8 million) in Sustainable Development Technology Canada funding to build a 5-MW, P2G demonstration plant.[209b] |
| **Germany** | ITM Power announced the award of €915,650 (US$974,000) through the HPEM2GAS project funded by the FCH JU. The three-year project will further develop ITM's electrolyzers, culminating in a six-month P2G field test with Stadtwerke Emden of an advanced 180-kW PEM electrolyzer.[210] BP and Uniper will jointly examine the potential use of P2G technology in the refining process and the technical and economic feasibility of locating a P2G plant at BP's Lingen, Germany, refinery.[211] |
| **Japan** | Yamanashi Prefecture, Toray Industries, Tokyo Electric Power Company Holdings, and Takaoka Toko Co. Ltd. will jointly develop a P2G system that will produce, store, and use 450,000 Nm3 of hydrogen annually using solar electricity.[212] |
| **Scotland** | The FCH-JU Project BIG HIT was launched in the Orkney Islands to create hydrogen from two wind turbines and tidal turbines, using 1.5 MW of PEM electrolysis. The hydrogen will be used to heat two local schools and transported by sea to Kirkwall in five hydrogen trailers, where it will fuel a 75-kW Proton OnSite fuel cell system that will supply heat and power to the harbor buildings (a marina and three ferries when docked) and a refueling station that will serve a fleet of 10 FCEVs.[213] |
| **Thailand** | Hydrogenics' 1-MW PEM HyLyzer™ electrolyzer will convert excess wind energy to hydrogen during off-peak hours. The stored hydrogen will be used by Hydrogenics' HyPM™ fuel cell to generate 300 kW of electricity, as needed, for the Electricity Generation Authority of Thailand's Learning Center in Nakhon Ratchasima Province, Thailand.[214] |
| **U.K.** | ITM Power, as part of the HyDeploy consortium, will supply a 0.5-MW electrolyzer for a demonstration of the use of blended hydrogen in the U.K. gas grid.[215] |

Table 14: Power-to-Gas (P2G) Demonstration Projects

# Stationary Power



Stationary power covers any application in which the fuel cells are operated at a fixed location for primary power, backup power, or CHP. The stationary sector includes both large-scale (200 kW and higher) and small-scale (up to 200 kW) and a wide range of markets including retail, data centers, residential, telecommunications, and many more. This section is organized by large scale, small scale, and backup and remote power.

## Large-Scale Stationary Power

The three major U.S. fuel cell manufacturers, Bloom Energy, Doosan Fuel Cell America, Inc. and FuelCell Energy, Inc., announced collective sales, installations, or agreements for almost 100 MW of fuel cell systems in 2016 (publicly disclosed). Half of these fuel cell systems (75 MW) will be shipped to South Korea to produce power for the electric grid.

Additional large stationary projects were announced around the world, including a 50 MW fuel cell project planned by Korea Power Electric Corp. to be delivered by an unnamed manufacturer.

### Bloom Energy

SOFC manufacturer Bloom Energy entered into a strategic alliance with Southern Company and its subsidiary PowerSecure, Inc. for project investment and joint technology development. PowerSecure will acquire about 50 MW of Bloom Energy Servers® that will be integrated with its smart storage solutions. The companies report that The Home Depot is expected to deploy the joint Bloom fuel cell and PowerSecure storage solution at approximately 60 stores, in addition to the 140 stores already operating Bloom Energy Servers, and another customer will deploy 30 MW of distributed power supporting hospitals, clinics, and administrative centers.[216]

GAIL (India) Ltd. and Bloom Energy announced a new partnership and signed a MoU to deploy natural gas-based fuel cell technology to generate electricity in India.[217]

In addition, Bloom Energy announced installations for both new and returning customers (Table 15).

**Examples of Bloom Energy Publicly Disclosed Installations and Orders - 2016**

| Customer | Power | Details |
|---|---|---|
| Apple | 4 MW | Revealed that its new campus in Cupertino, California, will be powered by 100 percent renewable energy, generated by 4 MW of baseload biogas-fueled fuel cells and 16 MW of rooftop solar, and supported by battery storage.[218] |
| Morgan Stanley | 750 kW | Installed a 750-kW fuel cell system at its global headquarters in New York City that will provide approximately 6 million kilowatt-hours of clean electricity annually.[219] This is Morgan Stanley's second fuel cell system – the first was installed at its Purchase, New York headquarters. |
| IKEA | N/a | Installed biogas-powered fuel cell systems at three additional IKEA retail stores in California (Costa Mesa, Covina, and East Palo Alto). The fourth retail store (San Diego) will start its fuel cell system in 2017.[220] IKEA also announced that a fuel cell system will be installed at its New Haven, Connecticut retail site.[221] |

| | | |
|---|---|---|
| **Legrand North America** | 500 kW | Installed a 500-kW fuel cell system to supply 88 percent of the power for LeGrand's 263,000-square-foot campus in West Hartford, Connecticut.[222] |

Table 15: Bloom Energy Orders and Installations

### Doosan Fuel Cell America

Doosan Fuel Cell America is a Connecticut-based manufacturer of PAFC systems. In 2016, Doosan Fuel Cell America had sales that included orders for more than 75 MW of fuel cell power plants from South Korean utility customers (Table 16).

Doosan Fuel Cell America's parent company, South Korea's Doosan Group, is building a fuel cell production plant in Iksan, Jeollabuk-do Province, Korea, that is anticipated to open in April 2017 with a production capacity of 60 to 70 MW annually. The company is also expanding in Connecticut and is additionally increasing investment in fuel cell R&D.[223]

