D6.5 Public report on experience & results from FCEV city car demonstration in Oslo

Final Report

Dissemination level: PU

February 2013

Introduction

WP6 Deliverable D6.5

Public report on experience & results from FCEV city car demonstration in Oslo

Below is provided the reporting of results for the deliverable D6.5 in WP6 in the H2MOVES project.

As part of the H2MOVES Scandinavia project five BEV City cars with fuel cell range extension were to be demonstrated in the city of Oslo in Norway.

The five vehicles were put in operation in May 2011 and have been operated until end of the project in December 2012, accumulating 28.014 kilometres.

Extensive results and lessons learned have been achieved during the entire process from manufacturing and homologation of the vehicles and during the delivery and operation. This report provides a description of experiences and lessons learned within the following areas:

1. Specification & vehicle supplier selection
2. Manufacturing, homologation & delivery
3. End-user training & Service facilities
4. Operation experiences & results
5. Evaluation of FC plug-in & range extender concept

The general statistical compiling of operation results for the entire project was conducted in a separate work package (WP7), thus this report focuses on the experiences around and behind the operation data, specifically for the FCEV City cars.

Table of content

1. Specification & vehicle supplier selection

1.1 Selection of vehicle supplier

The original plan and basis for the FCEV City car demonstration were to build on the TH!NK City Battery Electric Vehicle (BEV), installing a fuel cell system and hydrogen storage for range extension.

During preparation of the project proposal and the negotiation phase the financial situation of TH!NK was unclear and thus also the access to supply of the vehicles for the project. Therefore a first deliverable in the project where to clarify availability of the vehicle from TH!NK and look for alternative fallback solutions.

However the issues at TH!NK was solved in early 2010 and TH!NK resumed full production again. An agreement was therefore made with TH!NK on supply of five vehicles to the project.

Below is shown a picture of the TH!NK vehicle model used in the project.

1.2 FCEV City car specification

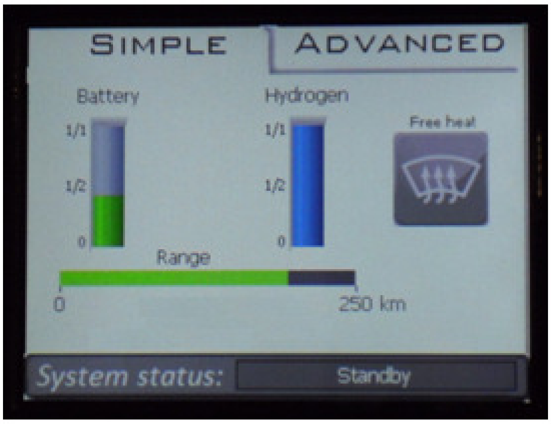
The specification of the FCEV City car was finalized prior to manufacturing.

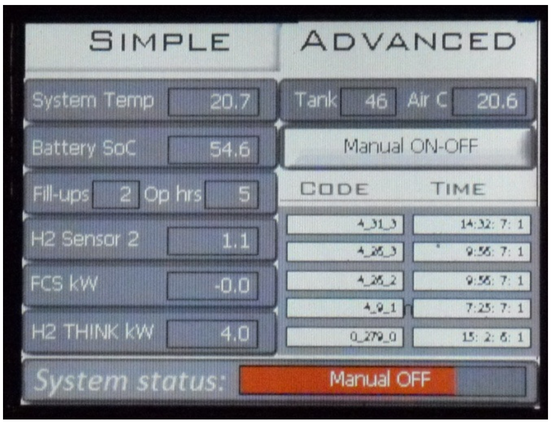
The base vehicle would stay as the conventional TH!NK City BEV, with only the modifications made for enabling integration of a fuel cell system and hydrogen storage.

The table below provides the final detailed specification for the FCEV City car. As can be seen the fuel cell system provided a number of improvements to the base BEV. Driving range was increased from ~110km to 250km. Excess heat from the fuel cell system was utilized for cabin heating, thus reducing impact on range in cold weather (compared to normal BEV operation).

