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Trends in Hydrogen Vehicles

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Acknowledgment/preface

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Abstract

In this study, an overview is given of the latest developments on the Fuel Cell Vehicle (FCV) market up to date, October 2009. Attention has been paid to the identification of the OEMs that are the most active in the FCV field. Following on the listing of the most active OEMs, the scale of their actual activity is identified in terms of cars put on the road. The report then describes the amount and nature of experiences gained with the FCVs on the road. Finally, trends in cost-price are reported, together with explanations on further cost-reduction intentions of the OEMs towards the future.

Contents

List of tables

List of figures

Summary

This report provides an update of the latest developments that have recently occurred in the car industry within the field of Hydrogen powered fuel cell vehicles (FCVs) to date, October 2009. To attempt to provide a clear and logical overview, the report starts with an overview of the original equipment Manufacturers (OEM)s that are actually active within the hydrogen vehicle business, and illustrates the intensity of FCV activity per OEM. This shows that there is a distinct group of OEMs that are most active, while others have tried to get some experience but have not seriously been involved in in-house technology development of FCV manufacturing. Furthermore, some manufacturers have chosen an alternative path when it comes to using hydrogen for vehicle propulsion and developed a hydrogen fuelled conventional Internal Combustion Engine (ICE). In the field of FCVs, most FCV activities are displayed by Honda, Daimler, Opel/GM, Hyundai/Kia, Toyota, Nissan and Ford. Volkswagen has given less priority to FCV development and has not been marketed itself as an OEM prioritizing hydrogen technology expertise. Mazda and BMW chose to put their efforts in the development of hydrogen fuelled ICE vehicles. Ford has put efforts in hydrogen fuelled ICE vehicles as well as FCVs.

After the active OEMs are mapped, an overview is given on how active they have been in terms of cars produced. It was difficult to come up with reliable estimations on the basis of numbers available for public. The sum of vehicles produced by all OEMs together was estimated around 500 - 550 vehicles. This estimation however was much lower than the figures published by Fuel Cell Today (FCT). FCT projects accumulated vehicles shipped in 2009 around 1100 units, double the numbers found by this study. Communication with FCT informed us that FCT has access to confidential information from the OEMs. This was especially relevant for the Asian OEMs who do not publicise numbers of FCVs shipped clearly, however FCT claims to have indirect insight to these numbers.

Lessons learned from driving the FCVs are in general encouraging. Durability and reliability are improving with experience. Fuel economy is increasing, range is increasing and costs are still going down. Generally it can be said that the OEMs are on schedule for delivering the required improvements, though they also warn that they cannot make FCVs a success on their own and call for market stimulation through the development of fuel cell refuelling station networks.

1. Introduction

Since the mid-nineties, global efforts to build hydrogen powered fuel cell cars have gained momentum. The first three to five years of the new millennium brought many promises and hopes to an impatient public who were eager to see the breakthrough of the next technology in mobility. It is not exaggerated to refer to that period as some sort of 'hydrogen hype'. The last two years, the media attention has shifted to the novelties of the field of battery electric vehicles, which resulted in the impression that the "hydrogen economy" would die a silent death. Indeed hydrogen may not provide the silver bullet to all energy dilemmas (as is the case for most other alternatives as well). However, in transport-applications hydrogen still provides a competitive alternative to conventionally fuelled vehicles, due to the high energy efficiency of fuel cells as well as the high energy density of hydrogen as an energy carrier.

In this report, we take a closer look at recent activities of the Original Equipment Manufacturers (OEMs) of the car industry relating to hydrogen vehicles in general and fuel cell vehicle development more specifically. In the last few years, several hydrogen vehicle demonstration projects have been performed and monitored. This has resulted in valuable knowledge accumulation which provides good insight into the performance of contemporary hydrogen vehicles, as well as their development over time.

This accumulated knowledge which is partially based on this feedback from real-world experiences is of great value for the industry and has been a contributing factor to substantial performance improvements. In general it can be stated that R&D efforts over the years have led to fuel cell cost price reductions, size and weight reductions and increased driving-ranges.

2. Global overview

2.1 Main brands involved in hydrogen vehicle development

An historical overview of hydrogen vehicle developments that have been trialled publically reveals that there are several main actors (brands) who spent considerable time in a structured manner on the development of hydrogen vehicles. In table 1, an overview is given of the number of hydrogen vehicles that different brands have produced over the last 14 years. The specification (type, name) of the vehicles has been left out for sake of clarity. In **Figure 1**, a graphical representation of table 1 is given in which the vehicle manufacturer data is aggregated to give totals for each year.

Table 1: *H2 vehicle activities per brand per year from 1990 to 2009 (source: hydrogen cars now).*

Year:	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	
OPEL			2		1	1	1		1						**6**
BMW (ICE)			1	1		1		1			1				**5**
GM			1		1						1		1		**4**
Toyota		1				3			1	1					**6**
Mazda (ICE)		1		1				1	1						**4**
Honda				2	1	1	1	1	1	1	1				**9**
Daihatsu				1		1			1						**3**
Nissan				1			1	1	1						**4**
Daimler				1	2	2	1		2	1					**6**
Ford (incl. ICE)				1	1	2	1	2	1		1	1			**8**
Volkswagen					2		1		1				1		**5**
PSA					1	1					1				**3**
Lada						1		1							**2**
Fiat								1	1		2				**4**
Mitsubishi								1							**1**
Suzuki								1		1					**2**
Hyundai								1	1						**2**
Kia									1				1		**2**
Audi									1						**1**
THINK										1					**1**
REVA										1					**1**
Hywet												1			**1**
Renault													1		**1**
		2	**4**	**8**	**8**	**13**	**6**	**11**	**14**	**4**	**7**	**2**	**4**		**81**

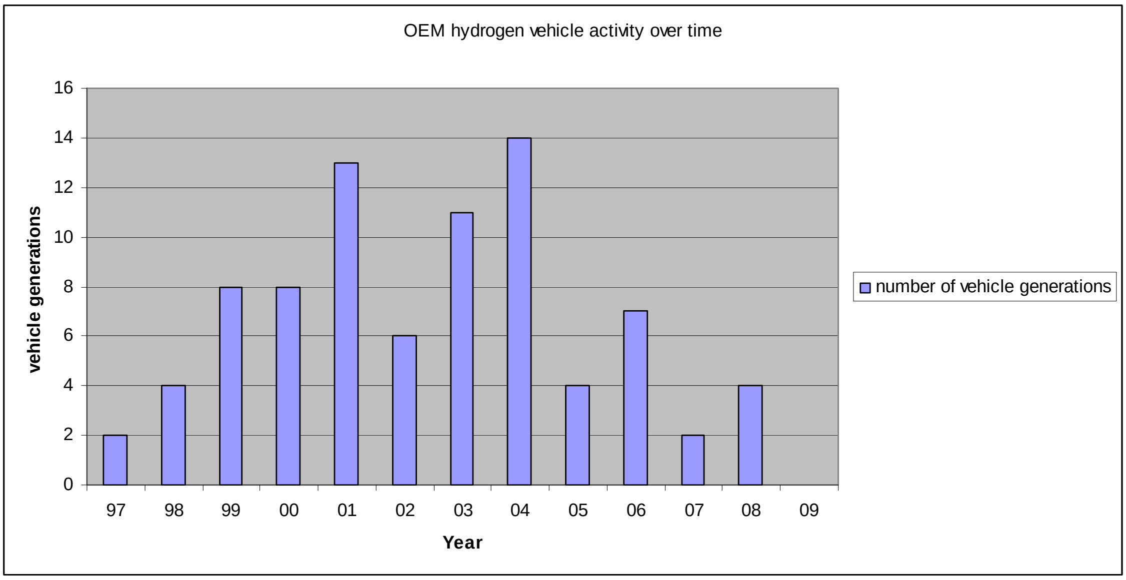

Figure 1: *OEMs' activity on hydrogen vehicle development, expressed in vehicle generations per year brought forward.*

Honda, Ford, Opel/GM, followed by Daimler, Volkswagen, Toyota, Mazda, Hyundai/Kia and Nissan account for most activity in the field of hydrogen vehicle development. 2004 was the year with the most activity in terms of new models exhibited by the automobile industry. The models taken into account in table 1 are those models that are or have been on the road. Ford has experimented with a variety of vehicle configurations, such as hydrogen powered combustion engines and onboard methanol reforming. BMW argues that the internal combustion engine (ICE) still has significant potential to be improved, therefore BMW has chosen for the strategy of increasing Hydrogen fuelled ICE efficiency. Mazda has an impressive track record in the development of Wankel ICEs and is focusing on hydrogen powered Wankel ICEs. Wankel ICEs are engines based on a rotary design instead of a piston based design.

