
Hybrid vehicles: a temporary step

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Abstract: The paper discusses the diffusion of hybrid technology in vehicles. It is questioned whether the current strong acceptance of the technology especially by US consumers is of sustainable nature. It presents and analyses different variables influencing the diffusion of the technology. Non-financial criteria drive buying decisions significantly. Furthermore, an overview of OEMs' and suppliers' strategies is presented. Most companies integrate hybrid electric vehicles in their technology portfolio. It is concluded that even though hybrid technology can not yet be applied profitably it seems to be a key option to the industry due to its current positive perception in the USA.

Keywords: automobile; hybrid technology; innovation; strategy.

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Julius Teske graduated in Industrial Engineering and Management at Munich University of Applied Sciences. With his background as car mechanic, he worked for several years in the automotive industry in Germany and in Thailand, in the areas of marketing and after sales. He obtained the Master's Degree in International Business at Grenoble Graduate School of Business in 2006. Focussing on Management of Technology, he intensively researched the Hybrid Electric car market in the USA and proposed scenarios for 2015. Today, he works as project leader in the automotive industry.

1 Introduction

This paper deals with the hypothesis that the recent growing craze for hybrid vehicles in the USA and Europe is simply a temporary step between the traditional technology based on gasoline and diesel engines and the forthcoming of full electric vehicles, probably with hydrogen-powered fuel cells. Such an assumption is shared by several observers from professional as well as academic backgrounds (Ashley, 2002; Hekkert and Vandenhoeed, 2004). Hekkert and Vandenhoeed (2004) is the most radical challenging the idea that the emergence of hybrid vehicles might be at the expense of the fuel-cell vehicle. Chanaron and Orselli (2002) suggest that hydrogen fuel cells will not be marketable in high volumes before at least 2025 and that most, if not all, information released so far are pure manipulation and marketing by the hydrogen lobby. The quest for low emission (clean) and high-mileage vehicles is on its way and will surely remain at the top of the OEM's agenda.

Because new facts and events occur on a daily basis, such a paper is inevitably out-dated as far as factual information and data are concerned. They have been updated up to the end of 2006. It has to be pointed out that the research is targeting only passenger cars, SUV and light commercial vehicles.

This paper is based on the following set of statements that it aims at illustrating and discussing:

- there is a general convergence of strategies towards promoting hybrid vehicles as the mid-term solution to very low-emission and high-mileage vehicles
- such a convergence is largely due to Toyota's strategy – learning the technology while building up its own 'quasi-standard', thanks to its high-quality and reliability reputation and its high market share on the North American market
- such a convergence is based more on customer perception triggered by very clever marketing and communication campaigns than on pure rationale scientific arguments and may result in the need for any OEM operating in the USA to have an HEV in its model range in order to survive.

Obviously, such statements lead to several unresolved questions: Is such a strategy sustainable in the long run? Or is it a short- to mid-term option, which would then last only for a few years and thus remain to limited manufacturing volumes? What are the triggers to technical choice? Is it the lowest CO₂ emission or a more complex efficiency mix between cost, pollution and energy?

2 Background

2.1 Literature review

The economic and managerial literature dealing with hybrid vehicles is still very poor, basically limited to enthusiastic press coverage for newly launched models or surveys on cost efficiency (Chanaron and Faudry, 2005). Most academic publications emphasise on scientific and technical issues, such as power train modelling and control, braking systems with regenerative devices, energy storage, energy management systems,

propulsion systems, electric engines, vehicle simulation, and vehicle design. Most key papers limit their scope to technical efficiency (Demirdöven and Deutch, 2004).

Within the available literature, as surveyed by Chanaron and Faudry (2005), most publications deal with general discussion about the potential technologies and innovations limited to qualitative analysis of key drivers and success or failure factors. Most information comes from professional materials, press cuttings and interviews of key researchers and decision-makers and also from previous research (Chanaron and Nicolon, 1976; Nicolon, 1977; Chanaron, 1983, 1994, 1998, 2003). They highly reflect the point of view of industrial actors of the automotive system (de Banville and Chanaron, 1991), not to say the automotive lobby. There is hardly any interest given to consumer acceptability, pricing, etc. Amongst these qualitative surveys, there are also historical essays such as Bardou et al. (1982) and general reflections on the future of the automobile technology. The vast majority of papers and books belong to industrial economics. Very few refer to management sciences.

Struben and Sterman (2006) start from the historic failure of the electric car at the end of the 19th century to build a model to explore the so-called transition between two technologies, i.e., Internal Combustion Engine (ICE) and Alternative Fuel Vehicle (AFV), including hybrids, natural gas and hydrogen fuel-cell vehicle. The authors introduce the concept of familiarity to capture the “cognitive and emotional processes through which drivers gain enough information about, understanding of, and emotional attachment to a technology”. Awareness and familiarity are correlated with the rate of adoption. Familiarity and consumer choice is highly dependent on marketing, direct social exposure, indirect word of mouth. They conclude that the transition will be longer than usually expected and will involve a wide array of interactions and feedbacks, which are not yet captured by the existing models, such as interactions with other industries and the fuel supply chain.

As far as market-related studies are concerned, it is worth mentioning about Kishi and Satoh (2005) and Sanchez-Repila and Poxon (2006).

Kishi and Satoh (2005) explore the evaluation of willingness to buy a low-pollution car in Japan based on a price sensitivity measurement model through a questionnaire survey run in Tokyo and Sapporo. Their research shows that the correlation between environmental awareness and willingness to buy is high as well as not surprisingly the relationship between decrease in price and willingness to buy. Their most interesting result is their evaluation of the minimum, maximum, standard and reasonable price for hybrid cars.

Sanchez-Repila and Poxon (2006) present the different technical alternatives and also devote a specific section to market status, examining the specificity in USA, Japan and Europe. They point out the necessity of tax incentives to compensate for the higher prizes. They also emphasise the fact that the customer motivation to buy a hybrid car seems to be environmental rather than economic, the savings in fuel being not so significant. Hybrids seem to benefit from a strong environmental and technological image or perception. The authors conclude with the obstacles to future developments of hybrids, and in particular the cost of shifting to 42 V supply, and they foresee no volume take-off before 2010.