Vehicle performance indicator	Unit	Specification
Maximum speed	Km/h	100
Acceleration	Sec	0-50 km/h @ 6.5 sec 0-80 km/h @ 16 sec
Steering	Type	Servo
Total driving range	km	250
Range on battery	km	110
Range on fuel cell/hydrogen	km	140
Passengers	No.	2
FC efficiency	% (FC incl. BoP)	>40
Battery technology	Type	ZEBRA
Battery capacity	kWh	~17,8
Fuel cell technology	Type	LT-PEM
Fuel cell power	kW	Rated: 14 Output: 10
FC waste heat for cabin heating	kW	<10 (Less range impact in cold weather)
Hydrogen storage capacity	kg	~1,7
Hydrogen storage pressure	bar	700
End-user interface	Type	Cabin display showing range, tank level and power supply (from battery and FC) plus other operation data

Below are shown screen-dumps of the fuel cell end-user interface integrated into the vehicle cabin.





2. Manufacturing, homologation & delivery

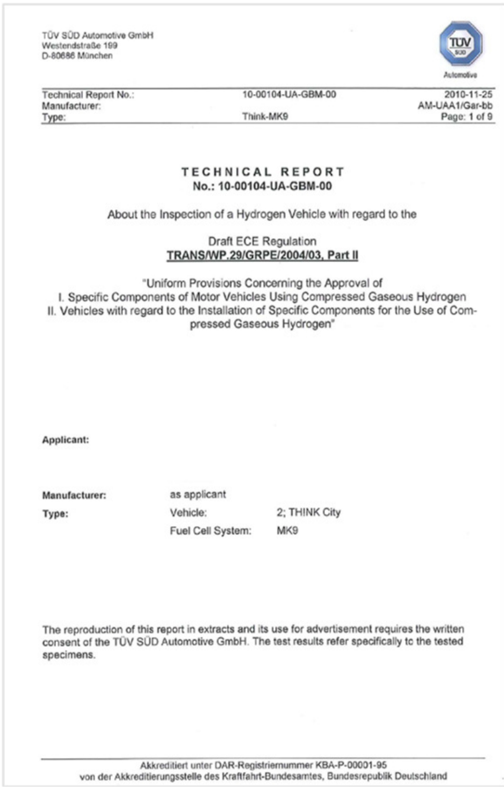
2.1 Manufacturing and certification of vehicles

Production of all five FCEV's was finished on schedule in November 2010. In the same month external safety certification of the fuel cell system on all five vehicles was secured from TÜV.

Extensive analyses of the systems were made and a report for each system/vehicles was delivered by TÜV, acting as part of the vehicle documentation for the following homologation, see next section.

Afterwards all vehicles underwent extensive test drives for one month before shipment to Norway.

Below are shown pictures from the manufacturing and the technical TÜV report.



TÜV SÜD Automotive GmbH
Westendstraße 199
D-80686 München

Automotive

Technical Report No.:	10-00104-UA-GBM-00	2010-11-25
Manufacturer:		AM-UAA1/Gar-bb
Type:	Think-MK9	Page: 1 of 9

TECHNICAL REPORT
No.: 10-00104-UA-GBM-00

About the Inspection of a Hydrogen Vehicle with regard to the

Draft ECE Regulation
TRANS/WP.29/GRPE/2004/03, Part II

"Uniform Provisions Concerning the Approval of
I. Specific Components of Motor Vehicles Using Compressed Gaseous Hydrogen
II. Vehicles with regard to the Installation of Specific Components for the Use of Compressed Gaseous Hydrogen"

Applicant:

Manufacturer: as applicant
Type: Vehicle: 2; THINK City
Fuel Cell System: MK9

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von der Akkreditierungsstelle des Kraftfahrt-Bundesamtes, Bundesrepublik Deutschland

