FuelCellToday

The leading authority on fuel cells

Fuel Cell Electric Vehicles: The Road Ahead

ACKNOWLEDGEMENTS

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'Fuel Cell Electric Vehicles: The Road Ahead' is based for the most part on information available up to August 2012.

GLOSSARY

AFC – Alkaline Fuel Cell.

AFCC – Automotive Fuel Cell Cooperation (organisation).

bar – Unit of pressure, equivalent to 100 kilopascals.

BEV – Battery Electric Vehicle.

CaFCP – California Fuel Cell Partnership (organisation).

CARB – California Air Resources Board (organisation).

CEP – Clean Energy Partnership (organisation).

CO_2 *– Carbon Dioxide.*

EU – European Union.

FCEV – Fuel Cell Electric Vehicle.

G8 – The Group of Eight (international government forum).

GBP – Great British Pound (currency).

GE – General Electric (company).

GHG – Greenhouse Gas (emissions).

GM – General Motors (company).

HySUT – Research Association of Hydrogen Supply/ Utilization Technology (organisation).

ICE – Internal Combustion Engine.

km – Kilometre.

kmph – Kilometres per hour.

kW – Kilowatt.

lbs – Pounds.

MoU – Memorandum of Understanding.

mph – Miles per hour.

NASA – (US) National Aeronautics and Space Administration.

OEM – Original Equipment Manufacturer.

PEMFC – Proton Exchange Membrane Fuel Cell.

PHEV – Plug-in Hybrid Electric Vehicle.

ppm – Parts per million (a measure of concentration).

R&D – Research and Development.

SAE – Society of Automotive Engineers (organisation).

SUV – Sports Utility Vehicle.

USA – United States of America.

USD – US Dollars (currency).

ZEV – Zero-Emission Vehicle.

°C – Degrees Celsius.

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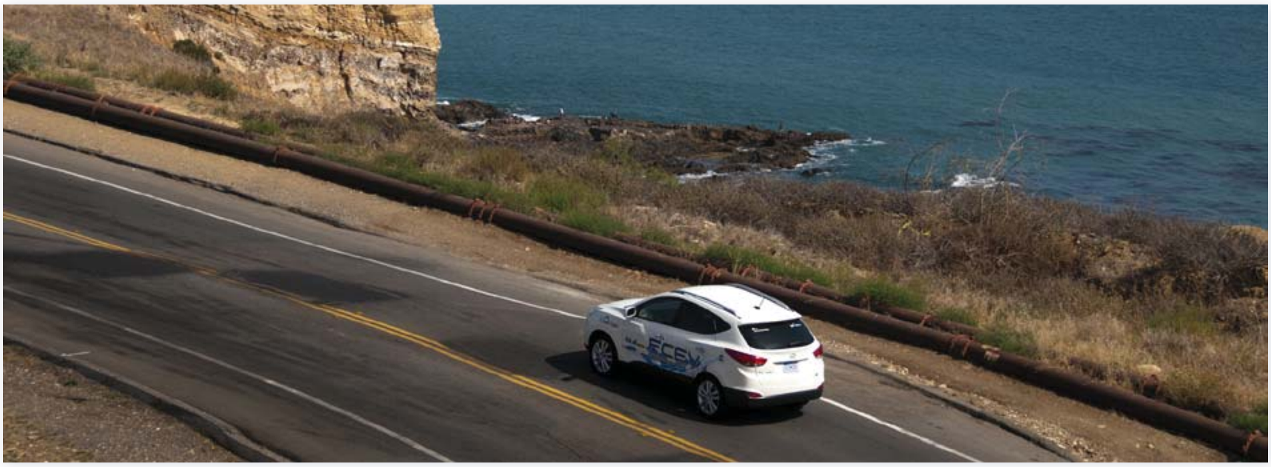


The Need for Zero-Emission Transport

EU and G8 leaders declared in 2009 that CO_2 emissions must be cut by at least 80% (from 1990 levels) by 2050 in order for atmospheric CO_2 to stabilise at 450 parts per million (ppm) and keep global warming below 2°C.[1] This level of decarbonisation could require up to 95% decarbonisation of the road transport sector[2] – a daunting target. The internal combustion engine (ICE) is not expected to improve more than 30% in efficiency during that timescale[3] and the availability and compatibility of alternative biofuels is uncertain; as such it is unlikely that conventional vehicles can meet this target alone. There is an evident need for zero-emission solutions across the full range of car types, from small cars for local use to larger, high-mileage vehicles.

Fuel Cells as a Technology

A fuel cell is similar to a battery in that it generates electricity from an electrochemical reaction. Both batteries and fuel cells convert chemical energy into electrical energy and also, as a by-product of this process, into heat. However, a battery holds a closed store of energy within it and once this is depleted the battery must be discarded, or recharged by using an external supply of electricity to drive the electrochemical reaction in the reverse direction.

A fuel cell, on the other hand, can run indefinitely as long as it is supplied with a source of hydrogen fuel (hence the name) and is similar to an ICE in that it oxidises fuel to create energy; but rather than using combustion, a fuel cell oxidises hydrogen electrochemically in a very efficient way. During the reaction, hydrogen ions react with oxygen atoms to form water; in the process electrons are released and flow through an external circuit as an electric current. The only exhaust is water vapour.