Doosan Group has also been designated a host company for a fuel cell development project supported by South Korea's Ministry of Knowledge Economy. Over the next five years, the ministry will support the domestic development of technology for MW-class fuel cells designed for operation in conjunction with power plants, feeding carbon dioxide produced at thermal power plants as oxidant, and re-using waste heat generated from the fuel cells at desalination plants.[224]

| Examples of Doosan Fuel Cell America Publicly Disclosed Installations and Orders – 2016 | | |
|---|---|---|
| **Customer** | **Power** | **Details** |
| **California State University, San Marcos** | 440 kW | Installed a PureCell® Model 400 fuel cell system, operated through a PPA with BioFuels Energy, LLC.[225] |
| **Implats** | 8 MW | Implats and its partners will install an 8-MW fuel cell system, financed under a 20-year PPA, at its South African Platinum Refinery by January 2018.[226] |
| **Korea Hydro & Nuclear Power Co., Ltd., Samchully Machinery Co., Ltd., and Incheon Total Energy Co.** | 39.6 MW | Doosan Engineering & Construction was selected as a preferred bidder to build a 39.6-MW fuel cell power plant in Incheon's Songdo business district.[227] |
| **Korea Western Power Co., Ltd. and Serveone** | 5 MW | Doosan will supply 11 PureCell® Model 400 fuel cells (5 MW) to Korea Western Power and Serveone to generate clean electricity for nearly 3,000 homes in the Seoul suburb of Incheon.[228] |
| **Petroconergy Co., Ltd.** | N/a | Selected by Petroconergy to provide 14 PureCell systems for the Baegot Fuel Cell Project in Ansan, a suburb of Seoul, Korea. |
| **Samsung C&T Corp. and KHNP** | 30.8 MW | Will manufacture and ship 70 fuel cells that will produce 30.8 MW of energy and heat to power to a new residential complex in Busan. KHNP and the city of Busan will share ownership of the fuel cells.[229] |

Table 16: Doosan Fuel Cell American Orders and Installations

### FuelCell Energy

FuelCell Energy is a Connecticut-based manufacturer of commercial MCFC for commercial use. The company is also developing power plant carbon capture technology using its carbonate fuel cells, is advancing its SOFC development, and is developing two methods of onsite hydrogen production – tri-generation (production of power, heat, and hydrogen using its carbonate fuel cells) and solid oxide electrolysis cells (SOEC).

FuelCell Energy announced several MCFC system installations in 2016, at both commercial facilities (Connecticut, Germany) and at wastewater treatment plants (California). These installations, totaling more than 10 MW, are highlighted in Table 17.

The following projects were announced in 2016:

An agreement with Exxon Mobil Corp. to pursue power plant carbon dioxide capture through a new application of carbonate fuel cells.[230] The companies announced that a 2.8-MW DFC3000® fuel cell system will be installed at Alabama Power's James M. Barry Electric Generating Station, through a project with DOE.[231]

A contract with Alberta Innovates for an engineering study on a fuel cell carbon capture application at a heavy oil thermal facility Saskatchewan, Canada. A second potential site, the Scotford bitumen upgrading facility in Alberta, Canada, which is part of the Shell-operated Athabasca Oil Sands Project (a joint venture between Shell Canada Energy, Chevron Canada Corp, and Marathon Oil Canada Corp.) will be evaluated as part of the engineering study.[232]

A contract with Cenovus Energy Inc. for preliminary front-end design and engineering for siting a fuel cell system to capture CO2 from flue gas. The system would be located at an existing 14-MW natural gas-fired co-generation facility at the University of Calgary in Alberta, Canada.[233]

FuelCell Energy was also awarded two DOE projects:

A $3 million cost-share contract to advance the commercialization of SOFC technology, building on an earlier contract to install and operate a 400-kW SOFC system.[234]

$3 million cost-share contract to design an energy storage solution that converts power during periods of low demand into hydrogen through high efficiency electrolysis using SOEC.[235]

The California Air Resources Board gave FuelCell Energy contingent certification under the Low Carbon Fuel Standard (LCFS) for a prospective pathway for its renewable hydrogen generation solution using fuel cells at wastewater treatment facilities (tri-generation). Each kilogram of renewable hydrogen supplied for vehicle fueling would be eligible for an LCFS credit that can be sold or traded to offset carbon-intensive petroleum fuel usage. Final certification is expected following a period of operation and review of performance data of a MW-class tri-generation system powered by biogas.[236]

| Examples of FuelCell Energy and Installations in 2016 | | |
|---|---|---|
| **Customer** | **Power** | **Details** |
| **E.ON Connecting Energies GmbH** | N/a | FuelCell Energy Solutions GmbH (Germany) sold a CHP fuel cell power plant to E.ON Connecting Energies GmbH that will be installed in Germany at a commercial location.[237] |
| **FRIATEC AG** | 1.4 MW | A 1.4-MW fuel cell, jointly installed by E.ON and FuelCell Energy, started operation at FRIATEC AG in Mannheim, Germany.[238] |
| **Pfizer Inc.** | 5.6 MW | Installed two 2.8-MW DFC3000® fuel cell power plants at Pfizer's Groton, Connecticut, campus to supply a portion of the 160-acre R&D facility's electricity needs. Pfizer is purchasing power and steam under a 20-year PPA.[239] |
| **Riverside Regional Water Quality Control Plant** | N/a | Installed a MW-class fuel cell power plant that utilizes approximately two thirds of the biogas generated during wastewater treatment to provide about one-third of the power needs for the facility. Riverside pays for power produced by the fuel cells.[240] |
| **Tulare Wastewater Treatment Facility** | 2.8 MW | Executed a PPA with Tulare to install a 2.8-MW CHP DFC® power plant at the Tulare Waste Water Treatment Facility. FuelCell Energy will install, operate and maintain the power plant, selling power and heat to the city.[241] |

Table 17. FuelCell Energy Orders and Installations Announced

### Additional Companies

Additional large stationary fuel cell announcements in 2016 included more than 50 MW of projects in Germany, Japan, and South Korea (Table 18).

