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Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context

TTW APPENDIX 1
Vehicle retail price estimation

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TANK-to-WHEELS Report - Appendix 1

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Notes on version number:

This document reports on the third release of this study replacing version 2c published in March 2007.

The original version 1b was published in December 2003.

Vehicle retail price estimation

Table of contents

This document has changed from version 2c of March 2007 with regard to the Diesel and CNG vehicle price estimation

1 Main price assumptions for components and systems

- Prices given for specific components are on a 'supplier retail' (equivalent to delivered costs to vehicle manufacturers). A mark-up to include further costs, e.g. warranty, is not included.
- The cost estimates are based on recent cost studies (see Chapter References) and we have focused on estimating the costs for various key powertrain components, such as motors, batteries, hybrid and fuel cell systems. Costs for upgrading some vehicle components were included for some configurations.
- Costs assume a volume of >50k units per annum and are projected for 2010+. The cost reduction estimates through volume production for some of the key components could be very optimistic and it is uncertain how much and at what rate future costs will decline under different circumstances.
- To cover these uncertainties a large upward range is included for future technologies.
- The study does not consider other associated costs beyond the key components for a certain technology. For example, vehicle body modifications are likely to vary depending on the base vehicle and the technology systems integration. For a more detailed cost calculation these additional costs need to be added.

The components or systems costs assessed for the technologies are shown Table 1.

Table 1 Components, systems costs

Component or system		Price	Reference
ICE			
Engine + transmission	€/kW	30	a
DICI	€	1500	b
DISI	€	500	b
Turbo	€	180	c
Friction improvement	€	60	j
20% downsizing SI	€	220	j
20% downsizing CI	€	200	j
Stop & go system SI	€	200	a
Stop & go system CI	€	300	a
Double inj. system for CNG or LPG Bi-fuel	€	700	c
EURO IV SI	€	300	a
EURO IV Diesel	€	300	a
EURO IV Diesel with DPF	€	700	c
Credit for three way catalyst	€	430	b
Fuel tank			
Gasoline	€	125	a
CNG	€	1838	d
DME or LPG	€	1500	a
Comp. Hydrogen @70 MPa(1)	€/kg H_2	575	e
Liquid hydrogen(1)	€/kg H_2	575	e,f
Electric motor			
Electric motor	€/kW	8	c
Motor controller	€/kW	19	j
Total electric motor + controller	€/kW	27	j
Hybrid electric powertrains			
Powertrain and vehicle components upgrade(2)	€	2630	j
Credit for standard alternator + starter	€	-300	j
Li-Ion battery(3)	€/kWh	600	g
Fuel cells			
FC system(4)	€/kWnet	105	h
FC system + reformer	€/kWnet	251	h

Notes:

- Hydrogen tank: Current costs are approximately twice as high. The figures used were estimated based on expectations of improvement.
- Cooling system upgrade (Battery, E-Motor), High Voltage Wiring, Electric Steering for E-Drive mode, Electric driven AC compressor, Power electronics, DC/DC Converter, Modifications for a regenerative braking system.
- Batteries: current battery costs are considerably higher (700-1500€, Reference h). The figures used were estimated based on expectations of improvement for the time horizon of the study. Although recent target values of the battery industry are considerably lower (200-300€), the technical advancement and cost reductions needed may not be achieved.
- Fuel cells: current fuel cell costs are considerably higher. The figures above should be considered as aspirational and may not be achieved until the end of the next decade. To put them further into perspective it is worth mentioning that the current US fuel cell research programme includes a target value of 45 $/kW in 2010 and 35 $/kW by 2015.

2 2002 vehicles

The retail prices assessed for the 2002 technologies are shown in ***Table 2***. All technologies are assessed against the reference gasoline PISI engine vehicle.