2.2 *Review of technology*

The conventional Internal Combustion Engine (ICE), along with its limitations, builds the basis for the HEV concept. The conventional un-supercharged combustion engine only has good efficiency in a small operating range. It works efficiently at a high level of cylinder charging, that is, when its displacement is fully exploited. For example, if an un-supercharged combustion engine is designed for a peak performance of 60 kW at 6000 revolutions per minute (rpm), it is basically working efficiently when it delivers 10 kW at 1000 rpm or 20 kW at 2000 rpm. The less performance the engine needs to produce at a certain level of rpm when compared with its current maximum performance, the less efficient it is. For example, if the engine runs at 2000 rpm but the driver only demands 10 kW. According to Bohner et al. (1999), this is often the case in daily driving situations, especially in cities. The greater an engine's displacement is, the more significant the loss becomes. Consequently, when running at low revolutions, e.g., in city driving, engines with smaller displacement are more fuel-efficient than engines with greater displacement. One measure getting this conceptual challenge under control is to supercharge the engine, e.g., by turbo charging or mechanical charging.

The basic idea of an HEV is to work around the above-mentioned challenge by running the combustion engine only at operating ranges of high efficiency. If the engines' respective peak performance is not fully needed for propulsion, mechanical performance is transformed into electric energy and then stored in a storage device, usually a battery. This energy is used to supply an electric engine, which is integrated in the drive train.

Since the early 1990s, the main bottleneck for full electric vehicles is their range between two recharging¹ or refueling² (Nicolon, 1977; Chanaron, 1994, 1998). No major breakthrough has been made since then despite billions of US dollars being spent in R&D, including for space exploration and promising theoretical electro-chemical options. As pointed out by Ashley (2002),

“with an estimated \$6–8 billion having already been sunk into the fuel-cell industry, including both stationary and portable power types as well as transportation versions (according to analysts at Citibank),”

car manufacturers (OEMs) are still struggling to take fuel cells off their laboratories and “move them onto the showroom floor” (Connors, 2005).

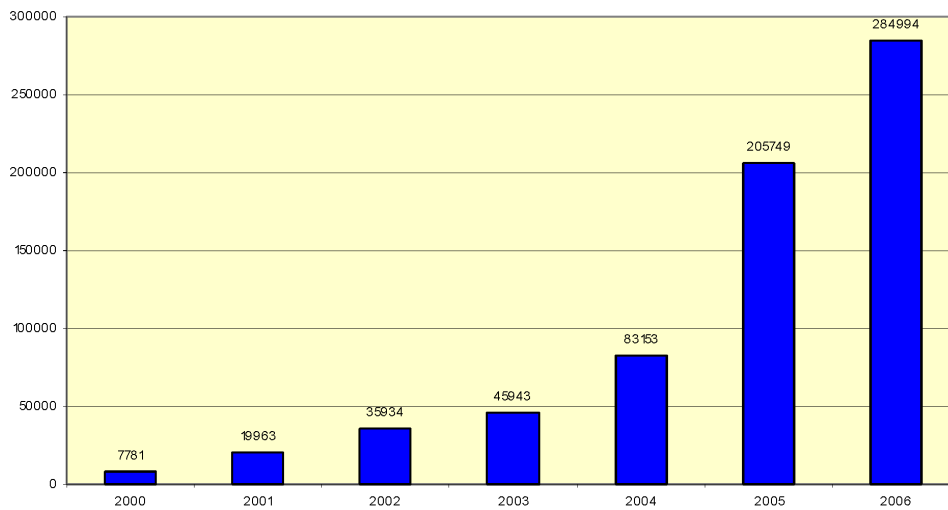
Obviously, one of the easiest ways to extend the range of an electric car is to carry fuel and a small ICE onboard to generate electricity in order to power the electric drive train. From the viewpoint of Electric Vehicle (EV) development, hybrid vehicles convert the problem of energy storage in a battery to one concerning the storage of fuel. Such a hybrid-electric approach has been employed in the Toyota Prius and Honda Insight, which have been innovators in this market, by combining small and highly efficient combustion engines with batteries that supplement engine power when necessary (acceleration, hill-climbing, high-speed motorway driving) and recovering energy when braking or the car slows down. This approach aims at increasing fuel efficiency; however, the higher weight of HEVs when compared with their gasoline-only cousins lower this potential.

3 Markets and diffusion

3.1 Evaluating markets for HEV

The diverse degree of diffusion of the technology makes it difficult to draw one common global picture on the HEV market. Therefore, an insight into key markets is provided. Sales and registration data exist for the USA as well as for Japan. In the USA, HEV sales (Figure 1) have risen consistently since 1999:

Figure 1 Sales of HEV vehicles in the USA



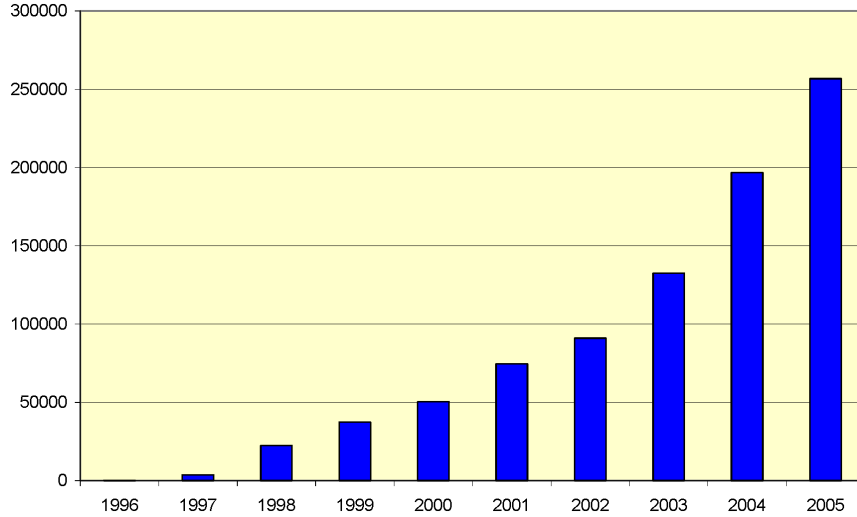
Source: Teske (2006)

As far as regional breakdown is concerned for 2005, new hybrid vehicle registrations in California strongly outpaced all other states with 52,619 units, with Florida being second with only 10,470 units. Texas came in third with 9,632 vehicles; then New York came in fourth with 9,372 units; and Virginia rounds out the top five with 8,650 new hybrid vehicle registrations. Indeed, Los Angeles remains the top metropolitan area for hybrid vehicles with 22,922 new hybrid vehicle registrations. San Francisco also kept its number two ranking with 15,828 units, followed by New York with 11,351 hybrids. Washington DC. came in fourth at 9,396 vehicles, followed by Boston with 3,641 new registrations.