Many manufacturers also have been exhibiting prototypes to the public, which mainly serve to increase the manufacturer's profile. These models have therefore been left out of consideration as they are not part of intensive, structured testing schemes. Note that the numbers in table 1 intend to give an indication of the number of iterations the manufacturers have made in their hydrogen car research and development (R&D), but do not give an indication of the number of cars they have manufactured so far. Mercedes for example manufactured a first series of 60 of the F-Cell cars, which is not illustrated by table 1. Similarly, table 1 and figure 1 could be interpreted as if the activity in hydrogen R&D by the OEMs has decreased since 2004, yet this is far from true (see e.g. section 3.1, **Figure 3**). The production of small series of hydrogen vehicles with better performance and durability has been started or will soon be started by different OEMs that have gained expertise and confidence by their iterations made in preceding years.

On September 9, 2009, the car manufacturers Daimler, Ford, GM/Opel, Honda, Hyundai, Kia and Renault/Nissan have signed letters of understanding and given a joint statement indicating they intend to the develop and introduce to the market electric vehicles with fuel cells. The car manufacturers think it is possible to have commercial fuel cell car available from 2015 onwards.

2.2 Globally acquired experience with Fuel Cell Vehicles: demonstration projects

Many of the vehicles developed by the individual brands have been driven within larger demonstration projects. In particular demonstration projects are:

- The US DOE National Hydrogen Learning Demonstration project.[1]
- The German Clean Energy Partnership (CEP) in Berlin. CEPI ran from 2003 to 2007. CEP II started in 2008 and is planned to continue until 2010. The last phase will be CEP III, starting in 2011 and ending in 2016.[2]
- The California Fuel Cell Partnership (CaFCP) which started in 1999 and is ongoing.[3]
- The Korean MKE fleet program which started in 2003 and is still ongoing with mile-stone goals defined for 2012. The program is split into 3 phases: phase I (2003-2005), phase II (2006-2008) and phase III (2009-2012)[4]
- The Vancouver Fuel Cell Vehicle Program (VFCVP) which started in 2005 and finished in 2008.[5]
- The Japan Hydrogen and Fuel Cell Demonstration Project (JHFC) which started in 2002 and is planned to end in 2010. [6]
- The European Zero Regio program which started in 2004 and was planned to finish in 2009.[7]

The sizes of these projects, expressed in numbers of vehicles and refuelling stations are:

- CEP: a total of 24 vehicles up to date, and 2 refuelling stations;
- CaFCP: a total of 193 vehicles op to date and 23 refuelling stations;
- The MKE fleet program: 30 vehicles up to date and 8 refuelling stations;
- The VFCVP program: 2 refuelling station and 5 vehicles;
- The JHFC program: 12 refuelling stations, 60 vehicles;
- The Zero Region program: 2 refuelling stations, 8 vehicles.

Vancouver will host the Olympic Winter Games in February 2010. By then, 20 fuel cell buses will be operational in and around Vancouver. For this reason, a hydrogen refuelling station has been built in Whistler, the ski resort near Vancouver. Furthermore, there will be a fleet of 8 GM's Chevrolet Equinox FCVs (**Figure 2**) operational throughout the Olympics. In total there will be 7 refuelling stations operational by the end of January 2010.

Figure 2: *The Chevrolet Equinox*

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[1] http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/fleet_demonstration.html
[2] http://www.cleanenergypartnership.de
[3] http://www.fuelcellpartnership.org/
[4] http://www.mke.go.kr/language/eng/index.jsp
[5] http://www.vfcvp.gc.ca/
[6] http://www.jhfc.jp/e/index.html
[7] http://www.zeroregio.com/front_content.php

3. Trends in Production scales and cars on the road

3.1 Overview of manufacturers: numbers of Hydrogen cars produced

From the most active manufacturers, some have built small series of their hydrogen vehicles or have planned to start building small series soon. The following subsections give an overview of the cars actually built and on the road, per manufacturer. The overview is based on announcements and publications of the OEM's as well as on the earlier ECN study "Market Perspectives of H2 vehicles – analysis of current status and requirements" by I. Bunzeck.[8]

3.1.1 Honda

Honda started the production of a small series of its latest fuel cell vehicle, the FCX Clarity mid-June 2008. The intention is to market 200 vehicles on a leasing basis over a period of three years. By lack of accurate information on the progress of numbers of Clarity's produced, a linear placement development is assumed. On the basis of the assumption, we estimate that around 80 vehicles should be on the road by October 2009.

3.1.2 Opel/GM

Opel has been working with fuel cell vehicles for a significant time. 18 third generation FCVs called Hydrogen 3 were built and tested. These vehicles are now followed up by Opel/GM's third generation, the Hydrogen 4 (Opel) or Equinox FCV (GM).
Through Project Driveway, Opel/GM promote their Fuel Cell SUV called Equinox, of which more than 100 units have been built up to date. Up to now, no market introduction announcement as been made by Opel/GM concerning the Equinox.

3.1.3 Toyota

Toyota has been producing small numbers of its latest fuel cell vehicle, the FCHV-adv. Toyota is not very forthcoming with information on production numbers. However, Toyota has reported that about 14 FCHV-adv's have been leased in Japan, and 24 of them are used as test vehicles. As they have announced that they would deploy some FCHV-adv's in the US, we conservatively estimate the number of units produced on roughly 40.

3.1.4 Daimler

Daimler was one of the first to produce a small series of a fuel cell car, they have had over 60 FCVs of the A-class F-Cell vehicle in operation for testing and demonstration. They have announced recently to start the production of a small series of 200 B-class based F-cell vehicles.

3.1.5 Kia/Hyundai

The Kia-Hyundai automotive group has produced up to 32 fuel cell powered versions of their Tucson and Sportage SUV's . These vehicles have been deployed in demonstration projects in the US and Korea. In a follow-up effort, they have presented the Kia Borrego FCV which is currently being road tested. Kia-Hyundai plans to start a small scale production of this Borrego FCV in 2010.

3.1.6 Mazda

Mazda, like BMW, is focusing on hydrogen powered ICEs. Mazda developed the RX-8 Hydrogen RE which has been available for lease in Japan since 2006. They sold 30 units of the RX-8

[8] http://www.ecn.nl/docs/library/report/2009/e09028.pdf

to the HyNor project in Norway. Recently they have built in their hydrogen fuelled rotary engine, the Mazda Premacy Hydrogen RE hybrid and started leasing a number of these units too.

3.1.7 Nissan/Renault

Nissan has not unveiled a new FCV's since their last X-Trail FCV (2003/2004). However, before this date, they had developed their own in-house fuel cell technology. In 2008, the Nissan fuel cell technology has been used as the basis for the Renault Scenic ZEV. Independently of Renault, Nissan has announced that it was testing its latest generation of their own FCV. This vehicle will be officially unveiled next year, according to Nissan. More on the Nissan fuel cell developments will be explained in Chapter 6, paragraph 1.4.

3.1.8 Volkswagen

Volkswagen China produced 16 VW Passat Lingyu FCV's for the Beijng Olympics which are now deployed at the California Fuel Cell Partnership in the USA. In addition, Volkswagen Germany has a fleet of around eight fuel cell vehicles based with two designs, the Touran and the Tiguan.

3.1.9 Ford

Ford will keep the 30 FCV's it had introduced in 2005 in demonstration projects, but has recently announced to shift some of its resources from FCV R&D into "technologies with more commercial short term potential", but still sticks to the statement that fuel cell technology is the ultimate goal and therefore Ford continues to invest in fuel cell R&D.

3.1.10 BMW

BMW has built the Hydrogen 7 as a bi-fuel ICE car in a small series of 100 units which were handed out to high-profile individuals. No follow-up plans have been revealed however.