Table 2 2002 vehicles

Fuel	Gasoline		LPG	CNG		Diesel	DME
Propulsion system	PISI (reference)	DISI	PISI bi-fuel	PISI bi-fuel	PISI dedicated	DICI	DICI
Engine Power (kW)	77	70	77	77	85	74	74
Prices (€)							
Baseline vehicle	18,600	18,600	18,600	18,600	18,600	20,300	20,300
Gasoline tank	*125*				-125		-125
Alternative fuel tank			1,500	1,050	1,838		1,500
Baseline engine + transmission	*2,310*	-2,310			-2,310	*2,220*	*2,220*
Alternative engine + transmission		2,100			2,550		
DISI		500					
DICI						*1500*	*1,500*
Double injection system			700	700			
Total Vehicle Retail Price	18,600	18,890	20,800	20,350	20,553	20,300	21,675
Difference to the 2002 reference		**290**	**2,200**	**1,750**	**1,953**	**1,700**	**3,075**
		1.6%	11.8%	9.4%	10.5%	9.1%	16.5%

Numbers in italic are for information only. They are not used in the calculations

Notes:

- Although the cost of the direct injection system is partly compensated by the lower power requirement the DISI vehicle is slightly more expensive than the reference.
- The need for two fuel systems increases the cost of both the LPG and the CNG bi-fuel vehicles.
- In spite of its larger engine, the dedicated CNG vehicle is cheaper than the bi-fuel version and only slightly more expensive than the diesel vehicle.
- The price of the DME vehicle includes the special tank.

3 2010+ vehicles

3.1 ICE vehicles (except hydrogen)

For all 2010+ vehicles the reference is the 2010+ gasoline PISI vehicle, the price of which is derived from the 2002 version including additional cost for downsizing, turbo-charging, stop & go system and Euro IV exhaust after treatment. The overall price increase is 5%.

Table 3.1 2010+ conventional ICE vehicles

Fuel	Gasoline		LPG	CNG		LPG	Diesel		DME
Propulsion system	PISI (reference)	DISI	PISI bi-fuel	PISI bi-fuel	PISI dedicated	PISI dedicated	DICI +DPF	DICI	DICI
Engine Power (kW)	77	70	77	77	85	77	74	74	74
Prices (€)									
Baseline vehicle	18,600	18,600	18,600	18,600	18,600	18,600	20,300	20,300	20,300
Gasoline tank					-125	-125			-125
Alternative fuel tank			1,500	1,050	1,838	1,500			1,500
Baseline engine + transmission	-2,310	-2,310	-2,310	-2310	-2,310	-2,310	-3,720	-3,720	-3,720
Alternative engine + transmission[(1)]	2,590	2,380	2,590	2590	2,830	2,590	2,480	2,480	2,480
Turbo	180	180	180	180	180	180			
DISI		500							
DICI							1500	1500	1500
Stop & go system	200	200	200	200	200	200	300	300	300
EURO IV exhaust after treatment	300	300	300	300	300	300	700	300	300
Double injection system			700	700					
Total Vehicle Retail Price	19,560	19,850	21,760	21,310	21,513	20,935	21,560	21,160	22,535
Difference to the 2010 reference		**290**	**2,200**	**1,750**	**1,953**	**1,375**	**2,000**	**1,600**	**2975**
		1.5%	11.2%	8.9%	10.0%	7.0%	10.2%	8.2%	15.2%

(1) Gasoline, LPG & CNG: includes downsizing and friction improvement; Diesel: friction improvement only

Notes:

- The differential between gasoline DISI and PISI generally remains the same as in 2002. The same applies to the LPG and CNG vehicles.
- The diesel vehicle price increases by 300 € to cover the EURO IV exhaust after treatment requirements and by 700 € if a DPF is installed. The stop & go system is also dearer than for SI engines.
- The DME vehicle price remains higher than its diesel counterpart because of the cost of the tank.

