2014 Hydrogen and Fuel Cell Global Commercialization & Development Update

International Partnership for Hydrogen and Fuel Cells in the Economy

Hydrogen and fuel cell technologies offer a pathway to enable the use of clean energy systems to reduce emissions, enhance energy security, and stimulate the global economy. As part of a portfolio of clean energy technologies, including energy efficiency, renewable energy and fuels, and battery-electric vehicles, employing hydrogen and fuel cells in the economy will help global stakeholders to achieve these goals. A decade of sustained global research, development and demonstration (RD&D) is now producing the necessary technological breakthroughs for hydrogen and fuel cells to compete in the market. This report offers examples of real-world applications around the world and technical progress of hydrogen and fuel cell technologies, including policies adopted by countries to increase technology development and commercialization.

Hundai

Toyota

Commercially produced hydrogen fuel cell vehicles have arrived: the Hyundai Tuscon Fuel Cell started leasing in the United States and Europe in September 2014, and the Toyota Mirai was available for purchase in Japan in December 2014, with plans for sales in the United States and Europe in mid-2015.

Hydrogen and fuel cell (HFC) technologies can use diverse domestic renewable and low-carbon resources and address multiple applications across stationary, transportation, and portable power sectors. The challenges facing full commercialization of hydrogen and fuel cell technologies can be addressed through both policy mechanisms and technology improvements, which require consistent and focused international collaboration to increase the incorporation of these technologies in the global energy portfolio.

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This report offers a summary of key developments in several areas in 2013 and 2014:

International Fuel Cell Electric Vehicles (FCEV) and Hydrogen Refueling Station (HRS) Status and Government Investment

The information below provides a status of government-supported fuel cell vehicle and hydrogen refueling station programs.

Region	FCEVs	Hydrogen Stations	Partnerships	Government Funding
EU	40	~30	Fuel Cells and Hydrogen Joint Undertaking (FCHJU) H_2-Mobility	FCH-JU, 2014-2020: **€667M** ($911M)
Germany	110	~12	National Innovation Program-Clean Energy Partners	National Innovation Program, 2014: *R&D: **€13M** ($18M)* *Station Build Out: **€47M** ($64M)* *Total: **€60M** ($82M)*
Japan	65	16	The Research Association of Hydrogen Supply/Utilization Technology	R&D: **¥3,250M** ($32M) Station Build Out: **¥7,200M** ($70M) Total: **¥10,450M** ($102M)
Korea	100	12	Korea Hydrogen Industry Association (KHIA)	Ministry of Environment Deployment and Infra Structure Program 2014: **$7.8M** (includes HRS, vehicles)
Scandinavian Countries	40	10	Scandinavian Hydrogen Highway Partnership	SHHP, 2006-2013: **€100M** ($137M) Norway, 2014-2018: **€44M** ($60M) (includes HRS, vehicles and O&M)
United Kingdom		6	H2 Mobility	A total of **£7.5M** (~$12M) from Government together with **£3.5M** (~$5.5M) from industry to cover 4-7 new HRS, 6-8 upgraded HRS and the deployment of approximately 40 FCEVs in 2015.
United States	>230	~50 (10 public)	H2USA California Fuel Cell Partnership Hawaii H2 Initiative (H2I) Other State Associations (CT, MA, etc.)	California (CEC), 2014: **$47M** CEC, 2015 - 2023: **$20M/yr** DOE, FY2014: **$170M**
Total	***>585***	***~136***		***~$750M***

COMMERCIAL ACTIVITIES AND DEVELOPMENTS

Significant progress in a variety of HFC technologies was made in the last year. Fuel cell markets for stationary generation, backup power, and material-handling applications continued to expand as the operational effectiveness and efficiency of HFC technologies increased. The global fuel cell market shipped over 35,000 systems last year, representing

an approximate 30% annual growth rate since 2010. Also during the last year, the global hydrogen market produced over 55 Mtons of hydrogen.