3.2 Estimation of total FCVs produced and shipped

The estimated cumulative number of vehicles rolled out by the different OEMs would be, based on the numbers from the previous paragraph (§ 3.1), somewhere between 500 and 550. The exact number remains unclear, since there are few facts available on for example the Japanese fuel cell demonstration project. Numbers produced by certain manufacturers, for example Nissan, also remain unclear. Furthermore, the above overview only addresses those OEMs who showed the highest hydrogen vehicle R&D activity. The 2009 Survey on hydrogen fuelled Light Duty Vehicles[9] published by Fuel Cell Today, shows significantly higher numbers on total shipped vehicles, with a cumulative figure of over 1000 vehicles today. The yearly numbers of shipped fuel cell vehicles as given by Fuel Cell Today are displayed in **Figure 3**, the cumulative amounts over time are given in **Figure 4**.

[9] http://www.fuelcelltoday.com/media/pdf/surveys/2009-Light-Duty-Vehicle-Free.pdf

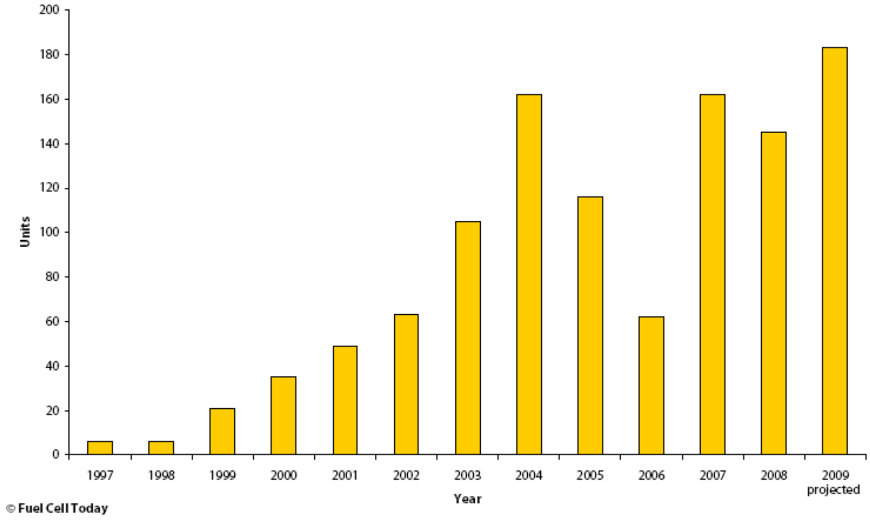

Figure 3: *Number of Hydrogen Vehicles shipped per year by the different OEMs (Source: Fuel Cell Today)*

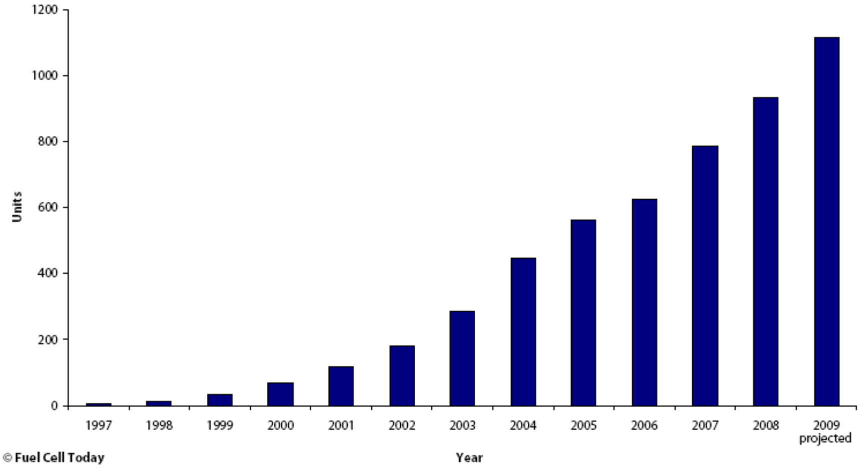

Figure 4: *Cummulative numbers of Hydrogen Vehicles shipped by the different OEMs (Source: FuelCellToday)*

4. Driving miles accumulated by vehicles on the road

The hydrogen vehicles which are on the road now, have been extensively monitored by a diverse range of demonstration programs. All demonstration programs publish their numbers, and there is occasional overlap between these numbers and numbers published by individual OEMs. We give here an overview of the highlights by demonstration program or OEM of the experience gathered by vehicles driven on the road.

4.1 National Fuel Cell Vehicle Learning Demonstration, USA

Within the National fuel Cell Vehicle learning Demonstration project governed by the USA's Department of Energy (DOE), a total of 2.3 million miles (3.680.000 km) have been driven by the FCVs to date, accumulated during over 100 000 hours drive-time.[10] The composition of the DOE fleet over time is explained in **Figure 5**.

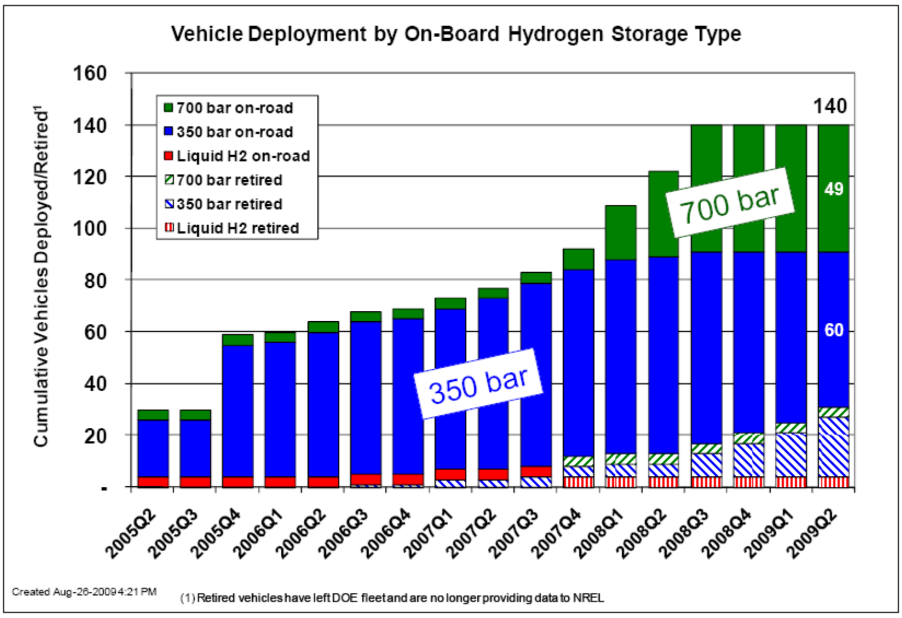

Figure 5: *The DOE FCV demonstration fleet over time (source: K. Wipke, NREL)*

As can be seen in figure 3, there is a trend within the OEMs to step from 350 bar hydrogen storage to 700 bar storage. (Source: K. Wipke, NREL)

4.2 California Fuel Cell Partnership

The CFCP program reports on a total of 2.8 million miles (4 480 000 km) driven by the pool of hydrogen vehicles and fuel cell buses. [11]

4.3 Individual OEMs

4.3.1 Opel/GM

GM reports in September 2009, that within the Project Driveway, they have accumulated over 1 000 000 miles (1 600 000 km). These miles are solely gathered by the 100 Chevrolet Equinox models that have been put on the road.

[10] http://www.arb.ca.gov/msprog/zevprog/2009symposium/presentations/wipke.pdf
[11] http://www.arb.ca.gov/msprog/zevprog/2009symposium/presentations/dunwoody.pdf

4.3.2 Daimler

Daimler reports they have covered over 4 000 000 miles (6 400 000 km) with their fleet of FCVs.

4.3.3 Ford

Ford accumulated over 1 000 000 miles (1 600 000 km) by testing their hydrogen vehicles. All 5 of their testing vehicles in Canada accumulated a mileage which exceeded 40 000 km.

4.3.4 Other OEMS

It remains unclear how many miles other OEMS have driven with their demonstration FCV's. The best indications are given by the demonstration projects in which the vehicles are being operated.

5. Operational specifications recorded during demonstration projects

5.1 Fuel Economy

In the National Fuel Cell Vehicle Learning Demonstration Project, second generation vehicles have been introduced, offering the opportunity to see possible consequences of technological progress, for example in improved fuel economy. **Figure 6** presents the fuel economy developments within the DOE fleet over the 2 generations of vehicles that have been tested.