For Japan, there are no official figures for sales of hybrid cars. The following data (Figure 2) on hybrid vehicles in use have been published by JAMA, the OEM professional association.

It is indeed very difficult to foresee market share for hybrid cars in the developed countries since it is an emerging technology competing with a well-established dominant design supported by a strong lobby. For the USA, there are many forecasts of market share published by professional experts as well as university sources. For a given year, they can vary considerably: from 11% (Mercer) to 30% (Polk) in 2015 for instance. Some are obviously over-optimistic, some rather pessimistic. Forecasts still vary significantly over time owing to adjustments and change of assumptions within the relevant key variables (see Section 3.2).

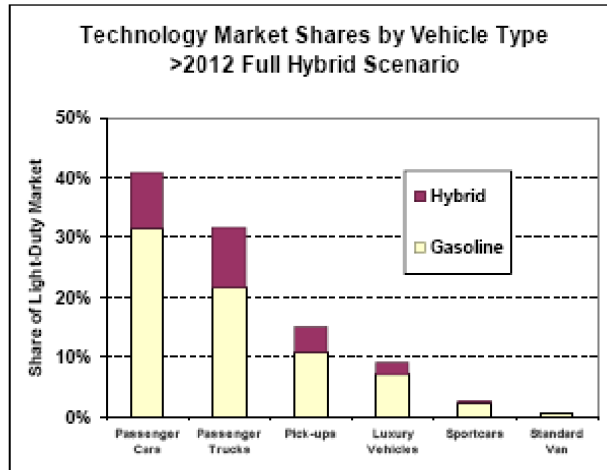
Figure 2 Hybrid vehicles in use in Japan



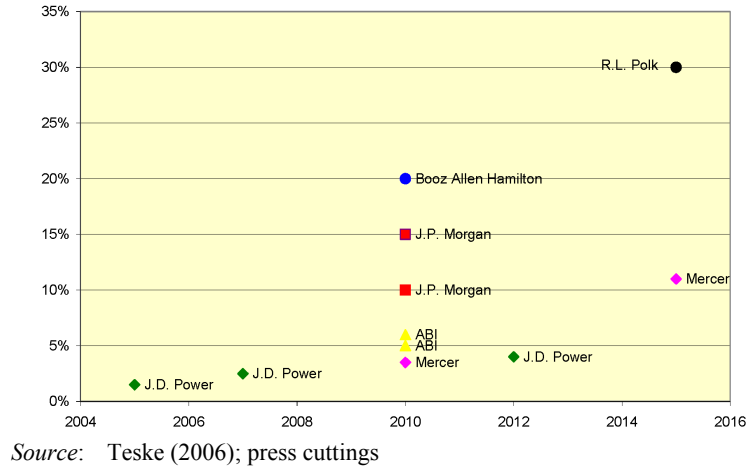
Source: JAMA

Greene et al. (2004) carried out an impressive survey in the USA about perception on hybrid vs. diesel power trains in the light duty vehicle market and provided a synthesis of most professional market literature available. They elaborated scenarios for 2008, 2012 and beyond, which show that market share for hybrids will remain limited and below usual expectations (Figure 3). Other forecasts are presented in Figure 4.

Figure 3 Market share of hybrid in 2012 in an ‘optimistic’ scenario



Source: Greene et al. (2004)

Figure 4 Forecast of HEV market share (US) by important consultant companies

3.2 Variables influencing the HEV market

Teske's analysis of the HEV market in the USA (2006) shows that future diffusion of HEV technology is driven by different variables. These can be grouped into three categories:

- The demand side of the market, including the perception of HEV technology among consumers (Klein, 2007), cost of ownership, maintenance constraints, and sociological reasons to choose HEV technology, such as the image impact of HEV technology.
- The supply side of the market, including the variety of HEV models offered, manufacturers' life cycle cost, characteristics of propulsion and fuel efficiency and emissions.
- Macro-economic factors, which influence the market as a whole. Examples are the development of the fuel price, the availability and relevance of alternative technologies such as clean diesel and natural gas vehicles, regulation and taxes.

The most relevant factors include:

Fuel price

Being a major driver in the cost of ownership calculation, fuel price is considered the central variable in future market scenarios. However, strong HEV sales at times of high fuel prices in 2005 and 2006 also indicate a psychological dimension of this variable: Although those fuel prices did not necessarily make the purchase of an HEV worthwhile financially (Teske, 2006), the continuous increase of the fuel price itself pushed consumers to react.

Growing environmental concerns

Environmental concerns become more and more a driver in consumers' purchase decisions. The broad public discussion on global warming due to CO₂ emissions, also by cars, is impacting buying decisions of consumers. In the USA, this is leveraged by the

argument of energy independence. Driving a 'green car' allows people to adopt a responsible and pro-active role in society. A new orientation towards ecology can be observed—in order to avoid remorse, the aspect of innovation gains importance over the classic interpretation of simply low fuel consumption.

Fuel efficiency and emissions

CO₂ emissions are directly proportional to the fuel burned in the internal combustion process. Modern combustion technologies such as high-precision gasoline injection allow reducing the fuel consumption and lowering harmful emissions such as CO, HC, and NO_x. HEV technology can help to lower emissions in different ways – by reducing a vehicle's fuel consumption through regenerative braking in stop-and-go traffic or by running the engine at highly efficient conditions.