Demonstration projects help to address user acceptance issues and can accelerate the transition to widespread consumer uses. The most dramatic growth in market application of HFC technology has been in several areas including: back-up power, stationary power, material handling equipment, hydrogen production and transportation. These early HFC deployments reflect the benefit of displacing conventional fossil fuels or batteries for special applications, which leads to longer term performance and shorter down time for refueling, For example, it can take 8 hours to recharge a battery, but it only takes 3 minutes to refuel a fuel cell forklift. This results in greater productivity and a reduced need for additional batteries.

The following are recent highlights of commercial deployment of HFC technologies.

Power Generation & Electric Grid Support

Fuel cells for distributed power continued to dominate the market in 2014, with 80 percent of total fuel cell units manufactured and megawatts shipped in stationary markets. Strong performance of this market segment can be justified with the paradigm shift in the power sector from traditional centralized power generation model towards distributed generation. Fuel cells fit very well into the spectrum of the technologies that support this transition.

The **United States** and **Canada** expanded commercial deployment of natural gas powered fuel cells.

- Bloom Energy announced the installation of 50 MW of solid oxide fuel cells (SOFC) at a number of well-known corporations, including a 27 MW installation for Delmarva Power in Delaware. Bloom Energy now has systems totaling more than 100 MW installed in the **United States**, and completed its first international installation in late 2013 at SoftBank's M-Tower in Fukuoka, Japan.
- FuelCell Energy completed a 14.9 MW fuel cell park in Bridgeport, Connecticut, (**U.S.**) consisting of five fuel cell power plants and an organic rankine cycle turbine as a bottoming cycle. The project is located on a remediated brownfield site in an industrial area, and is under a 15-year agreement with Connecticut Light & Power. FCE also completed installation of a 1.4 MW fuel cell at California State University, San Bernardino.
- Ballard Power commissioned a 1 MW PEMFC ClearGen™ system at the headquarters of Toyota USA, which supplies the campus with supplemental power during times of peak energy demand. Ballard has also entered into an Intellectual Property (IP) licensing arrangement with China based Azure Hydrogen. By doing so, Ballard has strategically positioned itself to expand sales of its systems into China.
- In **Canada**, Hydrogenics Corporation and Enbridge Inc. have been awarded a 2 MW Power-to-Gas energy storage project by the Independent Electricity System Operator for Ontario. Hydrogenics has also signed an agreement to create a joint venture (JV) with Kolon Water & Energy of South Korea. The objective of the JV will be to capitalize on the energy storage challenges and opportunities associated with distributed renewable energy systems in Korea and other Asian markets.
- FuelCell Energy, which is operating a waste-to-energy demonstration in Fountain Valley, California, (**U.S.**) reached agreement to demonstrate a comparable "tri-generation" power plant to provide electricity, heat and renewable hydrogen. The heat will be supplied to Village Farms of Vancouver, British Columbia, a hydroponic greenhouse business, while the renewable hydrogen will be exported for vehicle fueling or industrial applications.
- **Korea** Western Power Co., Ltd. installed an 11.2 MW capacity fuel cell power plant at the West Incheon. The fuel cell power plant that has the capability to produce 98,112 MWh of electricity and 24,892 Gcal of heat energy. The heat energy is to be sold as a source for district heating. By 2015, an additional 5.6 MW Fuel Cell Power Plant will be constructed at the existing west Incheon power plant site.
- Also in **Korea**, POSCO Energy and Doosan, plan a 360MW Fuel Cell Power Plant in Pyeongteak. This fuel cell power plant construction is a massive overall 2.5 trillion won enterprise consisting of two phases. By 2016, 500 billion won will be invested in a 100MW power plant. An additional 360MW is expected to be complete by 2018 in Pyeongteak.
- Also in **Korea**, the Seo-nam Water Recycling Center in Seoul will increase its electrical independence using renewable energy by installing a 30MW fuel cell power plant. The facility will produce 236GWh of electrical energy—enough for 65,000 households. It will also produce 120,000 Gcal of heat energy—sufficient to heat 10,000 households. Seoul City anticipates to increase its electrical independence from 4.2% in 2013 to 20% in 2020 by continuing its dispersive renewable energy enterprise.

Electrolyzers are being evaluated for use in grid balancing systems to help smooth out generation from wind turbines and solar systems. These systems would provide a load when grid demand is low and renewable power sources are available, and in some cases provide H_2 to fuel conventional generators when renewable power is not available. This type of grid support is increasingly necessary as the percentage of intermittent renewable generation on electric grids increases.