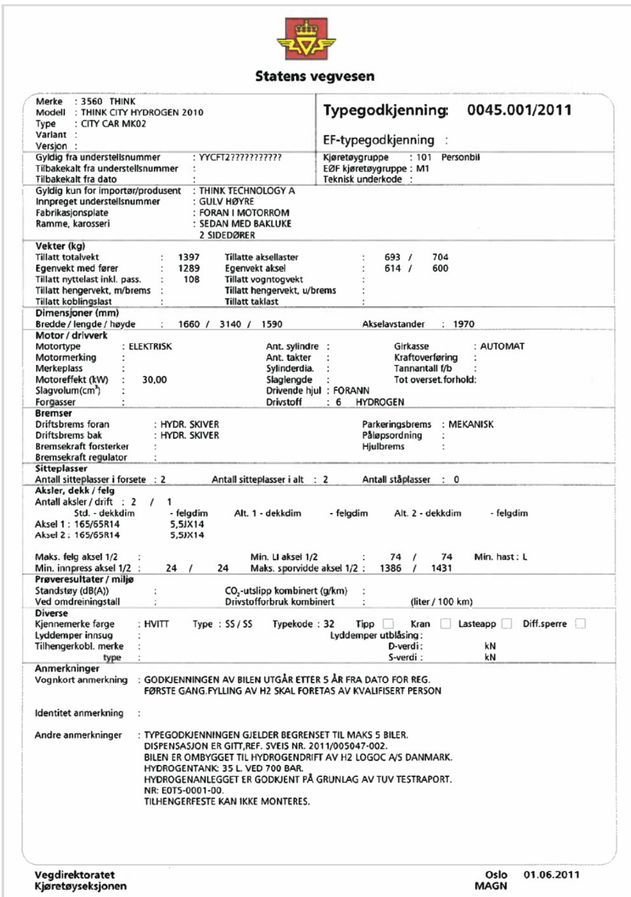
2.2 Delivery & homologation of vehicles

Based on customers' requests shipment of the vehicles were postponed from December to early 2011, to avoid overlap with holidays. The vehicles arrived in Norway early February 2011.

The final homologation of the vehicles in Norway and securing of the license plates were handled by the customers, with assistance from vehicle supplier on the vehicle documentation. This required more time than expected, as the Norwegian authorities had various technical questions and required further documentation. Among others documentation of Danish Authority approval of similar cars in Denmark was requested.

The final approval by authorities was secured in late May 2011 see copy of type approval below.

After finalized homologation the vehicles commenced operation at five various end-users all located in Lilleström just outside Oslo in Norway. Below is shown a picture of one of the delivered vehicles.



Statens vegvesen

Merke : 3560 THINK
Modell : THINK CITY HYDROGEN 2010
Type : CITY CAR MK02
Variant :
Versjon :

Typegodkjenning: 0045.001/2011
EF-typegodkjenning :

Gyldig fra understellsnummer : YYCFT2???????????
Tilbakekalt fra understellsnummer :
Tilbakekalt fra dato :

Kjøretøygruppe : 101 Personbil
EØF kjøretøygruppe : M1
Teknisk underkode :

Gyldig kun for importør/produsent : THINK TECHNOLOGY A
Innpreget understellsnummer : GULV HØYRE
Fabrikasjonsplate : FORAN I MOTORROM
Ramme, karosseri : SEDAN MED BAKLUKE 2 SIDEDØRER

Vekter (kg)
Tillatt totalvekt : 1397 — Tillatte aksellaster : 693 / 704
Egenvekt med fører : 1289 — Egenvekt aksel : 614 / 600
Tillatt nyttelast inkl. pass. : 108 — Tillatt vogntogvekt :
Tillatt hengervekt, m/brems : — Tillatt hengervekt, u/brems :
Tillatt koblingslast : — Tillatt taklast :

Dimensjoner (mm)
Bredde / lengde / høyde : 1660 / 3140 / 1590 — Akselavstander : 1970

Motor / drivverk
Motortype : ELEKTRISK — Ant. sylindre : — Girkasse : AUTOMAT
Motormerking : — Ant. takter : — Kraftoverføring :
Merkeplass : — Sylinderdia. : — Tannantall f/b :
Motoreffekt (kW) : 30,00 — Slaglengde : — Tot overset.forhold:
Slagvolum(cm^3) : — Drivende hjul : FORANN
Forgasser : — Drivstoff : 6 HYDROGEN

Bremser
Driftsbrems foran : HYDR. SKIVER — Parkeringsbrems : MEKANISK
Driftsbrems bak : HYDR. SKIVER — Påløpsordning :
Bremsekraft forsterker : — Hjulbrems :
Bremsekraft regulator :

Sitteplasser
Antall sitteplasser i forsete : 2 — Antall sitteplasser i alt : 2 — Antall ståplasser : 0

Aksler, dekk / felg
Antall aksler / drift : 2 / 1

	Std. - dekkdim	- felgdim	Alt. 1 - dekkdim	- felgdim	Alt. 2 - dekkdim	- felgdim
Aksel 1 :	165/65R14	5,5JX14				
Aksel 2 :	165/65R14	5,5JX14				