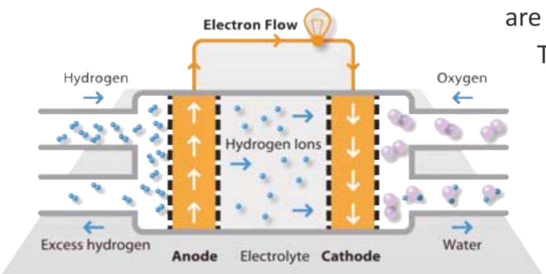


Figure 1: How a PEMFC works

The fuel cell type used in the automotive industry is the proton exchange membrane fuel cell (PEMFC), a low-temperature, hydrogen-fuelled cell containing a platinum catalyst; it is the most common type of fuel cell and allows for variable electrical output, ideal for vehicle use.

Fuel Cells in an Electric Powertrain

Fuel cell and battery electric vehicles both use electric drivetrains, but where battery electric vehicles (BEV) power their motors solely with batteries, fuel cell electric vehicles (FCEV) are hybrids, powered by a hydrogen fuel cell with a small battery. Both vehicle types benefit from near-silent operation, excellent driveability and no tailpipe emissions, or indeed no tailpipe at all.

BEV are best realised as smaller cars in applications that require a continuous range of less than 200 kilometres (125 miles): city run-arounds and second cars. Restricted range and long recharging times have limited their uptake to date. Plug-in hybrid electric vehicles (PHEV) provide a bridge between conventional cars and electric vehicles, offering an electric drivetrain with the convenience of using conventional fuel; however they can never be truly zero-emission.

FCEV provide all of the benefits of electric vehicles combined with the utility of a combustion-engined car: they can be refuelled in minutes by the driver using a nozzle similar to a conventional fuel pump and then driven for hundreds of kilometres before they need refuelling again. A large proportion of road fuel is used in large and high-mileage vehicles and only fuel cells are proven as a zero-emission power source for these vehicles. The mix of conventional conveniences and electric advantages that FCEV can offer is a compelling proposition for personal transportation.

Market Introduction

Two things are needed for the market introduction of FCEV: the cars themselves and hydrogen refuelling stations to support them. In any market, a minimum number of each is necessary to support demand for the other.

Initial deployments are likely to focus on government fleets, other return-to-base fleet operations and the high-end consumer car market in areas with an appropriate level of infrastructure. Following early market introduction, widespread consumer acceptance and adoption will be gradual, accelerating as infrastructure density increases and the cost of production of the vehicles and the hydrogen fuel decreases. Ultimately, take-up will depend on the advantages and costs of FCEV when judged against alternatives.

'A portfolio of powertrains for Europe: A fact-based analysis', a collaborative study between automakers, energy suppliers and EU government organisations, impartially assesses the varying merits of FCEV, BEV, PHEV and ICE from now to 2050. It expects that the total cost of ownership for these powertrains will converge after 2025; level pricing will allow vehicles to be selected on technological and environmental merits and a surge in FCEV sales should be expected after this point. Figure 2 below shows anticipated range and carbon emissions of the four drivetrain technologies between 2010 and 2050. BEV will have the lowest emissions but will continue to be range-restricted; the opposite is true for gasoline and diesel ICE. PHEV vary dramatically depending on the level of battery hybridisation; but the greater the range, the greater the emissions. FCEV is the only drivetrain that can achieve a high range with low emissions.

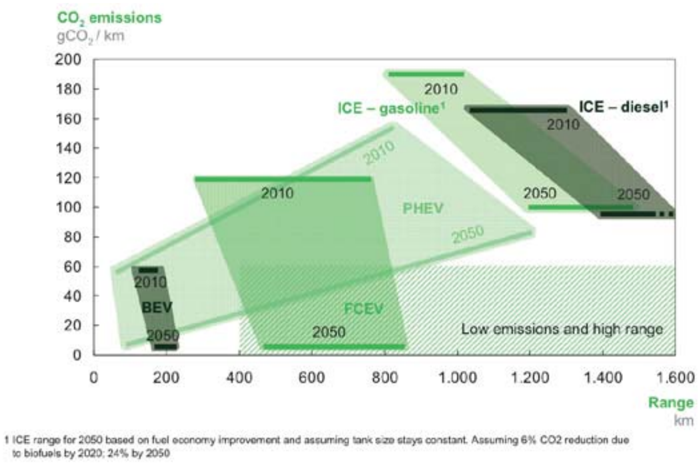


Figure 2: Powertrain ranges versus carbon emissions 2010–2050 [3]

FCEV: The Story so Far

Fuel cells are more an evolutionary technology than a revolutionary one. Originally invented in the early 1800s, the technology was developed gradually before being given a boost through use in the NASA Apollo space programme in the late 1960s and early 1970s. During this period the first fuel cell car was demonstrated by General Motors and was followed by several other early FCEV demonstrations, all based on alkaline fuel cell technologies similar to those developed for NASA. Fuel cells using proton exchange membranes, the type now used in FCEV, were first developed in 1958 but it took until 1993 for the technology to become viable enough for vehicle demonstrations.