Transportation

Global automobile manufacturers continued making major progress toward the commercialization of passenger cars equipped with proton exchange membrane (PEM) fuel cell technologies for motive power.

- Hyundai started leasing FCEVs in **California**, as well as regions in **Europe and Korea**, and are providing hydrogen fuel at no cost.
- Toyota announced plans to introduce production vehicles in 2015 in a number of regions such as **Japan**, **Northern Europe**, and **California**. Production volumes and target markets are expected to expand in 2015.
- Honda unveiled a new fuel cell concept vehicle at auto shows in 2014.
- Three collaborations with automobile manufacturers (Toyota-BMW, Daimler-Ford-Nissan and Honda-GM) and one major engineering services agreement (Volkswagen-Audi-Ballard) were established. They provide a means to accelerate development and minimize risks that are associated with commercializing automotive fuel cell technology. The collaborations are intended to share intellectual property, mitigate technological risk, share development costs, promote innovation, and accelerate development and achievement of manufacturing scale economies through shared designs. In announcing its collaboration with Nissan and Ford, Daimler delayed its plans to produce vehicles for **Germany** and other markets until 2017.
- Although manufacturers are reluctant to divulge costs, there are signals that key performance metrics such as power density, range, refueling time, and cold operation are sufficient to justify commercial deployment. Regarding costs, statements from the manufacturers suggest that the fuel cell system cost for an 80kW system, based on lab-scale technology projected to high-volume manufacturing (500,000 units per year), is reasonably consistent with **U.S.** Department of Energy's (DOE) modeled cost of $55/kW, shown in the following figure. Second generation technology is expected to continue progress toward 2020 cost targets.

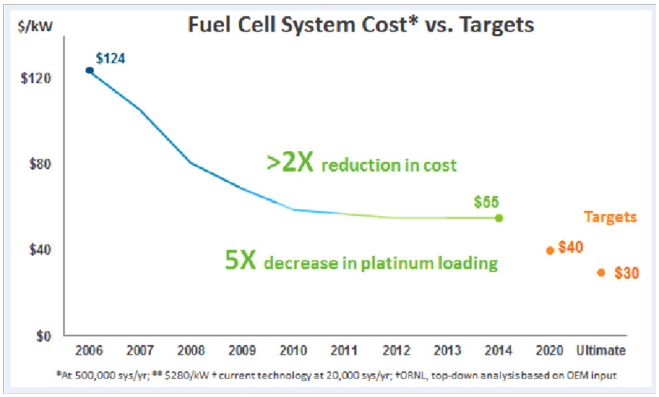

Figure 1: DOE modeled cost at high volume
Source: U.S. DOE

Fuel Cell Light Duty Vehicles

Automotive applications progressed as RD&D programs lowered the cost of fuel cells and validated performance and durability in real-world applications. Auto manufacturers continue to accumulate durability and practical field fleet experience with earlier generation vehicles, even as they prepare to launch commercial production.

- General Motors announced that its fuel cell field fleet, which was originally launched in 2007 as Project Driveway, is approaching 3 million miles of real-world driving. Individual vehicles have accumulated more than 100,000 miles.
- Hyundai announced its development fleet has accumulated 2 million miles of driving.
- Mercedes-Benz announced that its global F-Cell fleet had achieved over 1 million miles of driving by the third quarter of 2013.
- Daimler, Ford and Nissan have agreed to expand on and prolong their collaborative FC R&D efforts being conducted through AFCC (Automotive Fuel Cell Cooperation), with a planned commercialization date in 2017.
- Daimler has established a dedicated and automated FC stack manufacturing facility in Burnaby, BC. Mercedes Benz Fuel Cells's (MBFC) primary objective is to determine how to cost effectively manufacture FC stacks on an industrial scale.
- Ballard Power Systems has signed a long term engineering services R&D contract with Volkswagen (VW), valued at up to $100M over 4 years. VW and Audi have since announced they intend to produce at least 3 FCV models.

Auto manufacturers continue to expand their HFC demonstration fleets as they move toward their 2015 commercialization dates.