Maks. felg aksel 1/2 : — Min. LI aksel 1/2 : 74 / 74 — Min. hast : L
Min. innpress aksel 1/2 : 24 / 24 — Maks. sporvidde aksel 1/2 : 1386 / 1431

Prøveresultater / miljø
Standstøy (dB(A)) : — CO_2-utslipp kombinert (g/km) :
Ved omdreiningstall : — Drivstofforbruk kombinert : (liter / 100 km)

Diverse
Kjennemerke farge : HVITT — Type : SS / SS — Typekode : 32 — Tipp ☐ Kran ☐ Lasteapp ☐ Diff.sperre ☐
Lyddemper innsug : — Lyddemper utblåsing :
Tilhengerkobl. merke : — D-verdi : kN
type : — S-verdi : kN

Anmerkninger
Vognkort anmerkning : GODKJENNINGEN AV BILEN UTGÅR ETTER 5 ÅR FRA DATO FOR REG.
FØRSTE GANG.FYLLING AV H2 SKAL FORETAS AV KVALIFISERT PERSON

Identitet anmerkning :

Andre anmerkninger : TYPEGODKJENNINGEN GJELDER BEGRENSET TIL MAKS 5 BILER.
DISPENSASJON ER GITT,REF. SVEIS NR. 2011/005047-002.
BILEN ER OMBYGGET TIL HYDROGENDRIFT AV H2 LOGOC A/S DANMARK.
HYDROGENTANK: 35 L. VED 700 BAR.
HYDROGENANLEGGET ER GODKJENT PÅ GRUNLAG AV TUV TESTRAPORT.
NR: E0T5-0001-00.
TILHENGERFESTE KAN IKKE MONTERES.

Vegdirektoratet
Kjøretøyseksjonen

Oslo 01.06.2011
MAGN

3. End-user training & Service facilities

3.1 Training of users & handover of vehicles

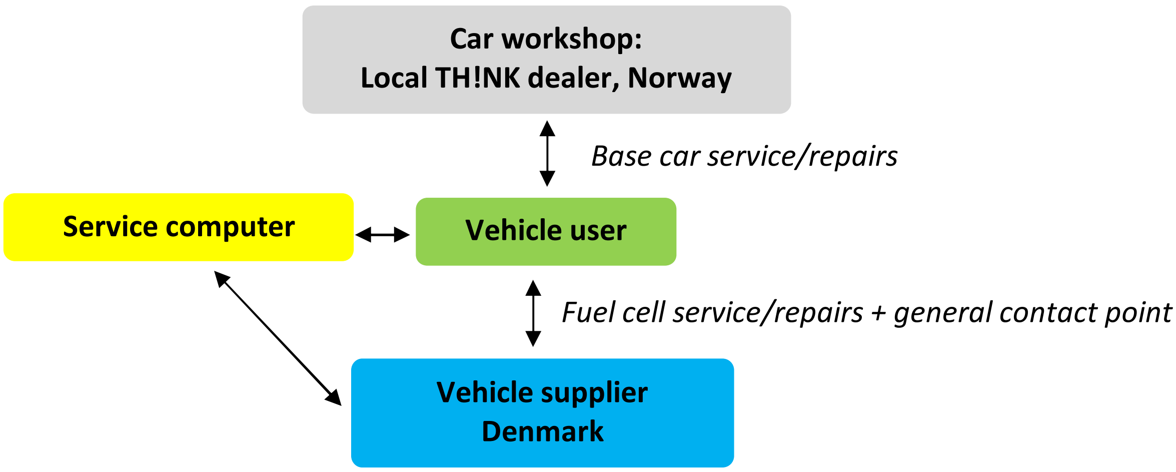
Part of the service strategy was a thorough hand-over of vehicles and training of users. Besides ensuring a safe and proper use of the vehicles, it would also enable the users to give more qualified feedback during service situations, which could help speed up the problem solving.

A training session was held with all end-users at a joint event in Oslo in June 2011. Here the vehicles were test driven by the users including a detailed introduction to both the vehicle and user-manual. Two guides was developed and introduced to the users:

1) A quick guide with the most important information, e.g. on handling daily practicalities
2) A detailed user manual with further practical and technical details

3.2 Service mechanisms & facilities

Below is shown an overview of the service mechanism that was established for the vehicles.