The First PEM Fuel Cell

General Electric (GE) chemist Leonard Niedrach (left) devised a way of depositing platinum onto the ion-exchange membrane created by fellow GE scientist Willard Thomas Grubb (right) three years earlier. This marked the beginning of the PEM fuel cells used in vehicles today. The technology was initially developed by GE and NASA for the Gemini space programme; it took several decades to become viable for demonstration in cars, primarily due to cost.

1958

1959

The First Fuel Cell Vehicle

The Allis-Chalmers tractor was a farm tractor powered by an alkaline fuel cell with a 15 kW output, capable of pulling weights up to 1,360 kg (3,000 lbs).

1966

The First Fuel Cell Car

General Motors designed the fuel cell Electrovan to demonstrate the viability of electric mobility. The Electrovan was a converted Handivan with a 32 kW fuel cell system giving a top speed of 115 kmph (70 mph) and a range of around 240 kilometres (150 miles).

1970

Progress Continues

Based on the Austin A 40, the K. Kordesch utilised a 6 kW alkaline fuel cell and was comparable in power to conventional cars on the road at the time.

1993

The World's First PEMFC Car

The Energy Partners Consulier was a proof-of-concept vehicle that sported a lightweight plastic body and three 15 kW fuel cells in an open configuration; it had a top speed of 95 kmph (60 mph) and a range of 95 kilometres (60 miles).

1994

Enter the Automakers

The NECAR (New Electric Car) was Daimler's first demonstration of fuel cell mobility. A converted MB-180 van, it utilised a 50 kW PEMFC that, alongside compressed hydrogen storage, took up the majority of space in the van. This was followed by the six-seat NECAR 2 in 1996 which placed the fuel cell under the rear seats and the hydrogen storage on the roof.

1997

The First Passenger Vehicles

Within a year Daimler, Toyota, Renault and Mazda all demonstrated viable fuel cell passenger vehicle concepts: the NECAR 3 (based on the A-Class), FCHV-2 (based on the RAV4), Fever (based on the Laguna) and Demio, respectively. Fuel cells ranged from 20 kW (Mazda) to 50 kW (Daimler); both the NECAR 3 and FCHV-2 used methanol as fuel instead of hydrogen. The next year GM demonstrated a methanol-fuelled 50 kW fuel cell Opel Zafira – the first publicly drivable concept.

1998–2000

Further Demonstration

During this period momentum was growing for the commercial viability of fuel cell vehicles and most of the world's major automakers (including Daimler, Honda, Nissan, Ford, Volkswagen, BMW, Peugeot and Hyundai) demonstrated FCEV with varying fuel sources (methanol, liquid and compressed gaseous hydrogen) and storage methods.

2000–2005

Re-evaluation

The public attention on FCEV peaked in 2000. At this point a realisation came that despite the promise of the technology, it was not ready for market introduction. Attention switched to hybrid-electric powertrains and BEV as technologies that might deliver smaller, nearer-term benefits. The public focus for fuel cell transport shifted from cars to buses. However, work continued on fuel cells as the long-term solution for zero-emission personal transport.

2005–2006

The Resurgence

2005 and 2006 saw the unveiling of two cars that continue to have an impact on the FCEV market today: the first generation edition of the Daimler F-CELL B-Class in 2005 and the next-generation Honda FCX concept in 2006. Both companies continued to work towards consumer editions.

The mid-to-late 1990s saw many major automakers develop PEMFC vehicles and media interest gathered momentum. The pace of expectation outstripped the development of the technology, which was unready for mass-market introduction; this led to a change in focus to more immediately available powertrain technologies such as batteries over the last decade. However, work continued on automotive fuel cells, and the technology is now ready for market introduction: commercial FCEV will be on the roads by 2015.

Commercialisation Begins

Honda began leasing its FCX Clarity to select Californian customers for $600 per month. The vehicle is the first FCEV to be commercially available.

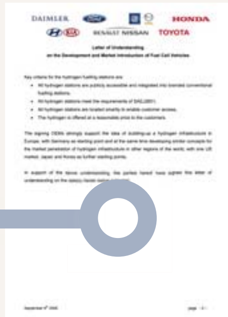
Interest in the East

A fleet of twenty Volkswagen Passat Lingyu FCEV was used for transporting dignitaries at the 2008 Beijing Olympics.

2008

2009: The Automakers Call for Infrastructure

On 8th September 2009 seven of the world's largest automakers – Daimler, Ford, General Motors, Honda, Hyundai-Kia, Renault-Nissan and Toyota – gathered to sign a joint letter of understanding. Addressed to the oil and energy industries and government organisations, it signalled their intent to commercialise a significant number of fuel cell vehicles from 2015. It urged for the development of hydrogen infrastructure, primarily in Europe and especially in Germany, to allow for this market introduction. Excerpts from the letter are shown below.