Fuel Cell Buses and Other Heavy Duty Vehicles

A study conducted by the National Renewable Energy Lab (Fuel Cell Buses in U.S. Transit Fleets: Current Status 2012) has shown that there is a factor of 1.8 to 2.4 greater fuel economy of hydrogen fuel cell buses than the fuel economy of diesel and compressed natural gas buses.

- Following multiple successful market deployments across **European** cities including Cologne, Hamburg, Bolzano, Oslo, Milan and London, the representatives of five major European bus manufacturers (Daimler Buses (EvoBus), MAN, Solaris, Van Hool and VDL Bus

& Coach) signed a joint Letter of Understanding on supporting the commercialization of fuel cell buses in Autumn 2014. The ambition is to deploy a total volume of 500 – 1,000 fuel cell buses in Europe by 2020.

- The U.S. Federal Transit Administration's National Fuel Cell Bus Program awarded $90 million over seven years for innovative research, demonstration and deployment projects to reduce fuel cell cost in transport applications. In early 2014, it issued a call for proposals under its Low or No Emission Vehicle Deployment Program; at least $24.9 M is available for fuel cell and other advanced buses.
- More than 25 buses have been demonstrated in the United States. States with demonstration projects include California, Connecticut, South Carolina, and Delaware.
- The FCH JU CHIC project (Clean Hydrogen in European Cities) has accumulated a total of 4 million km and over 201,000 hours of operation.
- Canada's Ballard Power's FC bus modules have 5.9M kilometers in revenue service throughout North America, Europe and China. Ballard's 2014 acquisition of UTC's transportation and stationary-related FC IP assets has further positioned the firm as one of the leader in the FC transportation industry.

Demonstrations for specialty vehicles also produced significant highlights:

- In 2014, the U.S. DOE launched projects for the development and demonstration of fuel cells in delivery vans, airport equipment, and refrigerated shipping containers. The U.S. DOE supported the development and demonstration of hybrid electric electric drayage trucks for use at the Port of LA. The range of these heavy duty electric Class 8 vehicles would be extended to approximately 200 miles through the use of a fuel cell range extender.

Combined Heat and Power (CHP)

- Japan's Ene-farm has deployed > 100,000 micro-CHP units domestically. Deployment rates are on the path to meet the targets of 1.4 million units by 2020 and 5.3 million by 2030.
- In Germany, the Ene-field project will deploy up to 1,000 residential fuel cell Combined Heat and Power (micro-CHP) installations, across 12 key Member States. It represents a step change in the volume of fuel cell micro-CHP (micro FC-CHP) deployment in Europe and a meaningful step towards commercialization of the technology. The program brings together nine mature European micro FC-CHP manufacturers into a common analysis framework to deliver trials across all of the available fuel cell CHP technologies. Fuel cell micro-CHP trials will be installed and actively monitored in dwellings across the range of European domestic heating markets, dwelling types and climatic zones, which will lead to an invaluable dataset on domestic energy consumption and micro-CHP applicability across Europe.
- FCEL is working with Vancouver, Canada based Quadragen Energy Corp on a waste-to-energy CHP power plant project which will produce electricity, heat, hydrogen and CO2 from a Vancouver land-fill. The electricity, heat and CO2 produced will be used in industrial greenhouses, while the renewable hydrogen will likely be sold for industrial applications or possibly as transportation fuel.

Back-up and Remote Power Generation

Fuel cells are generally regarded as superior to diesel back-up generators in many ways, including greater reliability, lower emissions, better energy efficiency, quieter and ready installation. Reliable back-up is especially important during a natural disaster, to power critical infrastructure such as communication networks, power for hospitals, and support systems for food and water supplies.

- Approximately 900 U.S. DOE-supported emergency backup power projects led to an additional 4,000 fuel cell systems with no DOE funding.
- Canada's Ballard Power has reached the 2,700-unit milestone on shipments of methanol-fuelled back-up power units for telecom applications. This is equivalent to 11.5MW of power. Markets have expanded to include China, India and South Africa (SA). Ballard is also working with the SA government on rural, off-grid community electrification demonstrations.
- In Canada, Glencore has partnered with the federal and provincial governments on a unique renewable electricity and smart-grid demonstration project at their remote, off grid mine in Raglan, Quebec. The objective of the project is to demonstrate that wind energy can be used to produce renewable hydrogen which, in turn, can be used to reduce the mine's dependence on diesel for electricity generation and ultimately as an inexpensive and clean transportation fuel.