The vehicle supplier (based in Denmark) acted as the general service contact point for the vehicle users in case of situations or breakdown. Based on the dialogue with the customer it was asserted what appropriate step that needed to be taken, either:

1) Problem was solved by user with guidance from vehicle supplier via phone
2) Vehicle was delivered to car workshop in Norway and repaired
3) User connected vehicle to service computer in Norway – Vehicle supplier checked the vehicle condition remotely from Denmark, possible solving the problem
4) If problem could not be solved, service personnel solved the problem at site
5) In case of critical problems or errors, vehicle were shipped back to supplier for repair

4. Operation experiences & results

4.1 Bankruptcy of TH!NK & insufficient quality of base vehicle

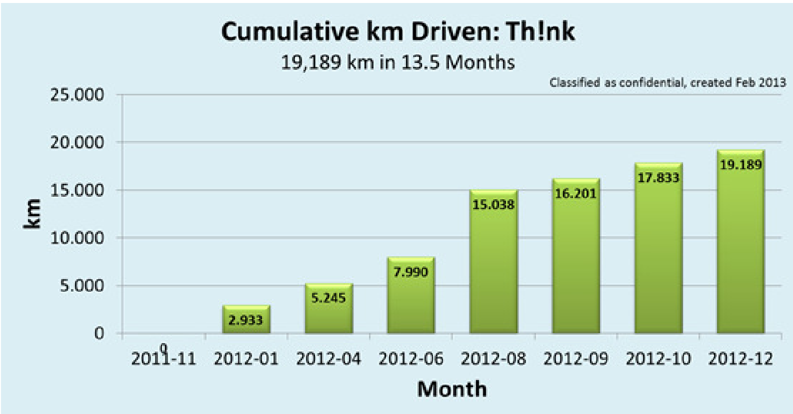
The operation and in particular servicing of the base vehicles was impacted by the bankruptcy of Think Global AS in June 2011. Despite of this the local TH!NK dealer was able to provide the necessary spare parts for the base vehicle during the project period, however with general delays.

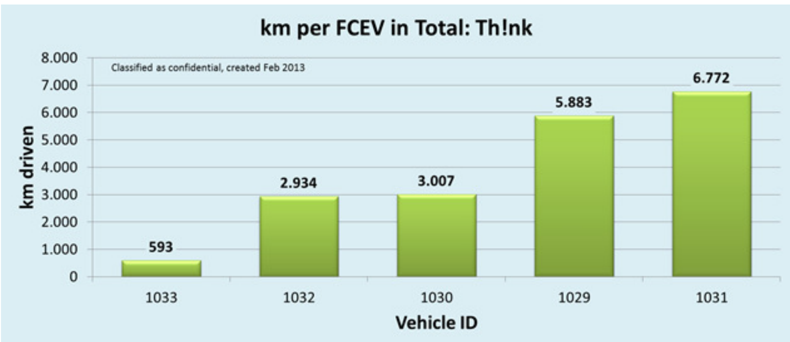
Quality of the base TH!NK City car was generally not on level with conventional gasoline vehicles. This also made the operation challenging as several errors and break-down of the base vehicle was experienced. The repair process of the base vehicle errors were also generally delayed as no TH!NK expert personnel was available for assistance due to the TH!NK bankruptcy.

Despite of the above TH!NK related challenges the vehicles was operated throughout the project period however with a lower than expected performance and availability, mainly related to issues with the base vehicle.

4.2 Operation results and availability

4.2.1 Driven distance & fuel cell operation hours





The five vehicles have in total driven 19.189 kilometres from November 2011 to December 2012. This period was the official data collection period within the project.

The distance driven per vehicle ranges from ~600 to 6.700 km which reflects that some vehicles had major technical issues, mainly due to errors on the base vehicle. Whereas the official vehicle data collection in the project commenced in November 2011, the actual operation of the vehicle commenced already in May 2011, thus the actual accumulated kilometres are higher than the 19.189 measured within the project data collection period.

The table below shows the actual total kilometres driven from the start of operation in May 2011 and until project ending in December 2012 a total of 28.014 km. Driven kilometres per vehicle range from ~1.500-9.350 km corresponding to an average of 5.600 kilometres per vehicle.