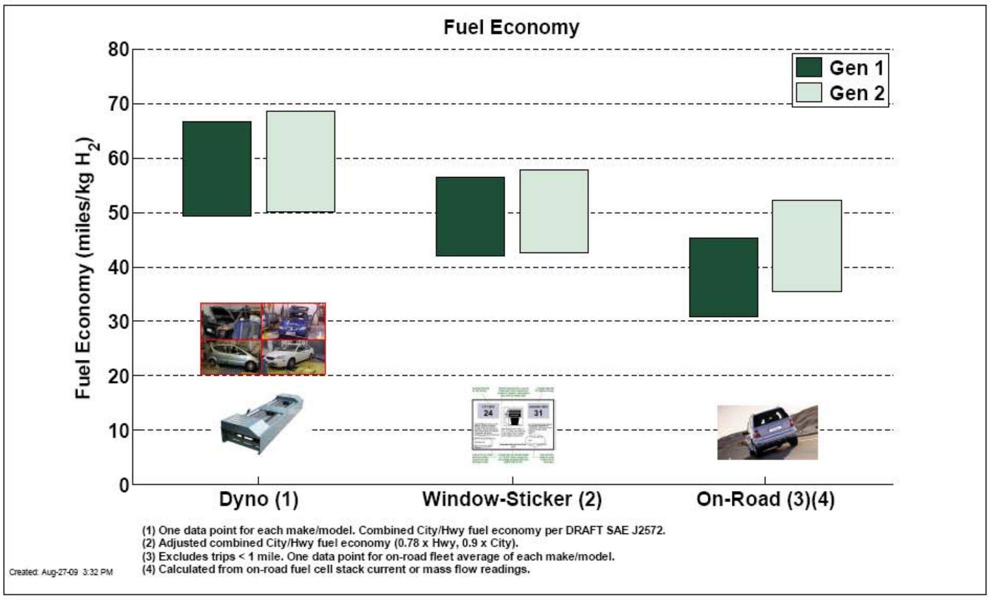

Figure 6: *fuel economy development of vehicles in the National Fuel Cell Vehicle Learning Demonstration Project, USA. Distinction is made between laboratory measurements (Dyno), values given by the OEMs (Window-Sticker) and practice (On-Road). For conversion to liters of gasoline equivalent (lge): 30 miles/kg = 12,2 km/lge; 40 miles/kg = 16,3 km/lge; 50 miles/kg = 20 km/lge; 60 miles/kg = 24,4 km/lge; 70 miles/kg = 28,5 km/lge (Source: K. Wipke, NREL)*

5.2 Range

Fuel economy does have influence on the range of a vehicle, but the biggest jumpe in range came from moving from350 bar hydrogen pressure tanks to 700 bar tanks. This has lead to larger amounts of hydrogen that can be stored onboard per unit volume. In **Figure 7**, the trend in vehicle range is presented, showing a clear “jump” between first and second generation vehicles.

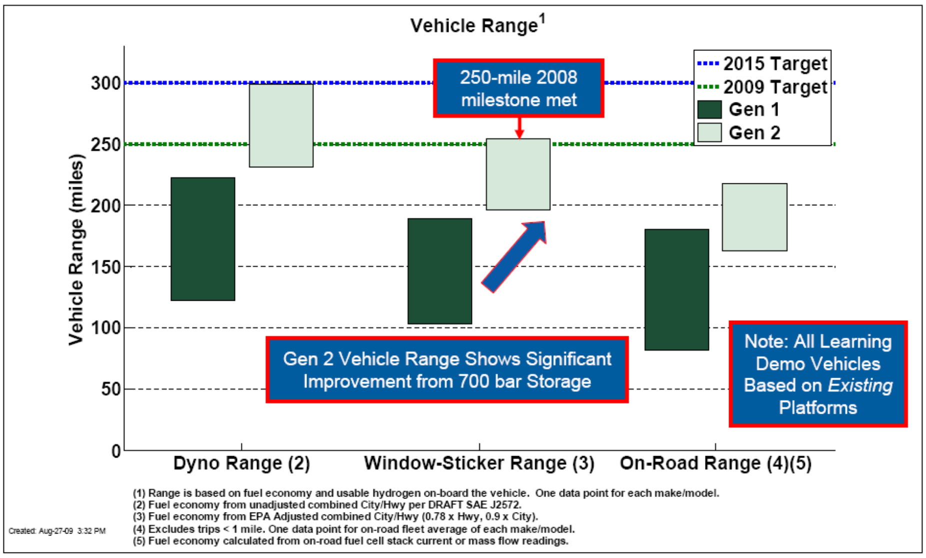

Figure 7: *Aggregated FCV range within the National Fuel Cell Demonstration Program (Source: K. Wipke, NREL)*

Improvement in range is also shown recently by the latest models of the OEMs. Recently, the latest Toyota FCV, the Toyota FCHV-adv, drove 332 miles (531 km) on a single refill. At the end of the journey, there was still hydrogen in the tank. Using the average fuel economy of the drive and the amount of hydrogen left in the tank it was calculated that, theoretically, it would be possible to drive an additional 100 miles (160 km). This adds up to a total range of 431 miles or 690 kilometers.[12] This is more than double the target range set for 2008. The OEM KIA claims a range of 426 miles for its Borrego FCV, or 681 kilometer.

Figure 8 and **Figure 9** present the development of the fuel economy (**Figure 8**) and the range (**Figure 9**) of FCVs over the last 3 years by means of 3 different models.

Whereas the increase in range can be assigned to a large extent to the tank pressure and the tank volume, the fuel economy could theoretically be explained by difference in vehicle weight and of course driving behaviour. The GM Equinox has a curb weight of 1982 kg, the Honda FCX Clarity has a curb weight of 1625 kg and the Toyota FCHV-adv has a curb weight of 1880 kg. The weight ratio between the Toyota and the GM of 0,95 but the fuel economy ratio between the Toyota and the GM is 0,56 demonstrating that the fuel economy has improved much more than weight reduction can explain. It is most likely that this improvement in fuel economy can be explained by progress in mastering the construction of fuel cell vehicles.

[12] http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/toyota_fchv-adv_range_verification.pdf