- A 6MW Bloom Energy system was turned on in September 2013 to power 30 servers at an eBay data center in Salt Lake City (U.S.).

Material Handling Equipment

The United States' materials handling market has been a growth sector for fuel cells, with hydrogen-powered fuel cell forklift fleets operating in warehouses, distribution centers, and manufacturing facilities for major companies including BMW, Coca-Cola, Fed-Ex, Wal-Mart Procter & Gamble, Sysco and Canada Tire.

Ballard has a supplier agreement with United States based Plug Power, and has shipped over 6,000 forklift fuel cell stacks, representing over 20 million hours of run time.

The U.S. DOE cost-shared funds toward the development of ~700 fuel cell fork lifts, helping validate the market for this application and leading to industry orders of more than 7,500 additional units.

Energy Storage

Several companies have announced and began major hydrogen energy storage projects and plans.

American and Canadian stakeholders are collaborating on a grid scale hydrogen energy storage project which aims to develop the techno-economic analysis tools which will be required to analyze under what circumstances excess and/or curtailed energy can be cost effectively used to create hydrogen which in turn could be stored in natural gas pipelines or elsewhere. This Power-to-Gas project is being supported through the Canada/U.S. Clean Energy Dialogue initiative.

In Europe, energy storage is high on the agenda as the share of renewable generation increases. Some successful pilot projects demonstrating the technology are in place and have delivered first results. For example, E.ON's Power-to-Gas pilot "WindGas Falkenhagen" has delivered a positive performance in its first year of operation (established mid 2013), injecting more than two million kilowatt-hours of hydrogen into the gas transmission system.

Hydrogen Infrastructure

Although the worldwide hydrogen fueling infrastructure is still in its infancy, this year saw significant new commitments of financing for stations. The number of fully operational H2 fueling stations globally exceeded 220 in 2013, though many are not open to the public.

As signals from the auto industry began to make it clear that the vehicles are coming, infrastructure activities in Japan, Europe and California accelerated and focused on public accessibility.

- In Europe, the provision of hydrogen infrastructure has been discussed at large resulting in the creation of a number of national "hydrogen mobility" groups based on the German H2Mobility model. Currently similar initiatives managed by national public private partnerships can also be found in Scandinavia, the UK, France, Switzerland and Netherlands.

- In California (U.S.), new legislation provides a $20 million per year commitment to fund publicly available H2 fueling stations by 2024.

- In Europe, an "Alternative Fuels Infrastructure" directive including measures aimed at supporting the deployment of alternative fuels in the Member States was adopted in autumn 2014. Hydrogen is among the fuels covered by the directive, which requires that the Member States develop national policy frameworks for market development of alternative fuels and their infrastructure. It stipulates that the countries that choose hydrogen as the fuel option should have the appropriate infrastructure in place by 2025. Furthermore, the directive foresees introduction of common technical specifications for a number of elements, including hydrogen refueling stations, hydrogen purity, fueling algorithms and vehicle connectors for refueling.

POLICY DEVELOPMENT AND PROGRAMS

As hydrogen and fuel cells begin to play a greater role in meeting the energy needs of the world, safety related to using hydrogen as a fuel remains a high priority. International progress on policies supporting hydrogen and fuel cell R&D and deployment continued in 2013. Individual states in the United States also launched new programs and policies.

China renewed government subsidies for new energy vehicles for three more years (2013-2015). According to the revised subsidy program, the central government will provide as much as 200,000 Yuan ($32,600) toward the purchase of a fuel cell passenger vehicle and as much as 500,000 Yuan ($81,600) for a fuel cell bus.

The European Union, Japan, and the state of California made significant new financial

commitments for research, demonstration, and infrastructure deployment.