Improvement of energy storage

Energy storage is considered the key functionality of HEVs. Functionalities like regenerative braking or additional performance for acceleration not only require high capacities of energy – the electric energy needs to be stored and released quickly. Today's HEVs mainly use batteries based on Nickel-Metal-Hydride (NiMH) technology – which is relatively heavy and expensive. Ongoing research activities focus on the exploitation of Lithium-Ion (Li-Io) technology—a lighter and more powerful alternative. However, the technology was not yet transferred to cars because of its inability to handle the quick charging and release cycles of the cars. Capacitors, as seen in the BMW X3 Efficient Dynamics, cope with this requirement, but have limited capacities when compared with currently used batteries.

Regulatory and tax regime

In some areas of the world, regulation clearly favours HEVs above conventional ICEs. This is especially the case in the eight US states who adopted the rules of the Californian Air Resource Board (CARB): New York, New Jersey, Massachusetts, Maine, Connecticut, Rhode Island, Vermont, and California. The Zero-Emission-Vehicle (ZEV) Program aims at drastically reducing emissions related to air quality. Besides setting up future emission standards, governments influence car sales with short-term interventions. Several states in the USA offer tax credits to support hybrid sales. The tax credit becomes effective upon purchase of an HEV. Tax incentives for HEVs are reported in at least 15 states of the USA and three cities; another 13 states are considering these measures. The tax credit amount is the sum of two factors: a fuel efficiency credit and a conservation credit. The fuel efficiency credit is based on a vehicle's increase in fuel economy over a 2002 comparable vehicle standard. The conservation credit is based on the estimated lifetime fuel savings. Thus, tax credits depend on the type of HEVs. In 2005, the highest tax credit of US\$ 3,150 was granted upon purchase of a Toyota Prius.

Although the US tax systems clearly favour HEVs, European legislation is more diverse: Currently, 11 EU member states have elements in their car and/or fuel taxation system that are totally or partly based on the car's CO₂ emissions or fuel consumption. With these tax systems being very different, they fail to send clear market signals.

To lower the fragmentation of the EU market, the Automobile Manufacturers Association (ACEA) is calling for a harmonised, cross-Europe CO₂ tax on cars and alternative fuels. According to ACEA, CO₂ should be the key criterion for taxation to

provide incentives to buy lower CO₂ emitting cars. Also, other than in some parts of the USA, taxation should be technology-neutral to allow competition for the best solution.

3.3 Fuel efficiency

The most common approach to compare fuel efficiency is to look at miles per gallon or at litres per 100 km. This approach can be also called TTW approach, since it compares fuel efficiency after the fuel was produced and made available to the car. It is the best practice when comparing cars using the same fuel with the same intrinsic energy.

However, for the comparison of cars using different fuels, the Well-To-Wheel (WTW) approach offers a holistic way to determine the overall implications of vehicle efficiency and includes the entire cycle of a fuel from the time it is extracted or produced until it is spent powering the vehicle. It also allows a more objective, technology-neutral analysis: The comparison of consumption figures is often impacted by differences in taxes on fuel and cars (see also Sections 3.4 and 3.5). The overall WTW efficiency is divided into a Well-To-Tank (WTT) and Tank-To-Wheel (TTW) efficiency so that $WTW = WTT \times TTW$ (www.usatoday.com).

In their important paper published in Science, Demirdöven and Deutch (2004) present the following figure of the WTW efficiency of the three types of vehicles (ICE, Hybrid and Fuel Cell).

Figure 5 gives an overview of four different simulations of WTW efficiency analysis and shows that efficiency improvements in HEVs on the TTW side are mainly due to regenerative braking and energy recovery at partial load.

Figure 5 Well-to-wheel efficiency

MODEL	ICE	HICE	AFC
Simple model	11.3	23.9	25.5
MIT-LFEE 2000	11.7	23.8	23.8-28.4
ANL/GM	15.2	18.6	24.6
NREL ADVISOR	11.3	24.5	23.9

Fig. 2. Comparison of WTW energy efficiencies of advanced vehicle systems using gasoline fuel. Color coding follows that in Fig. 1. 90% WTT efficiency in all cases; thus $WTW = 0.90 TTW$. Data for ICE and HICE is from (7), table 5.3. Data for AFC is from (8), which does not give energy efficiency directly. We derive a range for energy efficiency by comparing data in tables 8 and 9 for MJ/km for vehicle and fuel cycle for the 2020 ICE hybrid to that of the gasoline FC hybrid given in (7), table 5.3. Data from (6), table 2.1. Data from NREL's ADVISOR simulation; for details, see Table 1.

Source: Demirdöven and Deutch (2004)

With many different HEV models being marketed in the USA, many practical tests showed controversial efficiency results: Specifically, when comparing with modern diesel vehicles with high pressure direct injection and turbo charging, HEVs lose out when it comes to constant driving over longer distances. Other drawbacks to the consumer are smaller trunk capacities due to volume taken by the batteries or the higher initial purchase price. HEV technology offers advantages in stop-and-go traffic, which is in cities.

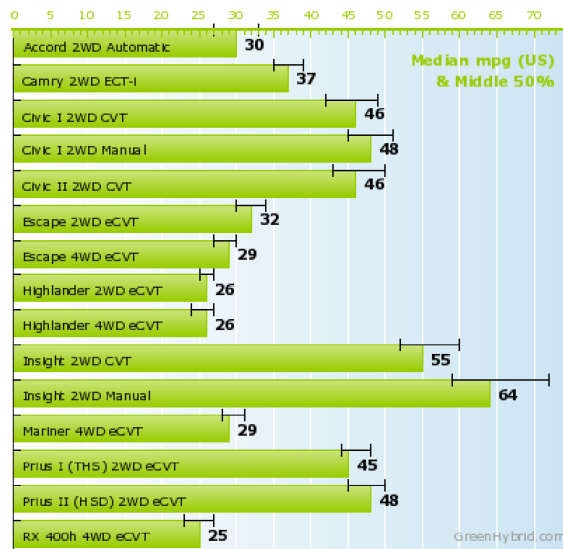
3.4 Is HEV a better alternative?

The hybrid technology still emits some pollutants and the combined electric and mechanical drive trains are a complex and costly solution. According to Ashley (2002), OEMs “must subsidise current hybrid car models heavily to make them affordable”. The Toyota Prius costs currently 4000 US\$ more than a comparable Corolla.³ In the US market, the hybrid version of the Honda Civic was sold 2500 US\$ more than the gasoline version. This is at the purchasing cost level. But their most recent hybrid models, such as Prius II and Honda Insight and Civic, are cheaper to run as indicated by their mileage records (Figure 6).