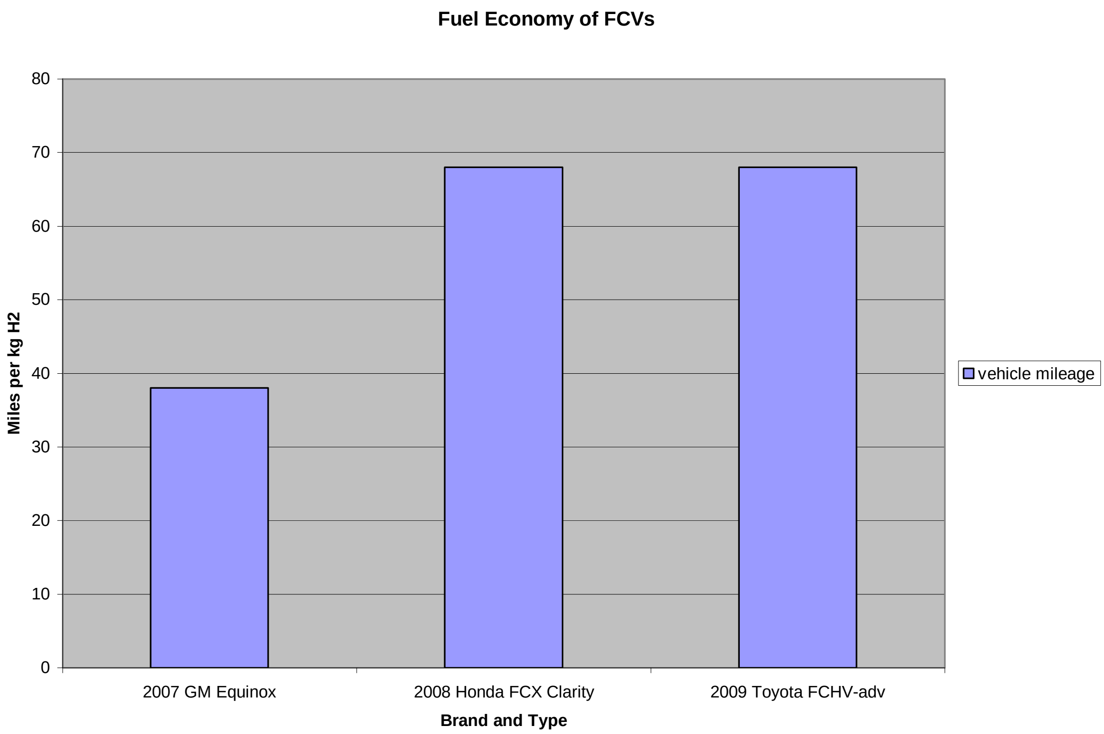

Figure 8: *Development of the fuel economy of FCVs over the last three years.*

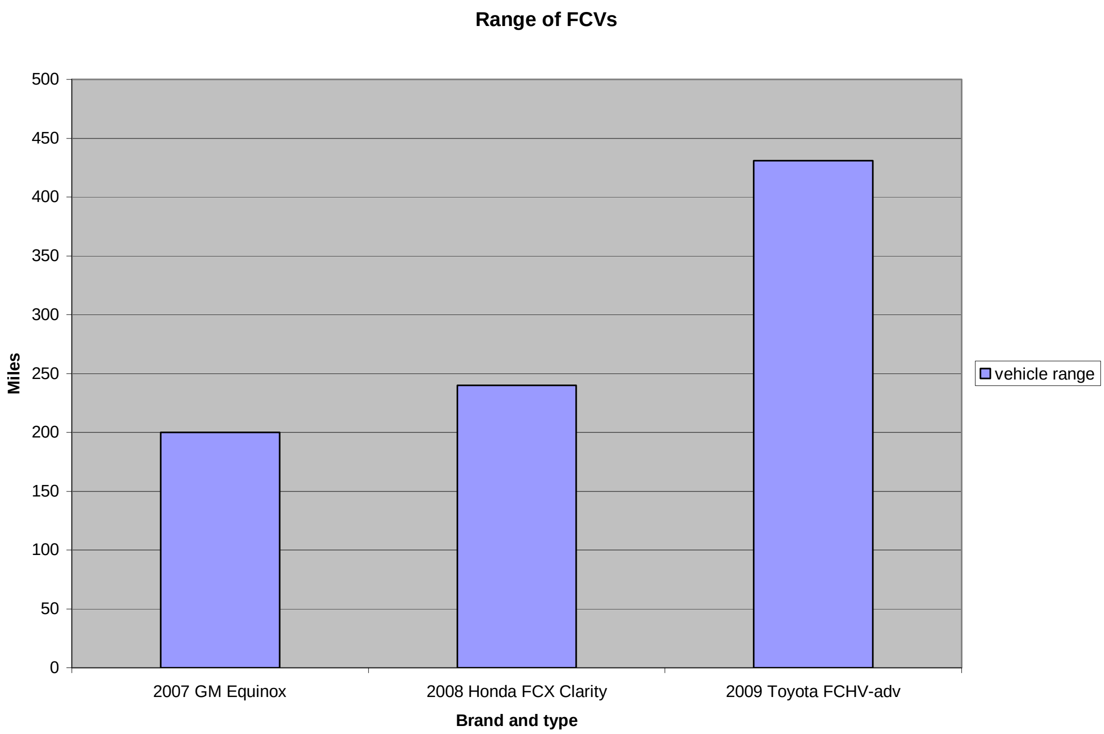

Figure 9: *Development of the range of FCVs over the last three years.*

6. Experience translating into technological improvement: learning trends

6.1 Size and weight reduction of fuel cell systems

6.1.1 Opel/GM

GM has recently announced its latest, fifth generation fuel cell system which weights 100 kg less and occupies 50% less space, now taking the space equal of a 4-cylinder ICE (**Figure 10**). Furthermore they have reduced the amount of platinum in the fuel cells by 50%. The Equinox still uses the fourth generation fuel cell.

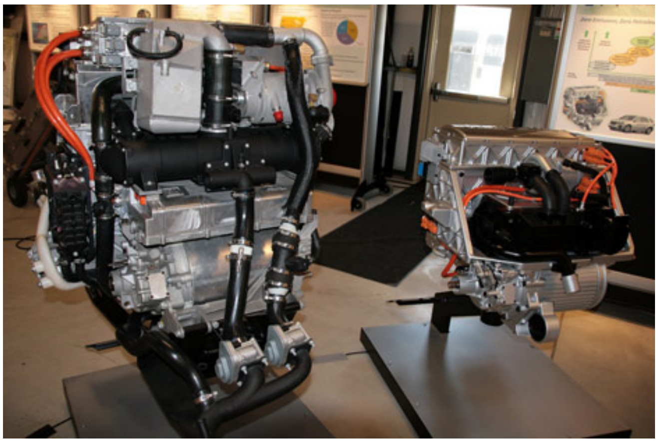

Figure 10: *GM's Fifth generation fuel cell system (on the right) compared to its fourth generation predecessor (left), showing a volume reduction of 50%. (Source: GM).*

6.1.2 Daimler

Daimler present improvements of their fuel cell system using 4 parameters: size, power, fuel economy and range. In **Figure 11**, the overall improvements of the Daimler fuel cell system are displayed, comparing the fuel cell system in the 2004-2009 demonstration models and the 2009+ small production vehicle.

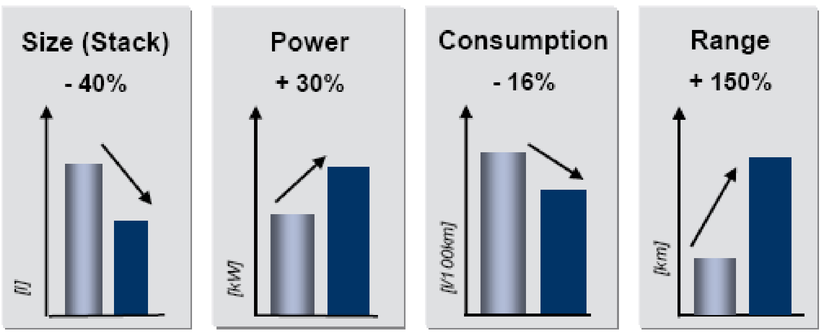

Figure 11: *Evolution of the Daimler fuel cell system. (Source: Daimler).*

6.1.3 Honda

Honda is one of the most active OEMs in the field of fuel cell powered propulsion of vehicles. In **Figure 12**, the evolution of the Honda fuel cell stack over the period 1999-2008 is shown in a graph. R&D efforts at Honda have lead to a power-per-weight output density increase of a factor 5 and a power-per-volume output density increase of a factor 4.

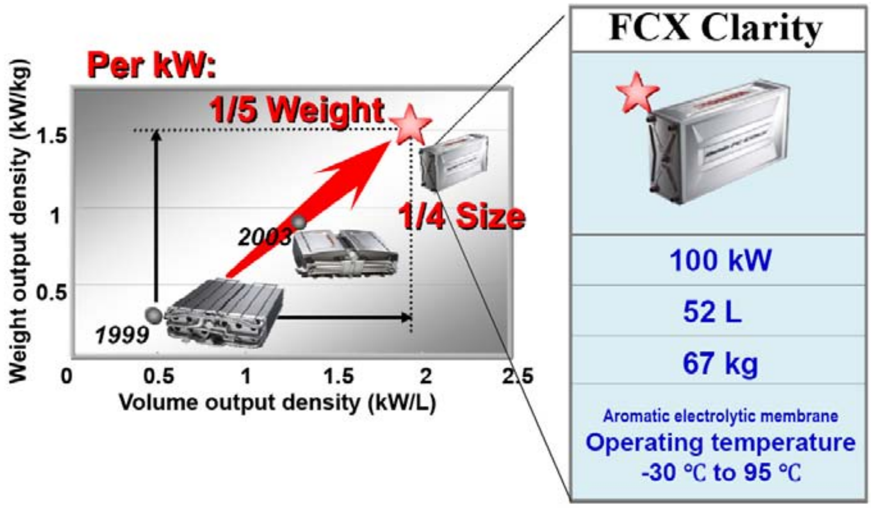

Figure 12: *Evolution of the Honda fuel cell stack over 1999-2008 (Source: Honda)*

While the system dimensions have decreased, Honda shows that the performances of the FCX models have improved over time. **Figure 13** shows the improvement of the acceleration of the FCX series over time.