3.2 Hybrid ICE vehicles (except hydrogen)

Table 3.2 2010+ Hybrid ICE vehicles (except hydrogen)

Fuel	Gasoline	CNG	Diesel	Diesel
Propulsion system: hybrid	DISI	PISI	DICI+DPF	DICI
Engine Power (kW)	70	68	74	74
Electric motor power (kW)	14	14	14	14
Battery size (kWh)	6	6	6	6
Prices (€)				
Baseline vehicle	18,600	18,600	20,300	20,300
Gasoline tank		-125		
Alternative fuel tank		1,838		
Baseline engine + transmission	-2,310	-2,310	-3,720	-3,720
Alternative engine + transmission[(2)]	2,160	2,100	2,480	2,480
DISI	500			
DICI			1500	1500
Euro IV exhaust after treatment	300	300	700	300
Electric Motor + modified transmission	600	600	600	600
Battery (Li-Ion)	3,600	3,600	3,600	3,600
Powertrain and vehicle components upgrade	2,630	2,630	2,630	2,630
Credit for standard alternator + starter	-300	-300	-300	-300
Total Vehicle Retail Price	25,780	26,933	27,790	27,390
Difference to the 2010 reference	**6,220**	**7,373**	**8,230**	**7,830**
	31.8%	37.7%	42.1%	40.0%

(2) Including friction improvement

Note:

In comparison with standard ICE vehicles, hybrids are penalised by the price of the battery, the electric motor with the power electronics and other additional requirements for vehicle component upgrades. The price differentials between the different fuel versions basically remain the same.

3.3 Hydrogen ICE vehicles

Table 3.3 2010+ Hydrogen ICE vehicles

Fuel	C-H_2 @70 MPa	L-H_2
Propulsion system	PISI	
Engine Power (kW)	77	
Hydrogen storage capacity (kg)	9	
Prices (€)		
Baseline vehicle	18,600	18,600
Gasoline tank	-125	-125
Hydrogen tank	5,175	5,175
Baseline engine + transmission	-2,310	-2,310
Alternative engine + transmission(3)	2,590	2,590
Turbo	180	180
Stop & go system	200	200
Total Vehicle Retail Price	24,310	24,310
Difference to the 2010 reference	**4,750**	**4,750**
	24.3%	24.3%

(3) Including downsizing and friction improvement

Although the hydrogen tank cost used here is based on an estimate (current costs are about twice that figure), it remains a very expensive piece of equipment that strongly penalises hydrogen vehicles.

3.4 Hydrogen hybrid ICE vehicles

Table 3.4 2010+ Hydrogen hybrid ICE vehicles

Fuel	C-H_2 @70 MPa	L-H_2
Propulsion system	Hybrid PISI	
Engine Power (kW)	77	
Electric motor power (kW)	14	
Battery size (kWh)	6	
Hydrogen storage capacity (kg)	7.5	
Prices (€)		
Baseline vehicle	18,600	18,600
Gasoline tank	-125	-125
Hydrogen tank	4,313	4,313
Baseline engine + transmission	-2,310	-2,310
Alternative engine + transmission(3)	2,590	2,590
Turbo	180	180
Electric Motor + modified transmission	600	600
Battery (Li-Ion)	3,600	3,600
Powertrain and vehicle components	2,630	2,630
Credit for standard alternator + starter	-300	-300
Total Vehicle Retail Price	29,778	29,778
Difference to the 2010 reference	**10,218**	**10,218**
	52.2%	52.2%

(3) Including downsizing and friction improvement

3.5 Direct hydrogen fuel cell vehicles

Table 3.5 2010+ Direct Hydrogen fuel cell vehicles

Fuel	C-H_2 @70 MPa	L-H_2	C-H_2 @70 MPa	L-H_2
Propulsion system	FC		Hybrid FC	
Fuel cell Power (kW)	80		80	
Electric motor power (kW)	75		75	
Battery size (kWh)			6	
Hydrogen storage capacity (kg)	4.7		4.2	
Prices (€)				
Baseline vehicle	18,600	18,600	18,600	18,600
Gasoline tank	-125	-125	-125	-125
Hydrogen tank	2,703	2,703	2,415	2,415
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)			3,600	3,600
Powertrain and 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	31,193	34,505	34,505
Difference to the 2010 reference	**11,633**	**11,633**	**14,945**	**14,945**
	59.5%	59.5%	76.4%	76.4%

Although this assessment of fuel cell cost is very optimistic in regards to current figures, there is no doubt that fuel cells will remain significantly more expensive than conventional powertrains as systems complexity is higher and the use of expensive materials, e.g. precious metal for the electrocatalyst and perfluorinated membrane. The additional battery cost further penalises the hybrid configuration.