| Examples of Additional Publicly Disclosed Large Stationary Fuel Cell Announcements – 2016 | | |
|---|---|---|
| **Manufacturer** | **Power** | **Details** |
| **AFC Energy** | 240 kW | In February, AFC Energy announced the completion of the final stage of the trial of its 240-kW KORE fuel cell system in Stade, Germany, that began in August 2015 and ended with more than 1.3 MW of power generated and sold into the German grid.[242] In November, AFC announced the completion of Generation 2 of the KORE fuel cell system, which has extended stack life and improved ability to accept lower grade hydrogen.[243] |
| **Fuji Electric Co., Ltd.** | 840 kW | Started an 840-kW PAFC power plant at a water purification plant in Tochigi Prefecture, Japan. The fuel cells are powered by biogas produced during the wastewater treatment process. Electricity generated by the fuel cells can be sold through the central government's feed-in tariff program for a period of 20 years.[244] |
| **Unknown** | 50 MW | KEPCO announced that its six power generation units will invest 3.7 trillion won (US$3.0 billion) to develop renewable energy sources, with 17.9 percent of the funds (approximately US$546 million) invested in fuel cells. A 50-MW fuel cell project will utilize byproduct hydrogen from Hanwha Total Petrochemical Co.'s Daesan, South Korea, factory. [245] The fuel cell manufacturer has not been announced. |
| **Mitsubishi-Hitachi Power Systems, Ltd.** | 200 kW | Started demonstration testing at Tokyo Gas Co.'s Senju Techno Station of its hybrid power-generation system integrating a SOFC stack and a micro gas turbine. The demo is supported under a program of Japan's New Energy and Industrial Technology Development Organization (NEDO).[246] |

Table 18: Additional Large Stationary Fuel Cell Announcements

## Small-Scale Stationary

Smaller stationary fuel cells (100 kW or less) were deployed in 2016 for primary and backup power. Most of the small stationary fuel cells deployed in 2016 were residential Ene-Farm units – Japan's residential micro-CHP fuel cell system – with about 40,000 sold in 2016. Ene-Farm branded systems are manufactured by several companies (Panasonic, Toshiba, and others) and offer capacity ranges from 0.3 kW to 1 kW. Cumulative sales of Ene-Farm surpassed 180,500 units in September 2016.

Additional small stationary fuel cell orders and announcements are summarized in Table 19.

| Examples of Small Stationary Fuel Cell Orders and Installations – 2016 | |
|---|---|
| **Ballard Power Systems** | Telecom operator Telia Company AB installed a 72-hour FCgen®-H2PM fuel cell backup power system on the first "Forsterket ekom" project site in Norway. |
| **Ceres Power** | Will conduct trials of its prototype residential fuel cell system with British Gas as part of the EU's ene.field demonstration.[247] |
| **Dominovas Energy Corp.** | Introduced its first RUBICON™ 50-kW SOFC system in Johannesburg, South Africa.[248] |
| **GenCell** | Installed a 5-kW G5 fuel cell backup power system at an Israeli municipality's emergency operating center.[249] |
| **PowerCell Sweden AB** | Received an order for a prototype S2 fuel cell from a global customer to provide micro-CHP for housing in the South Korea.[250] |
| **Proton Power Systems PLC** | Signed a seven-year agreement with an unnamed German company for fuel cell emergency power units for use in the Bavaria region of Germany.[251]<br>Received a €1.8 million order (US$1.9 million) for fuel cell emergency power units.[252] |
| **Toshiba Corp.** | Received an order for its 100-kW fuel cell to Tokuyama Corp. to supply power to a swimming pool managed by one of its group companies. Hot water produced through the generation process will help heat the hot water boilers in the shower rooms.[253]<br>Toyota Motor Corp. began operating a Toshiba fuel cell system operational in September at its Honsha Plant (Japan).[254] |

Table 19: Small Stationary Fuel Cell Orders and Installations

Several companies also announced collaborations for the development and deployment of commercial small stationary fuel cell systems. These include:

An agreement between Ceres Power and a global original equipment manufacturer to develop and launch a multi-kW combined heat and power (CHP) product using its SteelCell fuel cell technology.[255]

A collaboration between Ceres Power, Cummins, the University of Connecticut, and PNNL to develop a 5-kW SOFC modular system for data centers that can scale up to 100 kW.[256]

The FCH JU will provide almost €34 million (US$36 million) to fund the PACE initiative, which aims to ensure that the European residential micro-CHP sector moves toward mass market commercialization. By 2018, the four participating European manufacturers (Bosch, SOLIDpower S.p.a., Vaillant and Viessmann) will collectively deploy 2,650 fuel cells with customers and monitor them for an extended period.[257]

In addition, the German Ministry of Economics started a new program to support fuel cell heating systems, funded by the National Innovation Program Hydrogen and Fuel Cell Technology (NIP). Owners of both new and existing buildings are eligible for subsidies for the purchase of a fuel cell heating system ranging from 0.25 kW to 5 kW. The funding amount is tiered according to the system's electrical output.[258]

# Portable and Off-Grid Power

Fuel cells can power diverse portable applications, serving as a charger for cell phones; powering lighting towers, sensors, surveillance equipment, oil and gas pipeline equipment, and rail-side signaling; delivering power to soldiers in the field; and supplying power for aircraft, marine, and recreational vehicle applications. Portable fuel cell orders and announcements in 2016 are highlighted in Table 20.

| Examples of Portable Fuel Cell Orders and Announcements – 2016 | |
|---|---|
| **Company** | **Details** |
| **Altergy Systems** | Donated several fuel cell powered generators to light the streets and stages of Super Bowl City where performers played during Super Bowl 50. |
| **BOC** | Created the Ecolite-TH2 LED fuel cell-powered lighting tower powered by its HYMERA® fuel cell technology with Linde's GENIE® hydrogen cylinder. Engineering services company Costain has been using the lighting tower while working on part of a British railway upgrade plan. |
| **myFC** | myFC's JAQ-system, including the PowerCards, passed International Electrotechnical Commission (IEC) tests and received the European Conformité Européene (CE) approval.[259]<br>Signed an agreement with telecom service provider du, giving du exclusive rights to sell, distribute and market the JAQ fuel cell charger throughout the United Arab Emirates.[260]<br>Delivered the first JAQ order for testing and evaluating to Tre, a mobile phone operator in Sweden.[261]<br>Received an order for 1,000 fuel cell chargers and charging cards from Chinese mobile phone distributor, Telling Communication.[262] |
| **SFC Energy** | Received an order from a major international defense force for the delivery of its UFC Underground Fuel Cell to power sensor and surveillance equipment.[263]<br>Delivered an initial order from the Belgian Special Forces of its man portable SFC Energy Network, which includes the JENNY 600S fuel cell, for use in soldier devices.[264]<br>Received an order from Oneberry Technologies in Singapore for several hundred units of EFOY PRO 2400 to provide off grid power to security and surveillance equipment in Singapore.[265]<br>Received an order from its French distributor, AG Systems, for the delivery of 58 EFOY® Pro fuel cells to be installed by French system integrator 4G Technology, to power surveillance systems of the French Ministry of Defense.[266]<br>Installed its EFOY Pro Hybrid Cabinet with an integrated 500 W fuel cell to power off-grid pipeline applications for a company in the Western Canadian oil and gas sector.[267]<br>Received a design order for the development of a power supply for galley systems operated onboard commercial airplanes.[268]<br>Announced that WCCTV (U.K.) selected the EFOY Pro Fuel cell to power their Rapid Deployment CCTV Tower mobile surveillance systems utilized by local authorities, police forces, housing associations, train operating companies, construction companies, utilities providers and contractors.[269] |
| **Ultra Electronics USSI** | Follow-on contract for a large volume of P250i fuel cell systems from RedHawk Energy Systems, LLC, to provide 24/7 extended run back-up power for railway signals and crossings.[270] |