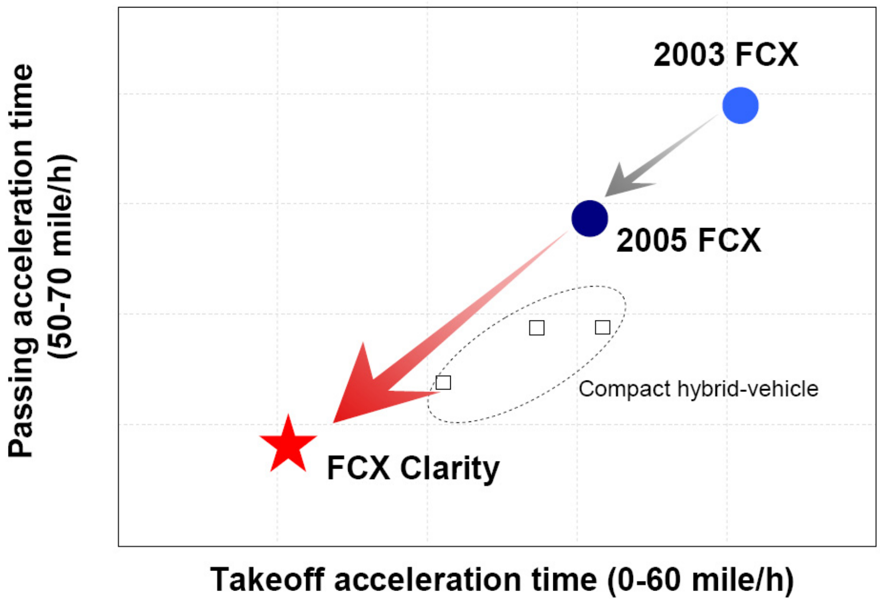

Figure 13: *Development of the acceleration characteristics of the Honda FCX fuel cell vehicles over time (Source: Honda). Exact numbers are not published by Honda. The figure presents only relative improvements within the Honda FCX line of vehicles that are achieved by increasing experience and technological know-how over time.*

6.1.4 Nissan

Nissan has announced in 2008 that its latest fuel cell system is 35% cheaper than the previous Nissan system due to a 50% reduction in platinum required. Furthermore, the 2008 generation fuel cell system has a reduced size of 68 liters, roughly reduced by one third compared to Nissan's previous generation's volume of 90 liters. Despite the volume reduction, the power output of the Nissan fuel cell stack has increased from 90 to 130 kW. The latest Nissan fuel cell stack is shown in **Figure 14**.

Figure 14: *Nissan's 2008 fuel cell stack. (Source: Nissan)*

6.1.5 Hyundai/Kia

Hyundai/Kia has achieved their power density improvements over time as presented in **Figure 15**. The graph shows the power density as a function of the total stack power. The 2010 Hyundai fuel cell should have a volume of around 70 liters, according to the graph.

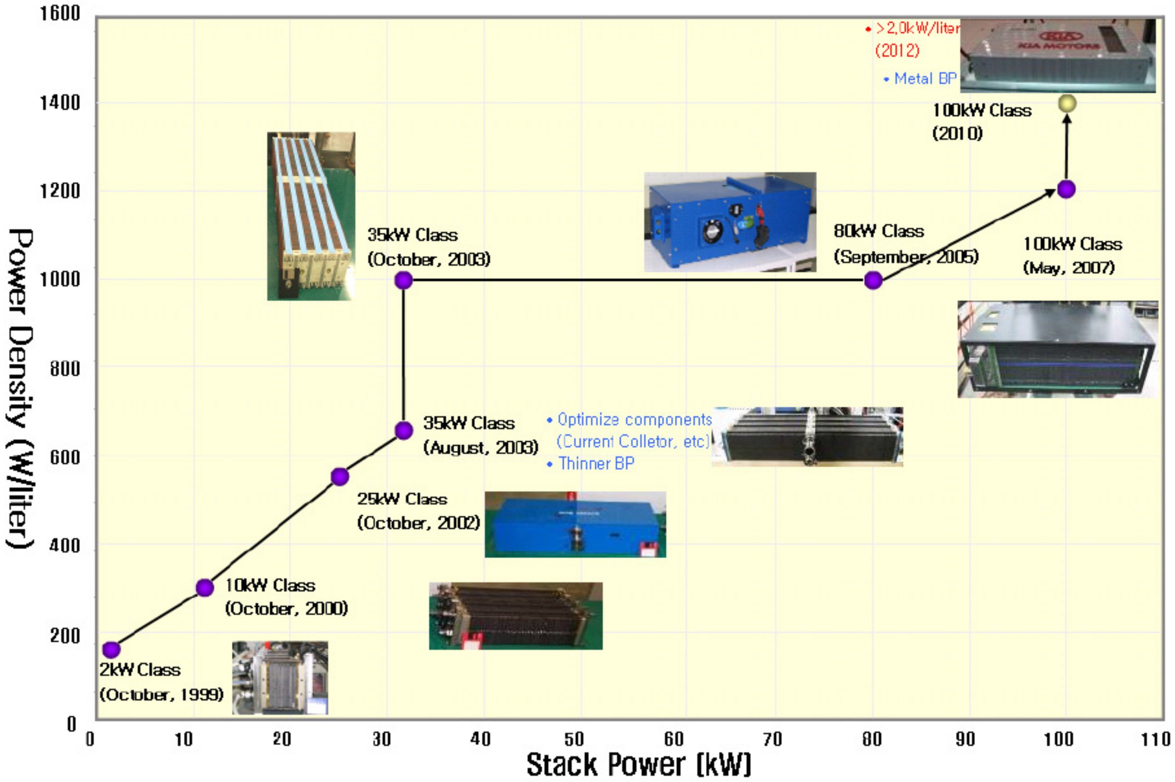

Figure 15: *Fuel cell power density development at Hyundai/KIA (Source: Hyundai/KIA).*

6.1.6 Automotive Fuel Cell Cooporation (AFCC)

AFCC, OEM of fuel cell systems such as those used by Daimler presents the power density of its systems as function of the time as shown in **Figure 16**. AFCC is owned by Daimler, Ford and Ballard Power Systems.

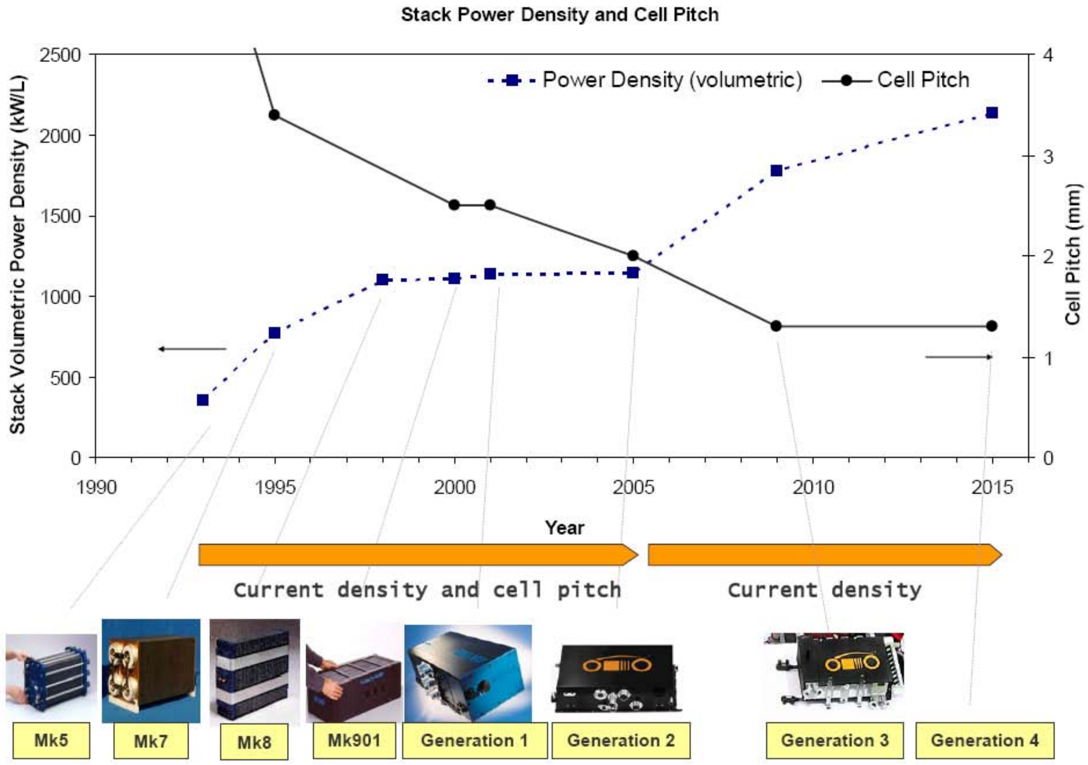

Figure 16: *Development of power density of AFCC fuel cell stacks from 1993 to 2015. Note that there is an error in the units of volumetric power density which is not kW/L but W/L. (Source: AFCC)*

Honda and Nissan both have achieved Volumetric Power Densities of 1.9 kW/l. AFCC's fuel cell stacks have about the same power density, according to **Figure 16**: about 1.8 – 1.9 kW/l. Hyundai/KIA seems to have somewhat lower power densities: around 1.4 kW/l at present.