Development and Production Plan for Fuel Cell Vehicles

Based on current knowledge and subject to a variety of prerequisites and conditions, the signing OEMs strongly anticipate that from 2015 onwards a quite significant number of fuel cell vehicles could be commercialised. This number is aimed at a few hundred thousand (100.000) units over life cycle on a worldwide basis.

All OEMs involved will implement their own specific production and commercial strategies and timelines, and, as a consequence, depending on various influencing factors, the commercialisation of fuel cell vehicles may occur earlier than in the above-mentioned expected year.

Build-up of a Hydrogen Infrastructure

In order to ensure a successful market introduction of fuel cell vehicles, this market introduction has to be aligned with the build-up of the necessary hydrogen infrastructure. Therefore a hydrogen infrastructure network with sufficient density is required by 2015. The network should be built-up from metropolitan areas via corridors into area-wide coverage. Key criteria for the hydrogen fuelling stations are:

- *All hydrogen stations are publicly accessible and integrated into branded conventional fuelling stations,*
- *All hydrogen stations must meet the requirements of SAEJ2601,*
- *All hydrogen stations are located smartly to enable customer access,*
- *The hydrogen is offered at a reasonable price to the customers.*

The signing OEMs strongly support the idea of building-up a hydrogen infrastructure in Europe, with Germany as starting point and at the same time developing similar concepts for the market penetration of hydrogen infrastructure in other regions of the world, with one US market, Japan and Korea as further starting points.

SAE J2601

Developed by SAE International (the Society of Automotive Engineers), the leading publisher of automotive industry standards, *'J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles'* is the globally-accepted standard for hydrogen station interoperability and design. It establishes safety limits and performance requirements for hydrogen dispensers *via* a look-up table, including temperatures and pressure limits.

Hydrogen as a Fuel

Hydrogen is an exceptionally energy-dense fuel by mass, higher than conventional fuels and substantially higher than batteries. However, volumetric energy densities are much lower so hydrogen in cars is compressed, either to 350 bar or more commonly to 700 bar.

Currently, more than 90% of road fuel is manufactured from crude oil globally. Hydrogen, by contrast, is manufactured from a wide variety of sources, presenting the opportunity for many countries to reduce their dependence on imported energy. There exists long industrial experience of manufacturing, storing, distributing and dispensing hydrogen: current world production would be sufficient to fuel 250 million fuel cell cars. Some hydrogen that is generated as a by-product in industrial processes is being used in FCEV.

One long-established production technology is the electrolysis of water: using electricity to split water into hydrogen and oxygen. This technique is particularly suitable for small-scale production, and many hydrogen refuelling stations make their own hydrogen on site by this method. If the electricity is provided from a renewable source, such as wind or solar power, then the production of the fuel emits no carbon. In this case, the hydrogen provides an additional benefit as a store of energy from renewable electricity.

The dominant industrial-scale production method at present is the steam reforming of methane, which can yield conversion efficiencies of up to 80%. This production method may be decarbonised in the future by the use of biogas as a feed, or by the capture and storage of the CO_2 by-product. A further sustainable technology, which is starting to be applied at an industrial scale, is the gasification of biomass and waste.

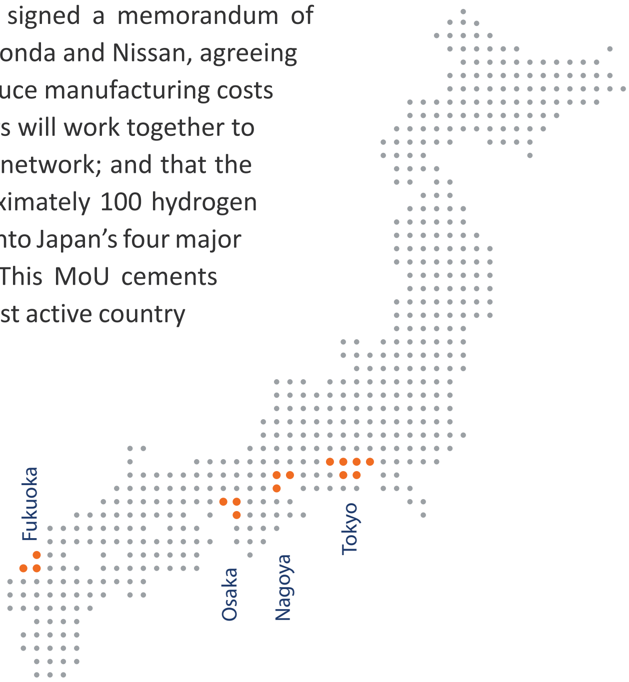
The World Prepares

By the end of 2010 there were 212 hydrogen stations across the world, according to the TÜV-SÜD-operated website H2Stations.org, though many of these are not publically accessible. Fifteen further stations were added in 2011 with 122 in the final planning stage: an indication of serious ramp-up in the few years before 2015. Preparations in the global regions indicated in the 2009 letter of understanding are gathering pace.