Table 20: Portable Fuel Cell Orders and Announcements

# Components

Several companies announced fuel cell and hydrogen-related supply agreements, many for motive applications. These are highlighted in Table 21.

| Examples of Component Supply Announcements – 2016 | |
|---|---|
| **BOC** | Agreement to provide infrastructure, including hydrogen compressors, and dispensers, for ITM Power's new electrolyzer-based hydrogen stations.[271] |
| **TM4** | Selected by Ballard Power Systems to supply electric motors and inverters to be coupled with new compressor units.[272] |
| **Bridgestone Corp.** | Announced that its ECOPIA tires are featured as standard equipment on the new Honda Clarity FCEV.[273] |
| **Tanaka Holdings Co., Ltd.** | Announced that platinum electrode fuel cells catalysts, manufactured by Tanaka Kikinzoku Kogyo K.K. are used in Honda's Clarity FCEV.[274] |
| **Hexagon Lincoln** | Subsidiary Hexagon Lincoln was selected by Daimler AG to supply new generation (Type 4) compressed hydrogen gas cylinders for Daimler`s next generation FCEV, the Mercedes-Benz GLC F-CELL.[275] |
| **Impact Coatings** | Signed a strategic partnership agreement with China Hydrogen Energy to deliver high volume coating equipment and Ceramic MaxPhase™ material that will be integrated into buses, trucks, and cars from several leading Chinese vehicle manufacturers.[276] |
| **IMPCO Technologies Inc.** | Announced that its 350 bar Hydrogen Integrated Tank Valve Regulator (H-ITVR) has been selected by a fuel cell system manufacturer.[277] |
| **W.L. Gore & Associates** | Announced its membrane was chosen for use in the fuel cell stack of Honda's new Clarity FCEV.[278] |

Table 21. Component Supply Announcements

In addition:

Plug Power Inc. announced that its modular ProGen fuel cell engine technology, which had only been available in its own products, will be available to global customers for use in mobility and stationary fuel cell systems.[279]

Isondo Precious Metals announced that it had entered into an agreement with the Chemours™ Company, acquiring the rights to manufacture, use, market, and sell licensed fuel cell components worldwide.[280]

Bennett Pump's hydrogen fuel dispensers received third-party regulatory type certification from MET Laboratories.[281]

A collaboration was announced between Nedstack, Africa Green Energy Technologies, and Hydrogen South Africa (HySA) Systems for the South African manufacture of PEM fuel cell components and systems.[282]

# Reports and Studies

The U.S. Department of Energy released State of the States: Fuel Cells in America 2016, which provides a comprehensive analysis of state activities supporting fuel cell and hydrogen technology, profiles of leading states, and a catalog of recent installations, policies, funding, and deployments around the country.

Argonne National Laboratory published the Cradle-to-Grave Lifecycle Analysis of U.S. Light-Duty Vehicle-Fuel Pathways: A Greenhouse Gas Emissions and Economic Assessment of Current (2015) and Future (2025–2030) Technologies.

The National Renewable Energy Laboratory released three fuel cell bus reports: Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fifth Report, Foothill Transit Battery Electric Bus Demonstration Results, and Fuel Cell Buses in U.S. Transit Fleets: Current Status 2016.

Sandia National Laboratories published Feasibility of the SF-BREEZE: a Zero Emission, Hydrogen Fuel Cell High Speed Passenger Ferry, a study funded by the U.S. Department of Transportation's Maritime Administration.

The California Governor's office released the 2016 ZEV Action Plan, which outlines progress to date and identifies new actions that state agencies will take in pursuit of the milestones in the Governor's Executive Order to place 1.5 million ZEVs in California by 2025.

The California Air Resources Board (ARB) published the 2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development.

The California Fuel Cell Partnership's (CaFCP) published a Medium & Heavy-Duty Fuel Cell Electric Truck Action Plan for California, recommending steps that government and industry can take to establish a foundation for fuel cell truck development.

The Fuel Cell and Hydrogen and Energy Association published the 2016 State Policy Wrap Up Report: Fuel Cells and Hydrogen which profiles state-level legislation, policies, and incentives that impacted the fuel cell and hydrogen industry during calendar year 2016.

Clean Hydrogen in European Cities (CHIC) released its final project report, Fuel Cell Electric Buses: A Proven Zero Emission Solution. Key Facts, Results, Recommendations, as a guide for cities and bus fleet operators to understand the reality of operating fuel cell buses today, based on the learnings and results of the CHIC project.