Consumers buying decisions are more and more driven by a car’s fuel economy. This is mainly due to increasing fuel prices. Consequently, if an HEV’s higher initial purchase price can be compensated by savings on fuel, the investment is worthwhile financially. As Teske (2006) pointed out in an analysis on cost of ownership, other cost drivers are taken into account:

- Tax advantages, such as credits granted in the USA upon an HEV purchase, help compensating the higher purchase price.
- The expected resale price of an HEV is still difficult to predict because of the absence of experience. In 2006, most HEVs on the used-car market were sold at relatively high prices, which can be explained by the high demand and the limited offer of new models during that time.
- To date, cost for maintenance and repair are very low, because most HEV manufacturers grant long-term warranty periods on HEV components to avoid obvious constraints of the new technology. For example, Toyota’s HEV-related components are covered by an eight-year warranty.

Figure 6 Real hybrid mileage database 41,637,141 miles, 33,380 tanks, 2558 cars within Green Hybrid database



Source: <http://www.greenhybrid.com>

The analysis, conducted for the US market, showed that in general the purchase of an HEV does not allow significant financial benefits for consumers. However, an analysis of the situation in France by Captital (2006) shows a different conclusion.

Here, the hybrid option looks attractive, in particular thanks to the decrease in fuel cost and to the tax incentive (Table 1).

With financial benefits being not significant, there must be other drivers to the current success of HEVs in the USA. A recent study conducted by Topline Strategy Group (2007) concludes that HEV drivers do not focus solely on financial performance. It is also some kind of environmental virtue driving the purchase decision. In the USA, driving a hybrid car shows social responsibility to many consumers. This is also due to successful marketing of the hybrid label by the early adopters Toyota and Honda. It is not necessarily the expected lower CO₂ output of one's car; the image attached to driving a hybrid car also creates value for HEV drivers.

Table 1 Total cost over four years

	<i>Toyota prius</i>		<i>Honda civic</i>		<i>Lexus 4WD</i>		<i>Citroën C3</i>	
	<i>Gasoline</i>	<i>Hybrid</i>	<i>Gasoline</i>	<i>Hybrid</i>	<i>Gasoline</i>	<i>Hybrid</i>	<i>Gasoline</i>	<i>Hybrid</i>
Purchasing	21,750	24,950	20,200	22,100	50,550	56,000	15,580	15,500
Tax incentive		-1,525		-1,525		-1,525		
Fuel	8,730	4,501	8,140	5,085	12,165	6,544	7,298	5,849
Insurance	2,514	1,835	2,514	1,835	5,091	5,091	1,960	1,837
<i>Total</i>	<i>32,994</i>	<i>29,761</i>	<i>30,854</i>	<i>27,495</i>	<i>67,806</i>	<i>66,110</i>	<i>24,838</i>	<i>23,186</i>

Source: Captital, Septembre 2005, pp.102, 103

3.5 Pricing

As highlighted above, the higher purchase price is a barrier to a faster diffusion of HEV technology. However, the price surplus differs significantly, taking into account regional and demographical preferences. As suggested by Teske (2006), the higher purchase price of an HEV can not only be compensated by savings over the car's lifetime; the technology also brings value of non-financial, i.e., qualitative nature. Examples are the surplus in torque delivered by the electric engines and the low noise during electric-only propulsion. Another important qualitative feature is the technology's image of social responsibility and sustainability. For example, Toyota successfully shaped these characteristics by strong marketing activities in the USA. These activities were leveraged by continuously rising fuel prices and an ongoing public discussion on climate change.

The issue of an 'ideal pricing' for hybrid cars has been raised by Kishi and Satoh (2005). They suggest the following prices for ICE and hybrid cars on the Japanese market (Table 2).

They also calculate the best pricing for the discount segment and the premium segment (Table 3).

Table 2 Prices for ICE and hybrid cars in Japan in US\$

	<i>Tokyo</i>		<i>Sapporo</i>	
	<i>ICE</i>	<i>Hybrid</i>	<i>ICE</i>	<i>Hybrid</i>
Minimum price	13,125	12,631	13,338	14,225
Maximum price	28,535	28,007	26,677	25,424
Standard price	21,222	20,932	20,148	19,978
Reasonable price	15,716	15,154	16,049	17,498

Source: Kishi and Satoh (2005). Exchange rate on 31/08/2006 was 1000 yen = 8523US\$

Table 3 Prices for hybrid discount and premium cars in Japan in US\$

	<i>Tokyo</i>	<i>Sapporo</i>
Discount market	14,583	14,625
Premium market	28,007	25,424

Source: Kishi and Satoh (2005). Exchange rate is 1000 yen = 8523US\$ (31/08/2006)

Tables 2 and 3 describe the results published by Kishi and Satoh (2005) on ‘acceptable pricing’ for HEV in Japan for better consumer acceptance and then for a fast growth of market shares.

At industry level, even if there is a consensus on the risk associated with a too expensive premium for clean vehicles, there are obviously diverging philosophies and approaches.

Nissan is considering that the market price of a fuel-cell powered vehicle should be not more than 1.2 times the price of a conventional car by 2015.⁴

The pricing issue is indeed a key one. Since the price premium for HEV technology when compared with comparable conventional gasoline vehicles is estimated at US\$ 4000 per vehicle,⁵ it means that so far, the OEMs cannot profitably sell HEV. The Ford Escape Hybrid market price is US\$ 3300 more expensive than its gasoline version and the Honda Civic is US\$ 2400 dearer than the traditional Civic.

In some countries, the gap is partly filled up by Government grants: €2000 in France for instance.⁶ In the USA, it was US\$ 3150 up to 1st September, 2006. Since then, it is US\$ 1575 and then US\$ 780 on 1st March, 2007.

4 Corporate strategies

4.1 OEMs

As the prime innovator, Toyota is indeed in a favourable position to achieve huge economies of scale through:

- expanding the number of models within its own range and its different brands
- sharing its technology as well as the cost of further R&D to prepare the next generations of devices to its affiliates such as Daihatsu,⁷ Fuji Heavy (Subaru)⁸
- supplying its technology to competitors such as Nissan, GM, etc.