Japan

In January 2011 ten Japanese oil and energy companies signed a memorandum of understanding (MoU)[4] with domestic automakers Toyota, Honda and Nissan, agreeing three main points: that the automakers will continue to reduce manufacturing costs and popularise FCEV; that the automakers and fuel suppliers will work together to expand the introduction of FCEV and the hydrogen supply network; and that the hydrogen fuel suppliers will construct a network of approximately 100 hydrogen refuelling stations by 2015. These stations will be clustered into Japan's four major metropolitan areas: Tokyo, Nagoya, Osaka and Fukuoka. This MoU cements Japan's position as a global leader in FCEV and by far the most active country in Asia in this field.

HySUT, the Research Association of Hydrogen Supply/Utilization Technology, is coordinating Japan's infrastructure efforts. Established in July 2009, it is an industry grouping of eighteen companies and organisations. It will demonstrate its commercial hydrogen station specification with the launch of two new stations in Nagoya and Ebina later this year.



***Saitama** – Honda – Opened March 2012*

Located at Honda's Saitama Prefectural Office, this solar station is the first of its kind in Japan, producing, storing and dispensing hydrogen with no CO_2 emissions. The platform is intended to be further developed for home use.

Germany

Germany is at the forefront of European fuel cell activity, not least FCEV. On 10th September 2009 an MoU was signed between industry partners to evaluate the deployment of a German hydrogen infrastructure in order to promote the serial production of FCEV, a direct response to the letter of understanding from global automakers published two days previously. The project, H_2 Mobility, brings together automaker Daimler and energy companies Shell, Total, Linde, Vattenfall, EnBW and OMV, as well as NOW GmbH, the National Organisation for Hydrogen and Fuel Cell Technology.

In June 2012 the German Government's Federal Transport Minister signed a letter of intent with industry partners Daimler, Linde, Air Products, Air Liquide and Total securing €20 million in funding to expand Germany's hydrogen refuelling network to 50 stations (from an existing sixteen) by 2015, enough to support initial demand for FCEV; these will be built in metropolitan areas and connecting corridors. A year earlier, Daimler and Linde had committed to build twenty hydrogen stations by 2014;[5] a total of 1,000 hydrogen stations are expected in Germany by 2025.[6]

***Hamburg** – Vattenfall – Opened February 2012*

Europe's largest hydrogen station, capable of delivering 750 kilograms of hydrogen per day, half of which is produced on-site *via* renewably-driven electrolysis.

***Freiburg** – Fraunhofer ISE – Opened March 2012*

Acting as both a research platform and a public refuelling station, this hydrogen station uses solar panels on its roof (and the roofs of neighbouring buildings) to part-power an electrolyser for hydrogen production.

***Hamburg** – Air Products – Opened August 2012*

This solar-powered Air Products SmartFuel containerised hydrogen refuelling station is located on an existing Shell forecourt and can deliver 40 kg of hydrogen per day, enough to support a fleet of 50 vehicles.

Scandinavia

The Nordic countries are extremely progressive in the adoption of renewable energies, and this enthusiasm is now spreading to fuel cell technologies. Norway has abundant natural gas reserves and plenty of hydropower, both of which can be used to create hydrogen for vehicle use, and Denmark is interested in the storage of excess wind energy as hydrogen vehicle fuel.

In June 2006, the Scandinavian Hydrogen Highway Partnership was formed, bringing together hydrogen associations in Norway, Sweden and Denmark in a common endeavour to build a regional hydrogen refuelling infrastructure.

In early 2011, Hyundai signed an MoU with representatives from Sweden, Norway, Denmark and Iceland under which Hyundai would provide FCEV for demonstration and the countries would continue to develop the necessary refuelling infrastructure. Following a series of successful vehicle demonstrations in Sweden and Denmark throughout 2011, Hyundai joined Daimler in the H_2moves Scandinavia project, collaborating in the official opening of the project's hydrogen station in Oslo. H_2moves Scandinavia aims to demonstrate the market readiness of FCEV and hydrogen refuelling infrastructure to the public through the operation of a fleet of nineteen FCEV (ten Daimler, four Hyundai, five converted Th!nk) in Scandinavia, focusing on Oslo.

The Danish Government's Energy Plan 2020, announced in March 2012, adopts the recommendations of an industry coalition and sets out an infrastructure plan to enable the establishment of a countrywide hydrogen refuelling infrastructure by 2015.

***Rovaniemi**, Finland – H2 Logic – Opened January 2012*

Located at Finland's Arctic Driving Centre, 150 metres north of the polar circle, the 700 bar station was requested by automotive OEMs to allow them to test FCEV in extreme conditions.

***Lillestrøm**, Norway – H2 Logic – Opened June 2012*

The world's first station to use hydrogen produced from domestic waste, located at the Akershus Energy Park, where a wide range of hydrogen technologies are being developed and tested.

United Kingdom

In January 2012 the UK Government cemented its interest in FCEV with the signing of an MoU with a range of industry partners, including six automakers and three industrial gas companies, to create UK H_2Mobility. Echoing the German H_2 Mobility, it aims to analyse the specific UK case for the introduction of FCEV, review the investments required for infrastructure and identify opportunities for the UK to become a global player in FCEV manufacture.[7] This evaluation, due for publication by the end of 2012, will be followed by the development of a business case for implementation.