3.6 On-board reformer and fuel cell vehicles

Table 3.6 2010+ indirect hydrogen hybrid fuel cell vehicles

Fuel	Gasoline	Methanol
Propulsion system	Reformer + hybrid FC	
Fuel cell Power (kW)	80	80
Electric motor power (kW)	75	75
Battery size (kWh)	6	6
Prices (€)		
Baseline vehicle	18,600	18,600
Baseline engine + Transmission	-2,310	-2,310
Fuel cell + reformer	20,080	20,080
Electric Motor + controller	2,025	2,025
Battery (Li-Ion)	3,600	3,600
Powertrain and vehicle components	2,630	2,630
Credit for standard alternator + starter	-300	-300
Credit for three-way catalyst	-430	-430
Total Vehicle Retail Price	43,895	43,895
Difference to the 2010 reference	**24,335**	**24,335**
	124.4%	124.4%

The combination of the reformer and fuel cell results in a very high cost. In addition these vehicles are assumed to have a hybrid configuration i.e. including the additional battery. On the positive side these vehicles do not require a hydrogen tank.

4 Results

The following table summarises the results and also shows the estimated uncertainty ranges. The range is fairly narrow for established technologies but widens when it comes to less developed options such as hybrids. For fuel cell technology we have applied a 100% upwards range reflecting the many uncertainties attached to these technologies.

Table 4 Cost differentials of 2010+ vehicles compared to the 2010+ PISI vehicle

Engine technology	Fuel	Price differential (€)	Uncertainty range	
			-	+
ICEs conventional				
DISI	Gasoline	290	5%	5%
PISI	CNG (bi-fuel)	1,750	5%	5%
PISI	CNG (dedicated)	1,953	5%	5%
PISI	LPG (bi-fuel)	2,200	5%	5%
DICI	Diesel	1,600	5%	5%
DICI + DPF	Diesel	2,000	5%	5%
DICI	DME	2,975	10%	10%
PISI	C-H_2 70 MPa	4,750	0%	15%
PISI	L-H_2	4,750	0%	15%
ICEs Hybrid				
DISI Hyb.	Gasoline	6,220	0%	50%
PISI Hyb.	CNG	7,373	0%	50%
DICI Hyb.	Diesel	7,830	0%	50%
DICI Hyb. + DPF	Diesel	8,230	0%	50%
PISI Hyb.	C-H_2 70 MPa	10,218	0%	100%
PISI Hyb.	L-H_2	10,218	0%	100%
Fuel cells				
FC	C-H_2 70 MPa	11,633	0%	100%
FC	L-H_2	11,633	0%	100%
FC Hyb.	C-H_2 70 MPa	14,945	0%	100%
FC Hyb.	L-H_2	14,945	0%	100%
Ref+FC Hyb.	Gasoline	24,335	0%	100%
Ref+FC Hyb.	Methanol	24,335	0%	100%

5 References

The data in the above table stem in part from literature references. Where no suitable reference was available, the matter was discussed amongst EUCAR experts to arrive at consensual figures.

a Institut Français du Pétrol (IFP), unpublished

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i Evaluation of Electric Vehicle Production and Operating Costs, by R.M. Cuenca, L.L. Gaines, and A.D. Vyas Argonne National Laboratory, P. 40, Nov. 1999

j EUCAR experts consensual view

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Abstract
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The JEC research partners [Joint Research Centre of the European Commission, EUCAR and CONCAWE] have updated their joint evaluation of the well-to-wheels energy use and greenhouse gas emissions for a wide range of potential future fuel and powertrain options.

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