6.2 Durability and reliability

6.2.1 Durability

Whereas the fuel cell performances per weight and volume have increased for all of the OEM's different systems, these improvements have little value if the systems do not deliver these performances with a sufficient level of reliability and durability. Studies performed by NREL have given an indication of the durability of first and second generation fuel cell systems. Currently, the durability of fuel cell systems is on and even ahead of schedule of the National Fuel Cell Learning Demonstration Project, which had set 2000 hours as a durability target for 2009. **Figure 17** shows the NREL recordings of accumulated actual operating hours to date. The second generation FCVs has not yet been in operation long enough to accumulate enough hours. Projections for the second generation vehicles are encouraging and are estimated at around 2500 hours durability. The DOE target for 2015 is 5000 hours. 3M has reported however that it had managed to operate their membrane electrode assembly (MEA), which featured one formulation of their Nano-Structured Thin Film (NTFS), for over 7300 hours, thus exceeding the DOE's target for 2015.[13]

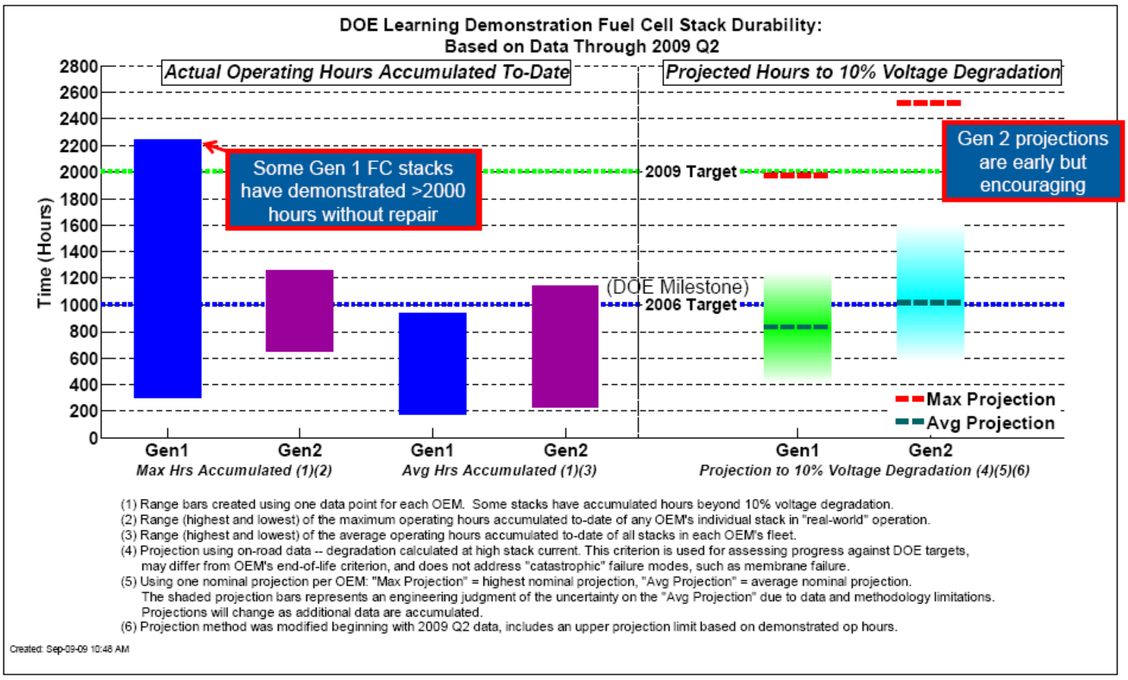

Figure 17: *Accumulated Operating hours within the Fuel Cell Learning Demonstration Program. (Source: K. Wipke, NREL)*

6.3 Reliability

Failures per unit time are an important parameter for OEMs as reliability is an important sales argument. Many system components in fuel cell vehicles are similar to those in conventional vehicles and many electric components such as the electromotor can also be assumed to be based on proven technology. It is therefore the reliability of the fuel cell system (storage tank, fuel cell stack, piping and perferials) itself which is most relevant. Dominant failure mechanisms are caused by deviations from optimal process conditions concerning contamination in the gas-flow, water-content and temperature. Most gains in reliability seem to come from improved control of the optimal operational parameters of the fuel cell stack. **Figure 18** shows typical improvements in fuel cell system reliability such as obtained by Daimler.

[13] http://www.greencarcongress.com/2008/06/3m-fuel-cell-me.html

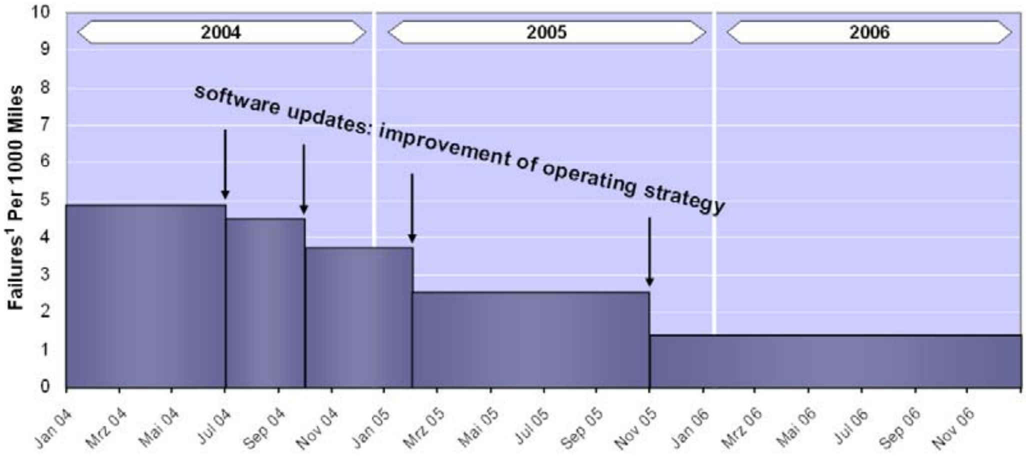

Figure 18: *Daimler's Fuel Cell Stack reliability improvements do to control-software changes. (Source: Daimler)*

7. FCV Cost price trends

7.1 Press releases and publications from the OEMS

7.1.1 Toyota

FCV cost price trends are a largely a consequence of R&D efforts in design & material, as well as a consequence of production-scale. Toyota for example foresees a cost-price reduction by a factor 10 due to design & materials, as well as a cost-reduction due to production-scale increases by a factor 10. Toyota's idea on the development of these cost-reductions is given in **Figure 19**.