***Heathrow Airport** – Air Products – Opened August 2012*

The UK's second public hydrogen station, it is the first in the UK to be located at a major transport hub. The station is supporting a fleet of fuel cell taxis deployed in late July 2012 to ferry VIPs to and from the Olympic Park.

California

California has historically been a heavily polluted area. In 1990, the California Air Resources Board (CARB) issued a mandate requiring the introduction of zero-emission vehicles (ZEV) in the state from 1998. Although later postponed and amended, this rule provided much of the impetus for the development of FCEV in the 1990s. In September 2011 the California Energy Commission invested $8.5 million to support the deployment of FCEV in 2015.[8] This was followed by the launch of the CARB's Advanced Clean Car programme in January 2012, which coordinates requirements for car model years 2017–2025, mandating that ZEV (FCEV and BEV) and PHEV must account for one in seven car sales by 2025. By 2050 it is hoped that 87% of the on-road fleet will be ZEV.

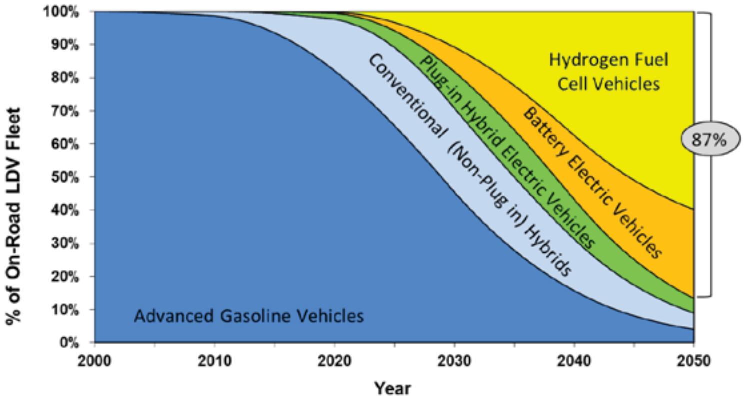


Figure 3: CARB on-road light duty vehicle scenario to reach 2050 GHG emission reduction goal [9]

A part of this programme, the Clean Fuel Outlet regulation,[9] requires the construction of alternative fuel outlets for a particular fuel (such as hydrogen) when there are 20,000 vehicles using that fuel in a region; for the South Coast, where air quality is worst, the threshold is 10,000. This means that the seven petroleum companies that currently supply 93% of California's gasoline are obliged to build hydrogen outlets in line with the introduction of FCEV, spreading the cost of new infrastructure amongst those who are profiting from the existing setup.

The California Fuel Cell Partnership (CaFCP, formed in 1999) is an automotive-OEM-backed outreach project to promote the commercialisation of FCEV in California and coordinate the development of supporting infrastructure. Honda has been leasing its FCX Clarity vehicles to Californian customers for $600 per month (over a three-year period, excluding fuel) since 2008. In the same year GM launched Project Driveway, an end user acceptance programme that leased over a hundred HydroGen4 (marketed as Equinox in the USA) in locations across the globe including California. Daimler has been leasing Mercedes-Benz B-Class F-CELL vehicles to Californian customers since December 2010 ($849 per month, three year period, including fuel). In August 2012, the CaFCP released a document entitled *'A California Road Map: The Commercialization of Hydrogen Fuel Cell Vehicles'* containing a strategy for infrastructure build-up from 2012 to 2017; it concluded that 68 station locations strategically placed around the state would adequately serve the first wave of FCEV customers in 2015.

***Emeryville** – Linde – Opened April 2012*

Located at AC Transit's municipal bus operating division, this publicly-accessible dual-purpose station can fuel up to twelve fuel cell buses and twenty FCEV per day.

***Newport Beach** – Shell – Opened August 2012*

California's eighth public hydrogen station is installed on an existing forecourt and offers unlimited free hydrogen to FCEV owners courtesy of Shell, who wants to learn about costs, consumer behaviour and dispensing efficiency.

Hydrogen Station Openings: January to August 2012

DAIMLER

2014

History

Daimler has a long history of fuel cell activity, spearheading the development of PEMFC for automotive use with its 1994 NECAR. The company remained active in the years after, producing four further variants of the NECAR before revealing its first-generation fuel cell passenger vehicle, the A-Class F-CELL, in 2002. Its second-generation vehicle, the B-Class F CELL (above) entered limited series production in late 2010 offering improvements in range, mileage, durability, power and top speed. A fleet total of 200 vehicles is now in operation across the world, including more than 35 in a Californian lease scheme.

Plans for Commercialisation

Daimler plans to commercialise its third-generation F-CELL from 2014, an update to the B-Class F-CELL that is currently in widespread demonstration, that will likely adopt the improved chassis design featured on 2012 edition conventional B-Class vehicles. Production of this vehicle will be limited and sales targeted at markets with supporting infrastructure; Daimler has been proactive with its involvement in German infrastructure-building initiatives. The German market is expected to be the largest early European market for FCEV, and the domestic manufacturer has positioned itself perfectly to capitalise on this. However, Daimler says that the scale of market introduction is intrinsically linked to cost reduction, so true volume production of the F-CELL will coincide with the fourth generation of the car, around 2017.