Toyota is planning to lower the production cost of the hybrid system by 30% and to reduce the gap in price from 3500€ to 2000€. ⁹ Toyota produced 230,000 hybrid cars in 2005, 312,500 in 2006 and sold 998,900 HEVs worldwide until April 2007. For 2007, Toyota expects to sell 430,000 units, including 300,000 in the USA. The official objective is 1 million units from 2010 with a range of 10 models, of which 600,000 sold in the USA. ¹⁰ At the end of 2006, Toyota started to produce the Hybrid Camry in the USA.

Toyota will offer a small hybrid Vitz (in Europe Yaris) in 2010 and a large hybrid Crown in 2008. The world leader is still controlling the manufacturing of key components for HEV in its own plants as well as through its partner component suppliers such as Denso.

Honda is indeed the main competitor to Toyota being the closest as far as technology and knowledge about hybrid are concerned. Honda has already several models, even if they are sold in smaller volumes. Honda has less ambitious targets: 200,000 units by 2010 when 50,000 were sold in 2005.

Regarding other OEMs, some are enthusiastic 'pros', even if it is by necessity, others are cautious 'pros' and a few are very reluctant. Amongst the 'enthusiastic pros' one could find:

- GM, which found itself in the position to accelerate its programme for hybrids because it was losing market share at the benefits of Toyota and Honda. From 2006, an ambitious range is under development with hybrid version of big SUVs such as Chevrolet Tahoe and GMC Yukon (late 2007), light trucks such as GMC Sierra and Chevrolet Silverado (2008 on a new technology designed with DaimlerChrysler and BMW). In 2007, two sedans, the Chevrolet Malibu and the Saturn Vue Greenline will be offered as well. GM already warned officially that these products "will lose money ... because it is early stage technology and the volume is low". ¹¹ At the 2007 Detroit Motor Show, GM revealed a rechargeable hybrid (plug-in hybrid) – Chevrolet Volt – with a lithium-ion battery and a small three-cylinder engine, allowing a 65 km ride on the battery. ¹² A plug-in hybrid Saturn Vue is also currently prepared. ¹³
- Saab, a GM subsidiary, is developing an ethanol-electric hybrid in Trollhättan to be launched in 2008.
- Ford, which has also launched an ambitious programme targeting 250,000 units by 2010, but is struggling to sell its hybrid models. In 2005, Ford sold only 17,000 units of the Ford Escape and the Mercury Mariner with a manufacturing capacity of 2000 units per month, and then initiated a 1000 US\$ discount and a 0% credit in 2006.

Amongst the more cautious 'pros', one could position:

- Hyundai, the leading Korean OEM, which has chosen a stand-alone strategy, delivering 350 prototypes of its Verna to the Government for testing and evaluation and expecting to initiate production not by the end of 2006, as initially announced, but in 2009. The objective to reach a total output of 300,000 units by 2010 is then postponed to a later date. ¹⁴
- Kia, which also sold around 400 units of its Click hybrid to the Korean Government and also postponed the production to 2009. ⁷

- Peugeot-Citroën in France, which is quite reluctant on developing hybrid vehicles. It has designed with Ricardo (UK) and QinetiQ (UK),¹⁵ a prototype of the Citroën Berlingo, thanks to grant given by the British Government through its “Ultra Low Carbon Car Challenge” project. Citroën is marketing the C3 ‘Stop and Start’ hybrid since mid-2005,¹⁶ Peugeot-Citroën will lead the consortium funded by the French Government within the Predit R&D initiative, together with Valeo, Bosch, Saft and Michelin.¹⁷
- Nissan, the Renault associate, which appears to lag behind its main competitors, Toyota and Honda, and which might be used as the pilot test partner. In 2002, Nissan signed an agreement with Toyota to use its technology: a Nissan Altima hybrid is due to be launched in the USA in 2007. With its in-house solution, Nissan announced a hybrid car for 2010.¹⁸
- BMW is indeed actively developing a hybrid technology. A hybrid BMW is due before 2010 and a hybrid Mini is prepared for 2013–2014.¹⁹ BMW cooperates with DaimlerChrysler and GM to develop a first-generation hybrid drive. To date, BMW offers different measures to increase fuel efficiency under their label ‘Efficient Dynamics’, including start–stop automatic, brake energy regeneration, and high precision injection in gasoline engines.

Amongst the most reluctant, not to say opponent, OEMs, one could classify those that are still at the R&D or the prototype level:

- Mazda, a partner to Ford
- Volvo cars, also a Ford subsidiary
- Renault, which stated that hybrid cars will remain a niche market.

Strategic alliances are one of the ways to overcome or at least contain Toyota’s domination:

- BMW, DaimlerChrysler and GM formed a consortium in August 2005 for developing in its Troy (Michigan) research centre and producing hybrid cars.²⁰ Mercedes Benz has launched two hybrid versions of its S Class during the 2005 Frankfurt Motor Show.
- GM has released that it will produce hybrid vehicles in China in partnership with SAIC by 2008.²¹ GM will also launch “as soon as possible” a hybrid vehicle designed with Suzuki.²²
- The VAG Group (VW, Audi) and Porsche are jointly designing hybrid vehicles and are expected to market hybrid versions of the VW Touareg, the Audi Q7 and the Porsche Cayenne SUV in 2008.²³ A VW Jetta is due to being sold in the USA in 2009.²⁴
- It is also the way used by Nissan through a strategic cooperation with its competitor.

Surprisingly, the Chinese OEMs are also involved in the race for the expected growing domestic market for hybrid cars:

- Chery et Geely might commercialise hybrid models by 2007 and Nanjing is preparing a hybrid version of the Rover 75, with a technology derived from the Toyota Prius.²⁵

As far as trucks are concerned, Volvo presented a diesel electric hybrid system to be launched in 2009. Volvo Trucks expects that this technology will take 10% of its turnover since its customers will see a 25–50% saving in petrol consumption despite a higher investment.²⁶

4.2 *Component and system suppliers*

Component manufacturer's struggle to keep up with the pace HEV technology was developed by the first OEMs.