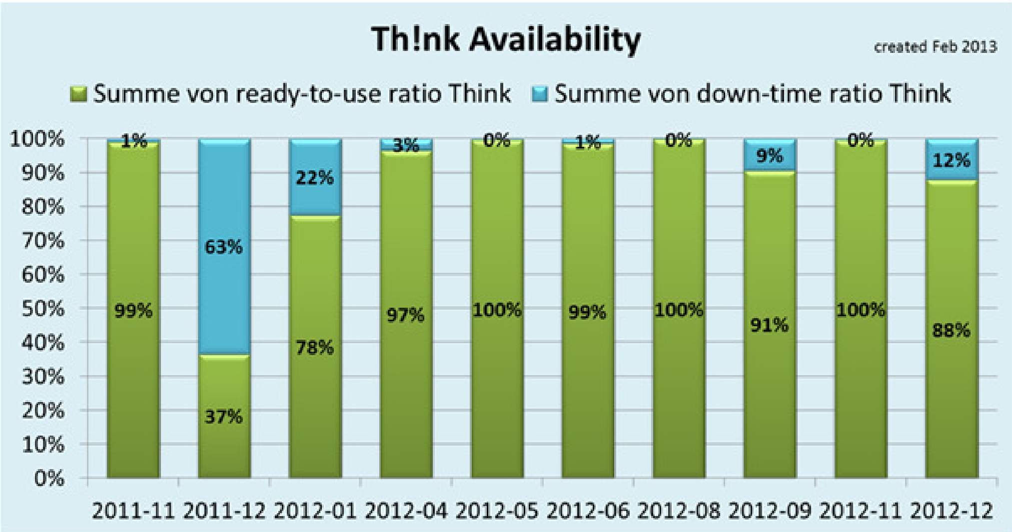
Vehicle ID no.	Km driven	FC standby hours	FC operation hours	Operation period
1029	6.535	236	78	May 2011 – Dec. 2012
1030	5.320	199	64	May 2011 – Dec. 2012
1031	9.350	346	111	May 2011 – Dec. 2012
1032	5.351	218	74	May 2011 – Dec. 2012
1033	1.458	102	41	May 2011 – Dec. 2012
	28.014	**1.102**	**368**	

The above table also shows the accumulated standby and operation hours for the fuel cell system. As can be seen the operation hours are significantly lower than the standby hours, reflecting that a high share of the kilometres driven happened on the battery alone. Approximately 2/3 of the kilometres were driven on batteries and 1/3 with the fuel cell system running.

4.2.3 Availability

The challenges arising from the TH!NK bankruptcy and the general low quality of the base vehicle also resulted in a low average availability of 91% across all of the five vehicles during the project reporting period. 63% of all down-time situations were solved within 2 days, 79% within 2 weeks and the remainder 21% within 3-4 weeks. Main cause of down-time was errors in the base vehicle control system.

The graph below shows the average availability for each month during the reporting period.



5. Evaluation of FC plug-in & range extender concept

The motivation for demonstrating the City cars as a Plug-in Fuel Cell Hybrid Electric Vehicles (PFCHEV) were similar to the reasons for introduction of Plug-in Hybrid Electric Vehicles (PHEV) based on internal combustion engines (ICE): A plug-in vehicle irrespectively of the supporting technology (ICE or FC) would enable most of the kilometres to be driven on the battery alone at a higher efficiency (Tank-to-Wheel).

The above motivation was very much in focus for PHEV's at the time of project start, thus it was naturally to pursue the same for a FCEV, thus creating a PFCHEV. However some of the same issues that are surfacing at the moment for PHEV's were also experienced during the project for the demonstrated PFCHEV's. The issues are mainly related to vehicle costs, and in some regional energy systems to the actual CO_2 emissions Well-to-Wheel.

5.1 Range extension vs. PFCHEV

A learning during the design and manufacturing of the TH!NK City car with fuel cell range extension is that a fundamental choice have to be made with regards to the vehicle performance.