Daimler has also shown interest in the luxury sedan sector, a promising market for early FCEV, with the multi-drive platform F 800 Style F-CELL concept it demonstrated at the 2010 Geneva Motor Show; the car has a maximum speed of 112 mph (180 kmph) and a range of 370 miles (600 km). More recently, the F 125! concept released to celebrate the firm's 125th anniversary in September 2011 is designed to showcase Daimler's vision for 2025; the car would offer top speeds of 135 mph (220 kmph) and a range of 620 miles (1,000 km) with a fully hybridised plug-in battery–fuel-cell drivetrain.

2020

FORD

History

Ford began actively pursuing fuel cells at the turn of the millennium with several fuel cell Focus models demonstrated in 2000 and 2001. Ford continued its development of fuel cell powertrains and in 2007 launched a fleet of 30 fuel cell equipped Focus cars for testing in the US, Canada and Germany. The cars proved a success and many have continued to be used far beyond their trial period, some even to today. In the same year a stylish fuel cell crossover concept, the Edge HySeries (above), was shown at several motor-shows.

Plans for Commercialisation

Ford, one of the 'Big Three' American automakers, was deeply affected by the global automotive industry crisis from 2008 to 2010; during that period and since, no fuel cell demonstration vehicles have been released and little-to-nothing has been heard of its fuel cell commercialisation plans. However, its interest in the core technology remained clear: in 2008 Ford and Daimler established a joint venture, the Automotive Fuel Cell Cooperation (AFCC), to purchase and continue the development of Ballard Power Systems' automotive fuel cell assets.

At the 2012 World Hydrogen Energy Conference in Toronto, Ford's head of fuel cell R&D, Chris Gearhart, clarified the company's current outlook for FCEV. Having narrowly avoided bankruptcy in 2009 the company is now unwilling to lose money on a technology before profiting from it, a hurdle accepted by those automakers that have chosen to undertake FCEV demonstration projects. That said, the company is still committed to the commercial release of vehicles and is targeting a 2020 timeframe, when the technology will have become more price-competitive, an exercise that Ford is actively involved in through the AFCC.

GM

2015

History

General Motors has the longest fuel cell history of any automaker, with the ElectroVan demonstrating the potential for fuel cell technology nearly 50 years ago. The company has had a succession of fuel cell test and demonstration vehicles, including the world's first publicly drivable FCEV in 1998. 2007 saw the launch of the HydroGen4 (marketed in the USA as the Chevrolet Equinox, above), representing the fourth generation of GM's stack technology. More than 120 test vehicles have been deployed since 2007 under Project Driveway, which put the vehicles into the hands of customers and has been the world's largest FCEV end-user acceptance demonstration: the vehicles have accumulated more than two million miles on the road.

A fifth-generation fuel cell stack, half the size and with significantly less platinum than its predecessor, was integrated into a fuel cell concept of the now popular Chevrolet Volt/Vauxhall Ampera but has yet to reach test vehicles.

Plans for Commercialisation

Shortly after Project Driveway launched, the automotive industry crisis hit America. In June 2009 General Motors Corporation filed for Chapter 11 bankruptcy reorganisation in a pre-packaged solution that saw all original investment lost and the company's remaining profitable assets sold to a new government-backed entity, General Motors Company, which issued an IPO in 2010, the largest in US history at $20.1 billion. GM subsequently returned to profit last year.

Despite these severe changes in the business, including recent cuts to R&D staff, the fuel cell development division has remained; this is a positive reminder of GM's belief in the technology. It is understandable that the company has neither released further demonstration vehicles since the HydroGen4, nor affirmed any substantial details of fuel cell commercialisation. With successful trials completed in California and Germany, and with the promise of further infrastructure in these areas, it seems likely that this is where GM will commercialise first; one would hope still within the 2015 timeframe.

2015 HONDA

History

Honda's first FCX fuel cell prototype was shown at the 1999 Tokyo Motor Show aiming to provide a 'foretaste of the 21st century'; several of the prototypes were used for demonstrations and were later superseded by an updated model featuring Honda's own fuel cell technology in 2002. In 2006 the company unveiled its new FCX concept, a sleek, high-end sedan vehicle that showcased Honda's latest fuel cell and electric technologies. The concept was refined and released in July 2008 as the Honda FCX Clarity (above), the world's first commercial FCEV. Built on its own production line in Japan, the Clarity is the only FCEV custom-designed from the ground up. (Other FCEV to date have been retrofits of existing chassis designs, most commonly crossover SUV.)

Launched on a limited lease in California (where hydrogen infrastructure was most available), customers pay $600 per month over a three-year term for the vehicle, maintenance and insurance. The Clarity was met with positive reviews and more than fifty vehicles are now on lease in California, with several more in Japan and two in the custody of the Clean Energy Partnership in Europe.