- In the **United States**, the Investment Tax Credit (up to $3,000 per kW or 30 percent of installation costs for fuel cells, set to expire in 2016) continued to stimulate the market and enable hundreds of deployments.
- The **California** Governor's office released the "2013 ZEV Action Plan" that includes a goal to have 1.5 million zero-emission vehicles, including hydrogen fuel cell vehicles, on the road by 2025.
- In the **United States**, California committed up to $100 million for H_2 infrastructure through 2024 as part of a $2 billion commitment to clean vehicles and low-carbon fuels.
- The governors of 8 states—California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island and Vermont—signed a memorandum of understanding to take specific actions to put 3.3 million zero emission vehicles on the roads in their states by 2025, along with the refueling infrastructure required to support those vehicles.
- The **European Union** committed to the continuation of the Fuel Cells and Hydrogen Joint Undertaking under the eighth iteration of the EU Framework Programme for Research and Innovation called Horizon 2020. The Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) started operations in 2014 with a foreseen EU contribution of €665M and an equivalent amount to be delivered from private side via in-kind contributions between 2014 and 2024. The FCH 2 JU will aim at accelerating the commercialization of HFC technologies, with energy security and sustainable transportation high on the agenda.
- In **Canada**, a 5% carbon tax is included in the price of all fossil fuels sold in the province of British Columbia (BC). BC has also introduced the Renewable & Low Carbon Fuel Standard. This Act has two parts that reduce the greenhouse gas emissions from fuel. The first part requires fuel suppliers to include renewable content in gasoline (5%) and diesel (4%) sold in the province and, the second part requires fuel suppliers to reduce greenhouse gases by reducing the carbon intensity of the fuel mix they supply by 10% over 2012 levels by 2020.

NATIONAL-LEVEL BUDGETS

There has been significant commercial adoption of hydrogen and fuel cell technologies in niche areas, such as fuel cell forklifts and backup power. Commercial passenger vehicle introductions are coming in 2015, but their success will be coupled to a commitment to build up fueling infrastructure. While limited hydrogen infrastructure networks are expanding in certain regions, more will be needed for large-volume commercial sales. However, this growth will not happen without continued support of RD&D from various venues. Government support can ensure that the early markets for HFC technologies successfully "cross the chasm" that is so often associated with early technology adoption. This will further stimulate private investment in these products and technologies, which have already been shown to be assets in niche areas. With support, these technologies will play a vital, more widespread role in meeting the energy objectives of the IPHE Partners.

This table summarizes the nation budgets from IPHE members in support of hydrogen and fuel cell RDD&D and subsidies for technology deployment.

Country	Local Currency		Millions USD	
	2013	2014*	2013	2014*
Austria	€10 M	€10 M	13.7	13.7
Canada	$30 M		26	
China	RMB 216M	RMB 45M	34.8	7.3
European Union	€150.9 M	€96 M	182	115
Germany	€78M	€82	95	100
India	158.5M Rs	108M Rs	2.55	1.74
Italy	€35M	€35M	42	42
Japan	37.9 Billion Yen	38.9 Billion Yen	374	383.9
Korea	30.364M Won	28.091M Won	33.4	30.9
South Africa	R71 M	R76 M	6.5	6.9
United Kingdom	£13.5 M		20.9	
United States	$150 M	$170 M	150	170

*If available.

*The members of the **International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)** have been coordinating activities since 2003 to accelerate the adoption of hydrogen and fuel cell technologies into the global economy. The four priority focus areas of the IPHE are: 1) Accelerating the market penetration and early adoption of hydrogen and fuel cell technologies and their supporting infrastructure; 2) Policy and regulatory actions to support widespread deployment; 3) Raising the profile with policy-makers and the public; and 4) Monitoring hydrogen, fuel cell and complementary technology developments. IPHE has 18 member governments, including: Australia, Austria, Brazil, Canada, China, the European Commission, France, Germany, Iceland, India, Italy, Japan, the Republic of Korea, Norway, the Russian Federation, the Republic of South Africa, the United Kingdom and the United States. Together, members have a combined population of approximately 3.5 billion people, use three-quarters of all the electricity produced on the planet, and account for two-thirds of global energy consumption and CO_2 emissions.*

To learn more about the IPHE and it's members, please visit our website at www.iphe.net.