# Appendix: Federal Funding Awards – 2016

## U.S. DEPARTMENT OF ENERGY (DOE)

| DOE – Small Business Innovation Research (SBIR)/ Small Business Technology Transfer (STTR) (Fiscal Year 2016)<br>Award amounts are rounded | | | |
|---|---|---|---|
| **Recipient** | **Amount** | **Program** | **Details** |
| **Phase I Release 1 Awards – SBIR (January)** | | | |
| Amsen Technologies LLC<br>Arizona | $0.15 million | Basic Energy Sciences (BES) | Will develop a new low-cost, proton-conducting membrane for intermediate-temperature fuel cells based on a novel composite approach, which encompasses both the development of new, highly proton-conducting ionomers and the integration of an innovative membrane support. |
| NanoSonic, Inc.<br>Virginia | $0.15 million | | Will develop and demonstrate high-temperature, hydrocarbon-based membranes that meet the chemical, thermal, and mechanical properties necessary to qualify for the demanding environments that exist within a fuel cell vehicle's lifetime. |
| NEI Corp.<br>New Jersey | $0.15 million | | Novel nanocomposite polymer electrolyte membranes for fuel cells. |
| PolarOnyx, Inc.<br>California | $0.14 million | | Direct 3D femtosecond laser manufacturing of SOFC. |
| **Phase I Release 1 Awards – STTR (January)** | | | |
| Giner, Inc.<br>Massachusetts | $0.15 million | BES | Will develop novel hydrocarbon-based ionomeric membranes with high conductivity and mechanical strength for use in high-temperature fuel cell applications. |
| **Phase I Release 2 Awards – SBIR (??)** | | | |
| General Engineering & Research LLC<br>California | $0.15 million | EERE | Development of commercially available low cost magnetocaloric materials for magnetic refrigeration systems would enable a highly efficient and economical solution to support hydrogen liquefaction infrastructure. |
| Nanohmics, Inc.<br>Texas | $0.15 million | | A new class of magnetic refrigerants will improve our national hydrogen storage infrastructure and lead to a clean, non-ozone-depleting refrigerant for commercial applications. |
| Nexceris LLC<br>Ohio | $0.15 million | | Will develop superior catalysts to convert still gases (methane and ethane) to hydrogen, which can be used for deep desulfurization for ultra-low-sulfur diesel and gasoline in refineries. |
| Precision Combustion, Inc.<br>Connecticut | $0.15 million | | High efficiency reformer for hydrogen production. |

| Phase II Release 1 Awards – SBIR (March) | | | |
|---|---|---|---|
| pH Matter LLC<br>Ohio | $1 million | BES | Will demonstrate low-cost stationary energy storage applications by improving the components of regenerative fuel cell systems. |
| Proton OnSite<br>Connecticut | $1 million | | Will work toward commercializing the first alkaline membrane-based water electrolysis product through the use of high efficiency, non-noble metal electrocatalysts and other advanced, low cost materials. |
| Sonata LLC<br>Connecticut | $1 million | | Novel surface-functionalized powders for SOFCs. |
| Southwest Sciences, Inc.<br>New Mexico | $1 million | | Will develop a laser-based instrument for the detection of hydrogen contaminants at fuel stations to prevent fouling of vehicular fuel cells. |
| Structured Materials Industries, Inc.<br>New Jersey | $1 million | | Fluidized bed production of surface functionalized powders for SOFC cathodes. |
| **Phase II Release 1 Awards – STTR (March)** | | | |
| Sustainable Innovations LLC<br>Connecticut | $1 million | EERE | Teamed with the University of Connecticut to develop an innovative multi-channel hydrogen fuel quality monitor to detect multiple impurities at low levels in hydrogen. |
| **Phase II Release 2 Awards – SBIR (??)** | | | |
| Advanced Cooling Technologies<br>Pennsylvania | $1 million | EERE | Will develop and demonstrate an efficient non-catalytic plasma-based fuel reformer for converting inexpensive natural gas to hydrogen-rich syngas. Partners include Drexel Plasma Institute, Air Products and Chemicals, Gas Technology Institute and FuelCell Energy. |
| Mainstream Engineering Corporation<br>Florida | $1 million | | Cross-polarized near-UV/Vis detector for in-line quality control of PEM materials. |
| Precision Combustion, Inc.<br>Connecticut | $1 million | | Onboard implementation of an ultra-compact hydrogen generator for efficiency and emissions benefits in internal combustion engines. |

| DOE FCTO – H2 Refuel H-Prize (January) | |
|---|---|
| **Recipient** | **Details** |
| SimpleFuel™ team:<br>Ivys Energy Solutions<br>Massachusetts McPhy Energy North America<br>Massachusetts<br>PDC Machines<br>Pennsylvania | DOE's FCTO and the Hydrogen Education Foundation (HEF) announced the SimpleFuel™ team as the finalist for the $1 million H2 Refuel H-Prize competition. The SimpleFuel™ Home Vehicle Refueling Appliance is a fully integrated hydrogen generation, compression, storage and dispensing system capable of delivering up to 5 kg/day of hydrogen to vehicles at pressures up to 700 bar. After testing and analysis of the prototype system, the SimpleFuel™ team was announced the H2 Refuel H-Prize winner in January 2017.[283] |

| DOE – Climate Action Champion Initiative Awards (May) | | |
|---|---|---|
| **Recipient** | **Amount** | **Details** |
| City of San Francisco<br>California | $4.75 million award for fuel cell projects (two awardees) | For comprehensive training and educational activities to harmonize local regulations and building codes to ease siting and construction of hydrogen stations, while reducing the cost and complexity of FCEVs for the community through regional education and outreach. |
| Strategic Analysis, Inc.<br>Virginia | | To analyze the cost competitiveness for a range of hydrogen and fuel cell technologies, including those used in hydrogen infrastructure relevant to San Francisco and other projects. |

| DOE – Technology Commercialization Fund (TCF) Awards (June)<br>Award amounts are rounded | | |
|---|---|---|
| **Recipient** | **Amount** | **Details** |
| Lawrence Berkeley National Laboratory<br>California | $0.15 million | Flame-powered SOFC generators. |
| Lawrence Livermore National Laboratory<br>California | $0.43 million | Cryo-compressed hydrogen tank technology in an internal combustion engine application. Joint project with GoTek Energy, Inc. (California). |
| Brookhaven National Laboratory<br>New York | $0.1 million | Direct fabrication of fuel cell electrodes by electrodeposition of high-performance core-shell catalysts. |
| Brookhaven National Laboratory<br>New York | $0.1 million | Nitride-stabilized Pt core-shell electrocatalysts for fuel cell cathodes. |
| Pacific Northwest National Laboratory<br>Washington | $0.17 million | Glass seals with low or zero boria content for high temperature SOFC applications. Joint project with LG Fuel Cell Systems, Inc. (Ohio). |
| National Energy Technology Laboratory<br>Oregon, West Virginia, Pennsylvania | $0.25 million | Cooperative development of National Energy Technology Laboratory (NETL) electrode engineering process for SOFC commercialization. Joint project with Acumentrics (Massachusetts). |