Plans for Commercialisation

Honda is a signatory to both the September 2009 global letter of understanding and the January 2011 Japanese MoU, both of which set 2015 as the year for first commercialisation. The company has stated that it does not plan to mass commercialise the FCX Clarity; whether a successor utilising the same unique design elements would supersede it is unclear. The company may opt to integrate a fuel cell drivetrain into an existing model in a fashion similar to what it has done for its CR-Z, Insight and Jazz PHEV.

Honda has been proactive in the development of Japanese hydrogen infrastructure and demonstrated its own solar hydrogen station in March 2012, a platform that it intends to develop for home use. It seems likely that the company is still on track to produce a commercial FCEV by 2015, even if details have been scarce to date. In the longer term Honda plans to co-develop both FCEV and BEV, with the former powering mid-to-large cars and the latter powering smaller models.

HYUNDAI

2015

History

Hyundai-Kia unveiled its first FCEV in 2000, a Hyundai SUV with an internally developed fuel cell stack; both methanol- and hydrogen-fuelled variants were demonstrated. The 2004 Hyundai Tucson FCEV and Kia Sportage FCEV had improved ranges and fuel cells from UTC Power. Hyundai-Kia returned to demonstrating its own fuel cell technology with the 2008 Kia Borrego FCEV, the predecessor of the now well-known Hyundai ix35 FCEV, which was first revealed in late 2010. The ix35 FCEV began appearing at global events in mid-2011 and has subsequently been deployed in a wide variety of demonstration programmes, with particular interest shown in Scandinavia.

Plans for Commercialisation

Hyundai demonstrated its ix35 FCEV extensively throughout late 2011 and 2012 for good reason: the company will be producing approximately one thousand of these vehicles for lease between 2012 and 2014, before entering full commercial production with a 10,000 unit full-scale production run planned for 2015. Lease schemes will vary in scale, from the consumer level through to the national level. In May 2012 Hyundai signed an MoU with Norwegian firm Hydrogen Operation to supply ix35 FCEV to public agencies, commercial fleets and taxi firms in Norway.

Hyundai has stated that it is seeking to sign further MoU with private enterprise firms in the Nordic region; the strong drive for sustainable technologies here makes it a perfect launch market for FCEV. Hyundai has also actively demonstrated its vehicles in Germany, the UK and the USA, all of which are promising early markets for FCEV. Hyundai is aiming for a competive cost of $50,000 (USD) (£35,000 (GBP)), a premium of approximately 40% over the premium ICE model. In the longer term Hyundai-Kia plans to use the Kia brand to sell smaller battery electric vehicles and the Hyundai brand to sell larger fuel cell electric vehicles.

NISSAN

2016

History

Nissan is a relatively new player in the FCEV game. Its first fleet of demonstration vehicles came in 2003: X-Trail SUV fitted with UTC Power fuel cells. These vehicles were leased to a number of Japanese businesses and authorities in 2004 and in 2005 the X-Trail FCV was updated with the first generation of Nissan's in-house fuel cell stack technology. Variants of this model, including a 2008 update with a second-generation stack, were showcased across the world until late 2009. As several other automakers began to release next-generation demonstration vehicles, Nissan decided to focus its efforts on further development of the fuel cell stack system instead.

Plans for Commercialisation

In October 2011 Nissan announced its next-generation fuel cell stack, claiming an industry-leading power density, substantial size reductions over existing stacks and a cost one-sixth that of its 2005 stack due to a lower platinum loading and more cost-effective parts. The company plans to integrate a version of this stack into a commercial FCEV from 2016. Launch markets and volumes are unknown at present.

TOYOTA

2015

History

Toyota's first fuel cell prototype, a hydrogen fuel cell powered RAV4, was demonstrated in 1996. There have been five revisions of this SUV concept since, each with improved fuel cells and electric drivetrains: the FCHV-2 in 1998 (methanol-fuelled), FCHV-3 (metal hydride storage), FCHV-4 (pressurised hydrogen storage) and FCHV-5 (hydrogen–gasoline hybrid) in 2001, and most recently the FCHV-adv in 2008. The FCHV-adv featured a custom-designed, high-performance fuel cell stack with 700 bar hydrogen storage and has been used in numerous demonstrations globally, most notably in Japan and the USA.

Plans for Commercialisation

At the 2011 Tokyo Motor Show Toyota unveiled its commercial FCEV concept, the FCV-R (above). This is Toyota's first fuel cell sedan design; the company, like several others, is targeting the luxury sedan niche for early FCEV as the high margins allow for some cost absorption of the fuel cell technology. The FCV-R offers a 435 mile (700 km) range and represents the earliest iteration of what will be Toyota's first commercial offering, which at the 2012 Geneva Motor Show the company affirmed would be on the market in 2015.

Cost is currently projected at $125,000 (USD) though this may come down with further improvements to both the fuel cell stack and Toyota's Hybrid Synergy Drive platform, an adaptable drivetrain solution that standardises and shares components across FCEV, BEV and PHEV. Such work is evidently underway as an un-badged Lexus (a subsidiary of Toyota) HS was seen refuelling with hydrogen in the USA in August 2012; Toyota confirmed it is using the HS as a platform for testing its fuel cell systems.

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