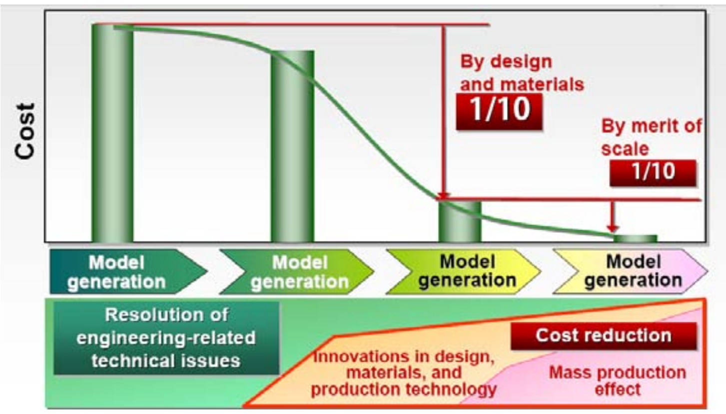

Figure 19: *Toyota's general cost-reduction prognoses for FCVs (Source: Toyota)*

Toyota has announced its first production FCV to be released in 2015. In a article in WardsAuto[14] , Toyota remained unclear about exact numbers, but announced that the price of an FCV would be so low, it would shock the US automobile industry. Exact amounts are not given.

7.1.2 Hyundai/KIA

Hyundai/KIA have published trends in the cost-price developments of fuel cell systems, extended with cost targets and estimations into the future. **Figure 20** shows these developments according to Hyundai/KIA. When we compare the graph from Figure 20 with the general figure as provided by Toyota (figure 19), we see that the figure given by Hyundai/KIA focuses solely on production scale effects. It is unclear whether they implicitly take design and materials into account but given the cost-reductions expected this is very likely. Cost-reductions are expected by Hyundai/KIA to be around a factor of 60 when the production-scale increases with a factor 10 000.

[14] http://www.wardsauto.com

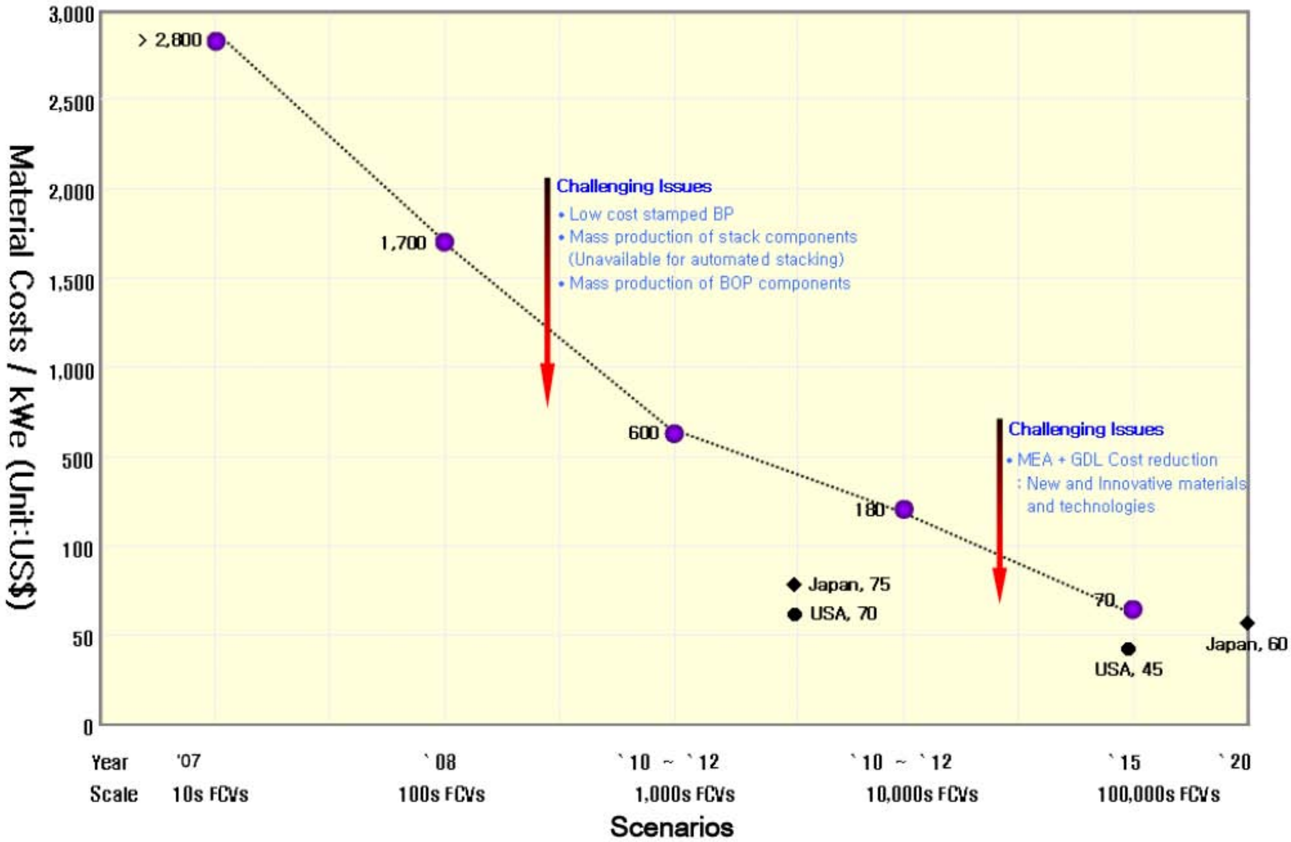

Figure 20: *Hyundai/KIA's expectations on cost reductions for fuel cell system (per Kilowatt). (Source: Hyundai)*

7.1.3 Toyota, Honda, Daimler and Hyundai/KIA

Toyota, Honda, Daimler and Hyundai Motor Co. have expressed the intention to work towards a proposed target of building FCVs that are only \$3600,- more expensive than normal midsize gasoline cars (source: Bloomberg). Condition for this reduced premium of \$3600,- is that enough units are mass-produced. Large serial production can only take off however if there is a market for FCVs, which strongly depends on the availability of hydrogen refuelling stations.

8. Summary and conclusions

Initial expectations in the nineties on the magic solutions that hydrogen could deliver may have lead to impatience by the public which as a result has lead to disappointment when the hydrogen car was not immediately commercially available. Despite the fact that high expectations may not immediately have been answered, steady progress is visible within hydrogen vehicle development which still holds the promise that the hydrogen vehicle can meet the expectations.
Since 1997, a yearly growth of the cumulative amount of hydrogen vehicles built and tested has been realized by the OEMs, to a cumulative total of over 1000 vehicles in 2009. Individual OEMs have also reported on the numbers of hydrogen vehicles they have manufactured and the distance these vehicles have driven. We focus on the FCVs since they are built on a new technology. Mazda and BMW both apply ICE technology which has a much longer track record in terms of durability and it is assumed that is being reflected in durability and numbers of hydrogen powered ICE vehicles.

In the field of FCV development, the following trends are observed. Daimler has built a series of 60 A – class based F-Cell FCVs, which have altogether been driving over 2 100 000 km. This means that on average, each F-Cell has driven 35 000 km. Ford has built 30 Focus-based FCVs which have covered altogether over 1 000 000 miles or 1 600 000 km, leading to an average of 53 000km per vehicle. The average vehicle from the Ford and Daimler fleets together has thus driven an average total distance of 41 000 km. At an average speed of 50km/h, this would represent a total operational time per vehicle of 822 hours. If we use this average to extrapolate, the total number of kilometres covered by most of the major players including Hyundai/KIA (32 vehicles), GM (100 vehicles), Honda (80 vehicles) and Toyota (40 vehicles), this would result in an estimated total amount of 14 022 000 km driven by fuel cell vehicles.

Furthermore, durability monitoring of FCVs reveals increasing lifetimes of the fuel cell systems which power the vehicles, thereby meeting the requirements of the standards as set by the US DOE. Labtests such as performed by 3M even show the potential to easily overcome the 5000 hours barrier, which is roughly equivalent to 200 000 km driven at an average speed of 50 km/h.

A strong argument for using hydrogen as an energy carrier for mobile applications is its high energy density. Theoretically, this would have to result in ranges at least comparable with those of today's conventional vehicles without losing much in terms of space and vehicle performance. Whereas first generation vehicles had much lower ranges relative to conventional vehicles, fuel cell technology improvement as well as the transition from 350 bar storage to 700 bar storage has led to driving ranges that come close to or equal those of today's gasoline vehicles.

Cost reductions of fuel cell systems have been and will be achieved by improving technological design, production-technologies and by increasing production-scales. Together with the improvement in range, these trends show the potential of FCVs to equal today's conventional vehicles in terms of performances and total costs of ownership in the near future. For many OEMs, this 'near future' starts around 2015, the year for which several manufacturers have announced commercial availability of their vehicles at competitive rates.