| DOE EERE-– Hydrogen Fuel Technologies (July) | | |
|---|---|---|
| **Recipient** | **Amount** | **Details** |
| Sandia National Laboratories<br>California, New Mexico | Up to $14 million | Will investigate and demonstrate a laboratory scale two-stage metal hydride-based hydrogen gas compressor. |
| FuelCell Energy<br>Connecticut | | Will demonstrate the potential of solid oxide electrolysis cell (SOEC) systems to produce hydrogen at a cost of $2 per kilogram. |
| Giner, Inc.<br>Massachusetts | | Will demonstrate a cost-effective method for compressing hydrogen while eliminating the need for mechanical compressors which can have significant reliability issues. |
| Giner, Inc.<br>Massachusetts | | Will develop high temperature alkaline water electrolyzers with improved electrical efficiency at a reduced cost. |
| Vencore Services and Solutions<br>Virginia | | Will apply integrated cryogenic tank approaches and novel technologies developed by NASA's Cryogenics Test Laboratory to build an integrated subscale insulation system prototype demonstrating the heat leak targets applicable to cryogenic hydrogen storage tanks for commercially produced fuel cell powered automobiles. |
| Greenway Energy, LLC<br>South Carolina | | To overcome the reliability issues of mechanical compression and the efficiency challenges of solid state compression technologies, this project combines two novel technologies, Electrochemical Hydrogen Compression and Metal Hydride Compression, into a new hybrid solid state hydrogen compressor. |
| Ceratec Inc.<br>California | | Will improve the performance of durable materials for high temperature water splitting stack technology through the development of a novel cell architecture that introduces macro-features to provide mechanical support of a thin electrolyte, and micro-features of the electrodes to lower polarization losses. |

| | | |
|---|---|---|
| Ford Motor Company<br>Michigan | Approx. $6 million | Ford Motor Company will use the funding to develop a uniquely American fuel cell catalyst production process that will result in lower cost, higher purity, more active and durable catalysts. |
| Los Alamos National Laboratory<br>New Mexico | | |

**DOE – Fuel Cell Consortium for Performance and Durability (FC-PAD) Awards and Hydrogen Materials-Advanced Research Consortium (HyMARC) Awards (July)**

| Recipient | Amount | Program | Details |
|---|---|---|---|
| 3M<br>Minnesota | More than $13 million | FC-PAD | Integrating novel electrode ionomers with nanostructured thin film low-platinum group metal electrocatalysts in powder form to develop an improved cathode-coated membrane and electrode structure in the fuel cell. |
| Argonne National Laboratory<br>Illinois | | HyMARC | To develop a new class of hydrogen storage materials composed of nanoparticles of complex metal hydrides wrapped in sheets of graphene for improved onboard hydrogen storage. |
| General Motors<br>Michigan | | FC-PAD | To employ both experimental and modeling approaches to study the effect of operating conditions on degradation, as well as the ways membranes fail, to improve overall performance of low-platinum group metal electrodes. |
| Pennsylvania State University | | HyMARC | To investigate the synthesis of high-surface area boron-doped polymeric sorbent materials for hydrogen storage, with improved performance for onboard hydrogen storage. |
| University of Hawaii, Manoa | | HyMARC | To investigate magnesium boride etherates as reversible hydrogen storage materials with properties that are vastly improved over un-solvated magnesium boride. |
| University of Missouri, St. Louis | | HyMARC | To use a novel approach to stabilize unstable metal hydrides with sufficient storage capacities, and render reversible stable high capacity hydrides that are irreversible in the bulk, resulting in a high-capacity material with kinetics suitable for onboard hydrogen storage. |
| UTRC<br>Connecticut | | FC-PAD | To develop more durable cell electrodes to lower the cost and improve the performance of PEM fuel cells. |
| Vanderbilt University<br>Tennessee | | FC-PAD | Testing a new technique to electrospin low-platinum group metal electrocatalysts with a proton-conducting binder to improve durability and performance of fuel cell electrodes. |

**DOE – Department of Fossil Energy SOFC Program - SOFC Core Technology and Innovative Concepts Funding Awards (August)**
**Award amounts are rounded**

| Recipient | Amount | Details |
|---|---|---|
| Auburn University<br>Alabama | $0.17 million | Chromium vapor sensor for monitoring SOFC systems. |
| University of Connecticut | $0.50 million | Development of chromium and sulfur getter for SOFC systems. |

| | | |
|---|---|---|
| Mohawk Innovative Technology<br>New York<br>FuelCell Energy<br>Connecticut | $0.60 million | High temperature anode recycle blower for SOFC. |
| General Electric<br>New York<br>SUNY Polytechnic Institute<br>New York<br>GE-Fuel Cells LLC<br>New York | $0.54 million | Highly selective and stable multivariable gas sensors for enhanced robustness and reliability of SOFC operation. |
| West Virginia University<br>Oak Ridge National Laboratory<br>Tennessee<br>Carpenter Technology Corp.<br>Pennsylvania<br>FuelCell Energy<br>Connecticut | $0.37 million | Minimizing CR-evaporation from balance of plant components by utilizing cost-effective alumina-forming austenitic steels. |
| Redox Power Systems<br>Maryland<br>University of Maryland Research Center and Center for Advanced Life Cycle Engineering | $3 million | Robust SOFC stacks for affordable and reliable distributed generation power systems. |
| FuelCell Energy<br>Connecticut | $3 million | Transformational SOFC technology. |
| Cummins Power Generation<br>Minnesota | $3.9 million | Metal-supported ceria electrolyte-based SOFC stack for scalable, low cost, high efficiency and robust stationary power systems. |
| Acumentrics<br>Massachusetts<br>University of South Carolina | $2.4 million | Performance and reliability advancements in a durable low temperature tubular SOFC. |

| DOE – Small Business Vouchers Pilot Program Awards<br>Award amounts are rounded | | |
|---|---|---|
| **Recipient** | **Amount** | **Details** |
| **Round 1 (March)** | | |
| Amsen Technologies LLC<br>Arizona | $0.15 million | Testing new fuel cell membrane designs with potential to reduce manufacturing cost. Working with Los Alamos National Laboratory (LANL). |
| Altergy Systems, Inc.<br>California | $0.15 million | Improving fuel cell efficiency through modeling thermal performance. Working with Sandia National Laboratories. |