1) **Range-Extension:**
   The fuel cell is dimensioned to charge the battery during driving to offer range extension. However to reduce cost of the fuel cell system this is down-sized to only accommodate an average vehicle driving speed (e.g. NEDC). In theory this mean at high speed operation (e.g. on highways) the fuel cell system could potentially lack behind in charging the battery.
2) **PFCHEV:**
   The fuel cell is dimensioned like the ICE in a PHEV, thus the fuel cell is capable of providing all the maximum peak power needed, e.g. at high speeds. Thus the fuel cell system will never lack behind in either charging the battery or providing the energy needed in any driving mode despite the battery may be fully emptied.

The above approached offers different performance and comes with a different cost.
The range-extension could reduce cost of the fuel cell system, but at the cost of performance. The PFCHEV would provide same performance as ICE today but at a higher cost.

The recent experiences with introduction of Battery Electric Vehicles (BEV) have shown that both performance and cost are of equally importance. Thus either of the two concepts may be challenging in terms of market and end-user acceptance.

5.2 FCEV vs. PFCHEV vehicle cost

Whereas a PFCHEV may offer a lower fuel cost compared to a FCEV (due to most kilometres driven on batteries at higher efficiency), a significant vehicle price difference can be expected.

The table below shows a vehicle price comparison between a FCEV and PFCHEV based on the pricing calculation method used in the EU CONCAWE study and the included targets for the technologies.

	CONCAWE		Calculated	
FCEV vs. PFCHEV[1]	**FCEV 2010+** Non-Hybrid	**FCEV 2010+** Hybrid	**FCEV 2010+** Today's Hybrid	**PFCHEV 2010+** Plug-in
Fuel cell system cost (€/kW)	€ 105	€ 105	€ 105	€ 105
Hydrogen storage cost (€/kg)	€ 575	€ 575	€ 575	€ 575
FCEV Hybrid battery cost (€/kWh	€ 600	€ 600	€ 600	€ 600
Range (km on full tank/battery)	600	600	600	600
Fuel cell power (kW)	80	80	80	80
Electric motor power (kW)	75	75	75	75
Battery size (kWh)	**0**	**6**	**1,3**[2]	**16**[3]
Hydrogen storage capacity (kg)	4,7	4,2	4,6	3,4
Baseline vehicle	€ 18.600	€ 18.600	€ 18.600	€ 18.600
Gasoline tank	-€ 125	-€ 125	-€ 125	-€ 125
Hydrogen tank	€ 2.703	€ 2.415	€ 2.640	€ 1.936
Baseline engine + transmission	-€ 2.310	-€ 2.310	-€ 2.310	-€ 2.310
Fuel cell system	€ 8.400	€ 8.400	€ 8.400	€ 8.400
Electric motor + controller	€ 2.025	€ 2.025	€ 2.025	€ 2.025
Battery (Li-Ion)	€ 0	€ 3.600	€ 780	€ 9.600
Powertrain & vehicle components	€ 2.630	€ 2.630	€ 2.630	€ 2.630
Credit for standard alternator + starter	-€ 300	-€ 300	-€ 300	-€ 300
Credit for three-way catalyst	-€ 430	-€ 430	-€ 430	-€ 430
Total Vehicle Retail Price	**€ 31.193**	**€ 34.505**	**€ 31.910**	**€ 40.026**
Difference to non-hybrid FCEV	**€ 0**	**+€ 3.313**	**+€ 718**	**+€ 8.833**

[1]*All figures based on EU CONCAWE data & methodology – only Battery sized changed*
http://iet.jrc.ec.europa.eu/about-jec/sites/iet.jrc.ec.europa.eu.about-jec/files/documents/wtw3_ttw_appendix1_eurformat.pdf
[2]*Battery size based on" A portfolio of power-trains for Europe: a fact-based analysis" – Exhibit 23 - page 36*
http://ec.europa.eu/research/fch/pdf/a_portfolio_of_power_trains_for_europe_a_fact_based__analysis.pdf
[3]*Battery size the same as in GM Volt Plug-in Hybrid: http://gm-volt.com/full-specifications*

As can be seen the PFCHEV 2010+ would have an extra cost of €8.833 compared to a non-hybridized FCEV. Comparing with an actual hybrid FCEV of today (non plug-in and with a smaller hybrid battery than anticipated for the hybrid FCEV in CONCAWE) the extra cost would be €8.115 coresponding to an extra price of 25%. Approximate additional calcuations on Total Cost of Ownership (based on above) have shown that the potential savings on fuel costs (due to efficient battery operation) would require between 5-10 years before recovering the extra vehicle cost.