- Continental and ZF Friedrichshafen expect to produce together hybrid engines, including braking and associated electrical components by 2007. ZF did develop a gearbox integrating the electric engine. Continental is also cooperating in design and development with Volkswagen.²⁷
- Bosch, one of the world's largest component manufacturers, has recently decided to invest heavily in hybrid components, realising that such technology will take 1% of the total vehicle registrations by 2010, i.e., around 700,000 vehicles, and 5% in 2025.²⁸
- Hitachi is one of the key suppliers of electric engines for the Toyota Harrier and Kluger, being the first component manufacturers non-affiliated to Toyota to be involved in the hybrid business.²⁹
- Panasonic EV Energy, making batteries nickel-metal-hydride (Ni-Mh) for hybrid, been taken over by Toyota (60% of its stockholding).
- Johnson Controls (51%), world leader in automotive batteries, and SAFT (49%) formed a joint venture to develop lithium-ion (Li-ion) batteries for hybrid vehicles.³⁰ A new plant will be operational in France (Angouleme) with an investment worth US\$ m20.³¹
- Sanyo, the leading Japanese battery manufacturer and key supplier to Toyota, Honda, Ford and others,³² has teamed up with Volkswagen for developing and supplying batteries and control systems for hybrids.
- On the high-voltage wiring market for hybrids, Yazaki, which supplies the batteries for the Toyota Prius and the Lexus UX 400h crossover hybrid, is expanding in the USA to supply the Toyota Camry Hybrid and the Ford Escape. Yazaki's competitors include Sumitomo Electric Industries Ltd., Hitachi Automotive Products Inc., Lear Corp. and Delphi Corp.
- Two multinational component manufacturers, Siemens VDO and Magna International, cooperate in developing a hybrid vehicle on the basis of a Mercedes Benz ML350, reducing fuel consumption by 20%.

4.3 The emergence of new players

4.3.1 AFS trinity power corporation

AFS Trinity Power is headquartered in Bellevue, Washington, and has an engineering centre in Livermore, California. This company has developed a new hybrid technology and claimed that it is much more efficient than current options.³³ It is Plug-in hybrid electric vehicles (PHEVs). The three plug-in designs that are mentioned most often today are: various plug-in conversions of the Toyota Prius; the Daimler Chrysler Sprinter van; and the AFS Trinity Extreme Hybrid™ (XH™). AFS Trinity published the following benchmarks (Table 4):

Table 4 Characteristics and performances of AFST extreme hybrid

<i>Model</i>	<i>Calcars prius+¹</i>	<i>Energy CS Prius²</i>	<i>DC sprinter van</i>	<i>AFST extreme hybrid™ sedan⁴</i>
Energy storage technology	Lead-acid Battery	Li-ion Battery	NiMH Battery	Li-ion Battery + Ultracapacitor
Energy storage capacity (kWh)	3–4	9	14.4	12.5 + Ultracapacitor
Electric-only Range (miles)	10 ⁵	30 ⁵	20–30 ⁶	40
Top Speed in electric-only mode (mph)	34	34	Not given	110
Electric-only optimum freeway speed operating range (mph)	N.A. ⁷	N.A. ⁷	Not given	55–75
Top SPEED in hybrid mode (mph)	Same as std Prius	Same as std Prius	Not given	110
Rated fuel economy ³	100 mpg	100 mpg	Not given	250 mpg
Battery life	11 months	Not given	Not given	10 years/150,000 miles

¹CalCars first generation prototype Prius conversion.

²EnergyCS Prius conversion.

³Based on 300-mile weekly drive cycle with 40 miles per day on 5 weekdays and 100 miles on one weekend day. This allows the XH™ to operate in electric-only mode for 240 miles and in HEV mode for 60 miles.

⁴Extreme Hybrid™ specifications are subject to change as development of the XH™ drive train continues.

⁵See CalCars PHEV Conversions Fact Sheet-April 20, 2006, PHEV Battery Comparison Chart.

⁶“A Giant Stride for the Future of Electric Transportation”, EPRI Pamphlet, 2004.

⁷With maximum electric-only speed of 34 mph Prius+ operation on freeways requires use of its gas engine.

4.3.2 Amberjac projects and energyCS

Two design companies, Amberjac Projects (UK) and EnergyCS (California, USA), developed the Plug-in hybrid version of a Toyota Prius 2004, equipped with lithium-ion-phosphates, which from 55 km/h is running on gasoline at 2.5 l/100 km. The conversion kit will be sold 10.000€ by the end of 2006.³⁴ The battery is still too heavy and this weight should be reduced by 35 kg.

4.3.3 *SVE*

SVE is a French joint-venture between Heuliez and Dassault, which has developed a hybrid car named Cleanova Plus equipped with a bio-ethanol engine.³⁵

4.3.4 *Swatch*

Nicolas Hayek, the Swiss entrepreneur, CEO of Swatch, has developed an HEV and is currently negotiating with OEMs for a technology and knowledge transfer.³⁶

5 Conclusion

Some of the biggest OEMs promote HEV technology as the best alternative to increase vehicle efficiency. Most press articles and corporate literature published by HEV manufacturers and suppliers look at HEV with optimism. Opponents to HEV obviously attack the technology with strong arguments against its technical complexity and challengeable overall efficiency.

Indeed, political pressures are also involved in the game. The three American OEMs, namely GM, Ford and Chrysler, recently urged President Bush to financially and politically support a national technological solution for hybrids, independent from the currently dominant solutions initiated by Toyota.

However, HEV technology is only one subset in the wide range of measures to lower fuel consumption. The main aims of current vehicle development, to increase fuel efficiency while lowering weight and costs can be solved alternatively as shown with current diesel models or intelligent cost-efficient solutions as the BMW example shows.

Consumers' buying decisions are driven by factors different from financial ones only. These are dynamic in nature owing to an ongoing public discussion on climate change and related changes within macro-economic factors such as taxes. Anticipating these changes will be central to successfully marketing cars in the future.

This paper comes to the conclusion that HEV will probably gain a significant market share in Japan and the USA due to market pressures, sustained by political lobbying, but will remain limited elsewhere in the mid-term. One of the clearer uncertainties is the potential effect of a development of HEV market in China where environmental issues are of significant concern. Chinese OEMs could see the HEV as a solution for their growth in a very competitive globalised market. A positive driving force to HEV is certainly the difficulties identified by fundamental and applied research and development units with OEMs or component suppliers as well as public laboratories in developing more sophisticated technologies such as fuel cells or batteries for full electric drive trains. Such alternatives require breakthrough disruptive innovations and would probably emerge in the very long future, i.e., at least not before 10 or even 20 years. In the meantime, HEV technology might have a real future.