| | | |
|---|---|---|
| **KWJ Engineering California** | $0.2 million | Improving hydrogen sensors to enhance fuel infrastructure safety. Working with Los Alamos National Laboratory and the National Renewable Energy Laboratory (NREL). |
| **Element One, Inc. Colorado** | $0.1 million | Development and testing of low-cost hydrogen leak detection. Working with NREL. |
| **Sustainable Innovations LLC Connecticut** | $0.2 million | Developing a fuel contamination detector to ensure quality at hydrogen refueling stations. Working with LANL. |
| **Midwest Energy Group Michigan, Indiana** | $0.1 million | Development and evaluation of perfluorinated electrolytes. Working with NREL. |
| **TreadStone Technologies New Jersey** | $0.1 million | Novel, lower-cost coating for fuel cell metal bipolar plates. Working with LANL and Oak Ridge National Laboratory (ORNL). |
| **Round 2 (August)** | | |
| **Altergy Systems California** | $0.1 million | Will leverage lab expertise to reduce cost and improve performance in its proprietary fuel cell products, observing the fabrication of membrane electrode assemblies (MEAs) at NREL using nonproprietary methods and evaluating MEAs made at NREL with Extended Thin Film Electrocatalyst Structures (ETFECS)-based catalyst to reduce costs and/or enhance durability. |
| **American Fuel Cell New York** | $0.2 million | Will optimize deposition techniques for roll-to-roll direct coating of electrodes on anode and cathode gas diffusion media leading to improved quality and lower-cost manufacturing of various fuel cell applications. Working with ORNL. |
| **Garmor Inc. Florida** | $0.1 million | Will utilize existing bipolar plate (BPP) technology to develop a BPP that will include composites that will be used to form micro-structured surface features to improve BPP surface tension for water droplet control. Working with NREL. |
| **Ion Power Delaware** | $0.26 million | Will work with the labs analyze various performance improvement mechanisms to improve the impact on durability of its fuel cell catalyst layer. Working with LANL. |
| **Nanosonic Virginia** | N/A | Will receive assistance in the preparation of MEA and performance of fuel cell testing and validation of new anion exchange fuel cell membranes. Working with LANL. |
| **Nzyme2HC Texas** | $0.1 million | Nzyme2HC has novel acellular biological approach, combining minimal electric current, bacterially-extricated hydrogenase, and industrial waste as the feedstocks/production materials. Will build end-to-end bench prototype at NREL to test/metric. |
| **Oorja Fuel Cells California** | $0.1 million | Will determine the efficacy and performance of MEAs of Oorja's direct methanol cells (DMFC) operating conditions and compare the results with the commercially available MEA used in Oorja DMFC power system. Working with NREL. |
| **Opus 12 California** | $0.2 million | Will receive assistance to develop a computational model of ions, products, reactants, and water transport within their PEM electrolyzer for the co-electrolysis of water and carbon dioxide to make syngas. Working with Lawrence Berkeley National Laboratory. |
| **Pajarito Powder, LLC New Mexico** | $0.2 million | Will work to improve electrode structures and to implement electrode manufacturing techniques that allow full catalyst utilization. Working with LANL. |
| **Proton Energy Systems Connecticut** | $0.2 million | Will develop and validate a small-scale advanced power converter to provide a pathway for reduced capital cost and improved efficiency of Proton's M-series electrolyzer that offers a carbon-free source of hydrogen fuel or process gas. Working with NREL. |

| DOE – Advanced Research Projects Agency-Energy (ARPA-E) Integration and Optimization of Novel Ion-Conducting Solids (IONICS) Program Awards (September)<br>Award amounts are rounded | | |
|---|---|---|
| **Recipient** | **Amount** | **Details** |
| 3M Company<br>Minnesota | $2.3 million | Will develop and evaluate polymer membranes based on hydrocarbon chains. |
| Rensselaer Polytechnic Institute<br>New York | $2.2 million | Will develop a highly conductive, chemically stable, and mechanically durable membrane using a hydrocarbon-based polymer backbone. |
| University of Delaware | $1.8 million | Will create a series of polymer-based alkaline exchange membranes. |

| DOE – BIRD (Binational Industrial Research and Development) Energy Grant (November) | |
|---|---|
| **Recipient** | **Details** |
| Pajarito Powder<br>New Mexico | The funding pairs Parajito Powder with Technion, the Israel Institute of Technology's Hydrogen Technologies Research Laboratory, to further lower the cost of catalysts. BIRD Energy is the implementation of a cooperation agreement between EERE, the Israel Ministry of National Infrastructure, Energy and Water Resources (MIEW), and the BIRD Foundation.[284] |

| DOE – ARPA-E Renewable Energy to Fuels Through Utilization of Energy-Dense Liquids (REFUEL) Program Awards (December)<br>Award amounts are rounded | | |
|---|---|---|
| **Recipient** | **Amount** | **Details** |
| Bettergy Corporation<br>New York | $1.5 million | Will develop a system to "crack," or break apart, ammonia, releasing pure hydrogen, using a non-precious metal catalyst at temperatures below 450 °C. |
| FuelCell Energy<br>Connecticut | $3.1 million | Will build a reversible electrochemical cell to produce ammonia from nitrogen and water or consume ammonia to generate electricity. |
| Gas Technology Institute<br>Illinois | $2.3 million | Will develop a reactor to synthesize dimethyl ether (DME), which functions as a substitute for diesel fuel, from carbon dioxide, hydrogen, and electricity. |
| Giner, Inc.<br>Massachusetts | $1.5 million | Will develop a variety of novel catalyst materials to improve nitrogen reduction reactions. |
| Materials and Systems Research<br>Utah | $1.1 million | Will develop a new solid oxide fuel cell design that generates power directly from ammonia at temperatures under 650 °C. The team also seeks to develop a manufacturing process for the cell. |
| Molecule Works, Inc.<br>Washington | $2.3 million | Will develop a modular reactor for producing ammonia using air and water at low temperatures. |
| Opus 12, Inc.<br>California | $1.9 million | Will develop a device to facilitate the direct conversion of carbon dioxide to ethanol using a PEM electrolyzer system. |
| RTI International<br>North Carolina | $3.1 million | Will build an improved Haber-Bosch ammonia synthesis system with an innovative process design to respond to changes in available power, making it ideal for intermittent renewable energy resources. |
| SAFCell, Inc.<br>California | $3.0 million | Will build a high-pressure stack designed to generate hydrogen from ammonia, purify it, and pressurize it in a single device, greatly simplifying the infrastructure required to deliver and store hydrogen fuel to refueling stations. |