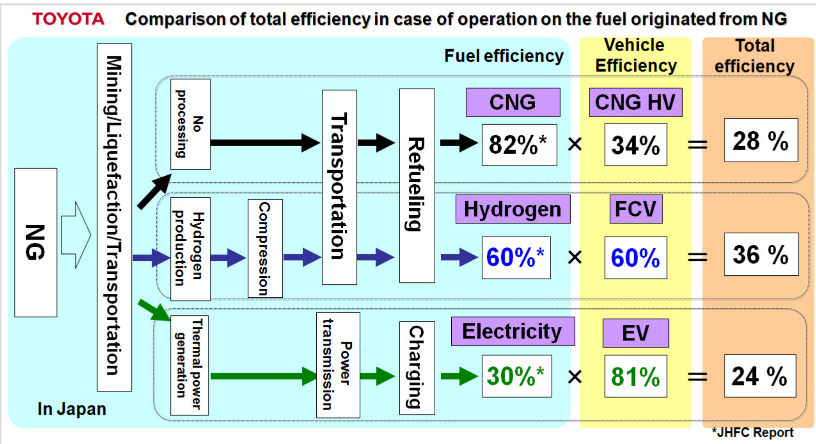
Again the recent experience from BEV market introduction have shown that customers tend to focus very much on the actual vehicle price rather than the potential fuel cost savings beyond 5+ years.

5.3 FCEV/BEV vs. PFCHEV CO_2 emissions (Well-to-Wheel)

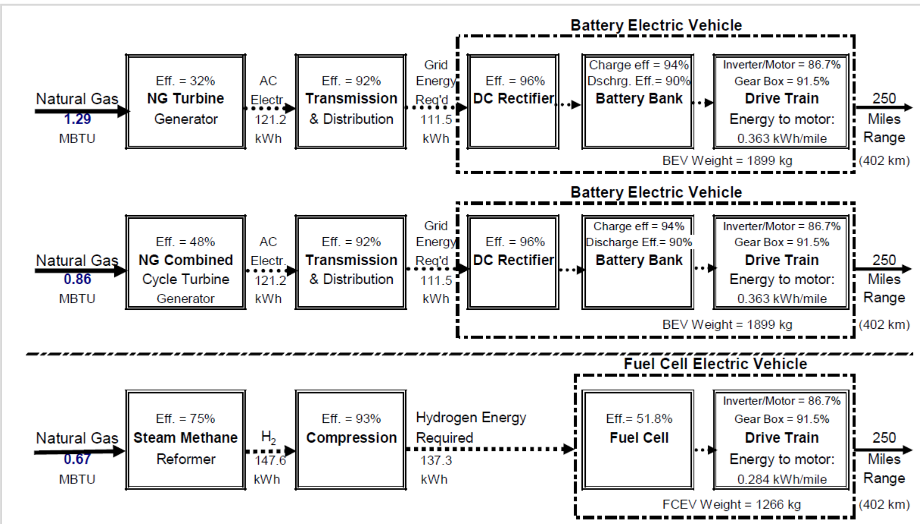
CO_2 emission savings from the potentially higher Tank-to-Wheel energy efficiency of the kilometers driven on the battery in a PFCHEV will depend on the CO_2 content in the charged electricity from the power grid in the area where the vehicle is operated.

In e.g. the Nordic countries where theres is a trend towards a higher share of renewable electricity in the power grid the PFCHEV may enable a reduction in CO_2 emissions compared to a FCEV. However in regions where the electricity is mainly provided by fossil based electricity this may not be the case.

The figure below is a simplified calculation from the JHFC report comparing the Well-to-Wheel efficiency for a BEV and FCEV, when based on natural gas. As can be seen the BEV has a signifigantly lower efficiency due to the lower conversion efficiency from natural gas to electricity compared to reforming of hydrogen. The kilometers driven on the battery in a PFCHEV in a natural gas based power system would thus have a higher CO_2 emission compared to operation on the fuel cell system.



The figure below shows the same conclusion from a simmilar calcuation from the US[1]:



[1] http://www.cleancaroptions.com/C.E._Thomas_Battery_vs_Fuel_Cell_EVs_Paper_for_Distribution.pdf (page 12)