But the complexity and high cost of the hybrid technology is also playing against itself. There is a huge strategic dilemma for the key players of the automotive industry where a mistake in technology decision-making might turn even a big player into a take-over candidate. The next five years will provide industry observers with more accurate trends and success or failure factors.

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Notes

¹For batteries.

²For fuel cells.

³Nihon Keizai Shimbun, 13/09/2005.

⁴Nihon Keizai Shimbun, 05/09/2006.

⁵Les Echos, 05/10/2006.

⁶€3,000 is an old vehicle is dismantled.

⁷Nihon Keizai Shimbun, 30/08/2005

⁸Nihon Keizai Shimbun, 26/11/2005.

⁹Nihon Keizai Shimbun, 01/04/2006.

¹⁰Les Echos, 13/03/2006.

¹¹R. Wagoner, CEO, quoted in Financial Times, 19/09/2005.

¹²Financial Times, 08/01/2007.

¹³Financial Times, 30/11/2006.

¹⁴Korea Herald, 19/05/2006.

¹⁵Le Parisien, 10/09/2005.

¹⁶Capital, Septembre 2005.

¹⁷Les Echos, 26/04/2006.

¹⁸Financial Times, 11/12/2006.

¹⁹Die Welt Am Sonntag, 29/10/2006.

²⁰L'Expansion, Octobre 2005.

²¹Wall Street Journal, 31/10/2005

²²El Mundo, 08/01/2007.

²³ddeutsche Zeitung, 13/09/2005.

²⁴Autocar, 27/12/2006.

²⁵Auto Journal, 07/12/2006.

²⁶Dagens Industri, 21/12/2006.

²⁷Frankfurter Allgemeine Zeitung, 10/06/2006.

²⁸Automotive News Europe, 10/06/2005.

²⁹Nihon Keizai Shimbun, 10/10/2005.

³⁰Les Echos, 12/10/2005.

³¹Les Echos, 22/09/2006.

³²Supplying for the Ford Escape and Honda Accord, see Nihon Keizai Shimbun, 31/01/2006.

³³Les Echos, 10/05/2006. See the company's website at <http://www.afstrinity.com>.

³⁴Usine Nouvelle, 27/10/2005.

³⁵Le Figaro, 27/09/2006.S.

³⁶Frankfurter Allgemeine Zeitung, 20/03/2007.

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Appendix: Back statistics

Appendix A Most fuel-efficient cars (by EPA size Class)

	City	Hwy
<i>Most efficient two seaters</i>		
Honda Insight Hybrid – 3 cyl, 1 L, Manual(5)	60	66
Honda Insight Hybrid–3 cyl, 1 L, Automatic(variable)	57	56
<i>Most efficient minicompact Cars</i>		
MINI Cooper–4 cyl, 1.6 L, Manual(5), Premium	28	36
MINI Cooper –4 cyl, 1.6 L, Automatic(variable), Premium	26	34
<i>Most efficient subcompact Cars</i>		
VW New Beetle (Diesel)–4 cyl, 1.9 L, Manual(5)	37	44
VW New Beetle (Diesel)–4 cyl, 1.9 L, Automatic(6)	35	42
<i>Most efficient compact Cars</i>		
Honda Civic Hybrid –4 cyl, 1.3 L, Automatic(variable)	49	51
VW Golf (Diesel)–4 cyl, 1.9 L, Manual(5)	37	44
<i>Most efficient midsize cars</i>		
Toyota Prius (Hybrid) –4 cyl, 1.5 L, Automatic(Variable), Regular	60	51
Hyundai Elantra–4 cyl, 2 L, Manual(5), Regular	27	34
<i>Most efficient large cars</i>		
Hyundai Sonata–4 cyl, 2.4 L, Manual(5), Regular	24	34
Hyundai Sonata–4 cyl, 2.4 L, Automatic(4), Regular	24	33
<i>Most efficient large cars</i>		
Hyundai Sonata – 4 cyl, 2.4 L, Manual(5), Regular	24	34
Hyundai Sonata – 4 cyl, 2.4 L, Automatic(4), Regular	24	33
<i>Most efficient small station wagons</i>		
Pontiac Vibe–4 cyl, 1.8 L, Manual(5), Regular	24	34
Toyota Matrix - 4 cyl, 1.8 L, Manual(5), Regular	24	33
Scion xB–4 cyl, 1.5 L, Automatic(4), Regular	24	33

Source: <http://www.fueleconomy.gov/feg/bestworst.shtml>

Appendix B Fuel consumption of three competing luxurious station-wagons

<i>Measures</i>	<i>BMW 535D</i>	<i>Mercedes-benz E500</i>	<i>Lexus GS450h</i>
Maximum speed	250 km/h	250 km/h	250 km/h
<i>Fuel consumption</i>			
Average	8.6 L/100 km	10.3 L/100 km	8.8 L/100 km
Highway	8.3 L/100 km	9.2 L/100 km	7.4 L/100 km
City	10.3 L/100 km	12 L/100 km	11.1 L/100 km
Range	810 km	770 km	730 km
Weight	1820 kg	1920 kg	1890 kg

Source: Revue automobile, 27/07/2006

Appendix C Consumption with and without air conditioning and heating

	<i>Without AC and heating (L/100 km)</i>	<i>With AC and heating (L/100 km)</i>	Δ (%)
Honda civic gasoline	6.8	7.1	+4
Honda civic hybrid	4.9	6.5	+32

Source: Le Figaro, 20/01/2006

Appendix D CO₂ emissions in grams per kilometre

<i>Models</i>	<i>Emissions</i>
Smart for two CDI (diesel)	90
Toyota Prius II (hybrid)	104
Citroën C2 1.4 HDI	107
Renault clio 1.5 DCI	110
Toyota land cruiser SW TD (diesel)	292
Volkswagen touareg V10 (diesel)	346
Ferrari enzo (gasoline)	545

Source: Le Monde, 15/09/2005