| | | |
|---|---|---|
| Storagenergy Technologies, Inc. Utah | $2.5 million | Will build a system to produce ammonia from water and nitrogen. |
| Sustainable Innovations Connecticut | $1.2 million | Will use electricity, carbon dioxide, and hydrogen to create a sustainable and economic source of dimethyl ether (DME), a fuel similar to diesel. If successful offer compelling applications for fuel cell vehicles. |
| University of Delaware | $2.5 million | Will build a fuel cell with a hydroxide-ion conducting membrane electrolyte that consumes ammonia directly to generate electricity. |
| University of Minnesota – Twin Cities | $2.9 million | Will insert an inorganic absorbent material in the ammonia synthesis loop of a traditional Haber-Bosch process to remove ammonia from the gas stream. |
| University of South Carolina | $1.6 million | Will build a membrane reactor to generate hydrogen fuel from ammonia decomposition, which may then be used by a hydrogen fuel cell vehicle or stationary generator. |
| West Virginia University Research Corporation | $1.25 million | Will develop a method to produce ammonia from hydrogen and nitrogen using a microwave plasma. |
| Wichita State University Kansas | $885,000 | Will demonstrate a method for creating ammonia from air using a hydroxide exchange membrane (HEM) powered by renewable electricity. |

## U.S. DEPARTMENT OF DEFENSE

**Department of Defense (DOD) – Fiscal Year 2016 SBIR**
**Award amounts are rounded**

| Recipient | Amount | Program | Details |
|---|---|---|---|
| API Engineering LLC Colorado | $0.72 million | FY16 DOD/ Navy SBIR Phase II | The proposed research deals with production of oxygen for use by air independent SOFCs in unmanned undersea vehicles. |
| FTL Labs Corporation Massachusetts | $0.75 million | FY16 DOD/ Air Force SBIR Phase II | FTL proposes a powerful new enabling technology,"ElectroSeptic," for deployable wastewater treatment using high-capacity flow-through microbiological fuel cells. |
| Advanced Cooling Technologies Pennsylvania | $1 million | FY16 DOD/ Army SBIR Phase II | The innovative non-catalytic thermal partial oxidation (TPOX) reformer is very simple, compact, lightweight, and minimized parasitic power consumption, and therefore it is well-suited for the applications such as portable fuel cell power generation. |
| Precision Combustion, Inc. Connecticut | $0.99 million | FY16 DOD/ Army SBIR Phase II | PCI has developed and demonstrated an extremely compact Microlith based reformer for enabling effective and efficient SOFC operation with up to 3000 ppmw sulfur JP8 or diesel fuels. PCI will build and demonstrate a power dense, standalone, packaged, Technology Readiness Level (TRL) 5/ 6, 10 kWe JP8 Reformer System integrated with associated balance of plant components for delivery to U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC) for further evaluation. |

## NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

| National Aeronautics and Space Administration (NASA) – Fiscal Year 2016 SBIR<br>Award amounts are rounded | | | |
|---|---|---|---|
| **Recipient** | **Amount** | **Program** | **Details** |
| **Precision Combustion, Inc.<br>Connecticut** | $0.75 million | **FY16 NASA SBIR Phase II** | Proposes to develop and demonstrate an innovative high power density design for direct internal reforming of regolith off-gases (e.g., methane and high hydrocarbons) within a SOFC stack. |
| **Infinity Fuel Cell and Hydrogen<br>Connecticut** | $0.12 million | **FY16 NASA SBIR Phase I** | High Efficiency Advanced Lightweight Fuel Cell (HEAL-FC). Improvements are planned to make the fuel cell stack more amenable to unmanned aerial systems by reducing mass and volume. |
| **NexTech Materials, dba as Nexceris, LLC<br>Ohio** | $0.12 million | **FY16 NASA SBIR Phase I Award** | Will establish a process model for an externally reformed SOFC system that operates with oxygen and methane reactants, design a reformer and a stack for the system, refine the reformer and stack designs via modeling and analysis, validate the design and performance predictions via catalyst and stack testing. |

## NATIONAL SCIENCE FOUNDATION

| National Science Foundation (NSF) – Fiscal Year 2016 SBIR<br>Award amounts are rounded | | | |
|---|---|---|---|
| **Recipient** | **Amount** | **Program** | **Details** |
| **Proton OnSite<br>Connecticut** | $0.7 million | **FY16 NSF SBIR Phase II** | Hydrogen bromine electrolysis for highly efficient hydrogen-based energy storage and high value chemical applications. |
| **Ecolectro, Inc.<br>New York** | $1.5 million | **FY16 NSF SBIR Phase II** | PEM synthesis to enable low cost, durable fuel cells through novel material innovation. |

# Photo Credits

All images were approved for use by the relevant fuel cell manufacturer or customer.

Cover top left: Plug Power GenSure units at Stone Edge Farm in Sonoma Valley, California. Photo courtesy of Plug Power.

Cover top right: Plug Power GenDrive fuel cells powering forklifts at Volkswagen manufacturing facility in Kassel, Germany. Photo courtesy of Plug Power.

Cover upper middle right: Doosan Fuel Cell America, Inc. units at CBS Studios. Photo courtesy of Doosan Fuel Cell America, Inc.

Cover lower middle left: Bloom Energy fuel cell system at Morgan Stanley headquarters in New York City, New York. Photo courtesy of Bloom Energy.

Cover bottom left: Altergy Freedom Power fuel cell unit providing power at Super Bowl 50. Photo courtesy of Altergy systems.

Cover bottom right: Altergy Freedom Power fuel cell units on a Florda rooftop. Photo courtesy of Altergy Systems.

# Endnotes

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