MARKET PROSPECTS OF FUEL CELL VEHICLES: A DRIVER-BASED APPROACH

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1 Introduction

The market analysis in this report is carried out by following the framework described in Freemand and Louça (2001) and Geels (2002). Geels (2002) adopts a three-tier "multi-level perspective" to technological change, the two highest levels of which are the socio-technical landscape and socio-technical regime, the lowest level being market niches. Regimes can be described as "configurations that work" (Rip and Kemp 1998), a definition which clearly refers to the fulfilment, in an economically and socially acceptable way, of a *function* that is considered useful or desirable. According to Geels (2002), socio-technical regimes include not only the organisational and cognitive rules and routines adopted and followed by engineers and firms, but also the routines influencing the behaviour of "users, policy makers, social groups, suppliers, scientists and bankers etc". On the other hand, the socio-technical landscape is an external "structure or context for interactions among actors" (Geels 2002, p.1260) in a regime. This landscape contains a set of "heterogeneous factors, such as oil prices, economic growth, wars, political coalitions, cultural and normative values and environmental problems". Freemand and Louça (2001) state that fundamental changes in technological systems are processes that are rooted at the deepest level in the social contexts in which they occur. The authours maintain that such development requires the co-evolution of five 'semi-autonomous' social subsystems: science, technology, economics, politics, culture. They are semi-autonomous because, although the five variables are linked and interact, they also have autonomous elements. Fundamental technological changes are possible when, and only when, the co-evolutionary direction of change of all five variables is basically supportive of such change. As described in more detail in Agnolucci and Ekins (2006), technology adopted by the socio-economic actors in a regime will need to fulfil the function defining the regime in the best possible way. The effect of the landscape and regimes on the choice of technologies can be analysed through analysing the relevant variables in the sub-systems of the physical and the socio-economic dimensions of Freeman and Louça (2001).

Fuel cells are electrochemical devices that convert chemical energy directly into electrical energy. In a typical fuel cell, the electrochemical reactions between gaseous fuels and oxygen produce electric current. Despite having components and characteristics similar to those of batteries, fuel cells have the capability of producing electrical energy as long as fuel and oxidant are supplied. In reality, degradation, primarily corrosion, or malfunction of components limits the practical operating life of fuel cells. Fuel cells can be run on hydrogen directly fed on the cell or reformed from a plethora of energy sources, such as petrol, natural gas or methanol. Methanol can also be fed directly to the cell (US DoE 2002).

Fuel cells have been described as a Disruptive Innovation for a number of applications (Adamson, 2005; Hendry et al 2004), which in the logic of this paper can be grouped around three regime functions: provision of portable, automotive and stationary power. Although the hydrogen economy is normally presented as an overarching and all-embracing concept (e.g. Rifkin 2002), the analysis of fuel cell markets needs to be undertaken in terms of the distinct regimes in which they are used if one wants to individuate both the competing technologies and the attributes, which can make fuel cells successful. Bearing in mind the trends in the regime focused on the provision of automotive power (from now onwards automotive regime), this case study discusses the potential adoption of a Fuel Cell Vehicle (FCV) by drivers sometime into the future. The market analysis carried out in this paper applies the framework above to the adoption of Fuel Cell Vehicles (FCVs) by a representative consumer.

Internal Combustion Engines (ICE) are currently the incumbent technology providing mobility services. Although there has been a certain amount of research on alternative powertrains, notably in electric cars powered by batteries in the 1990s (Pelkmans and Christidis 2003; Cherry, 2004), much of the effort in the past has focused on the provision of alternative, cleaner fuels to an ICE or on the development of bi-fuels vehicles such as LPG. Many representatives of the industry and academia have touted fuel cells as being able to supersede the ICE as incumbent in this regime. However, fuel cells will have to compete with a) future advanced configurations of Internal Combustion

Vehicles (ICEVs) working on normal fuels and new energy carriers (such as hydrogen or biofuels) and emission reduction technologies; b) hybrid powertrains; and with c) other current niche markets technologies, such as electric battery-powered drives. In the following section we analyse the factors that can help or hinder the adoption of Fuel Cell Vehicles (FCVs), grouped according to the clusters mentioned above: Technological Performance, Infrastructure Requirements, Economic Factors, Institutional Factors, Policy Instruments and Cultural Perceptions.

2 Technological Performance

According to many authors in the literature (Davis et al 2003; Oertel and Fleischer 2003, MacLean and Lave 2003), the advantages of FCVs when compared with ICEVs are higher fuel efficiency, the provision of an efficient on-board energy and voltage supply and higher mechanical simplicity implying fewer vibrations, noise and maintenance. Other benefits from FCVs are reduction of pollutants and their ability to function as a mobile source of electricity. One can notice that among the benefits of the FCVs higher mechanical performance is unfortunately missing.

Mechanical Performance

There seems to be in the literature a fairly widespread acknowledgment that in terms of mechanical performance, i.e. acceleration, top speed, start-up time and range, FCVs will be at best equivalent or nearly equivalent to ICEVs. The aim is to make “the FCV indistinguishable from the ICEV in terms of performance” (James et al. 1996). As ICEVs have benefited from almost one century of targeted R&D activities, drivers are unsurprisingly fairly satisfied with their cars. Given the effort and capital investment dedicated to ICEVs, it will be challenging for FCVs to match the performance of ICEVs. Nonetheless, considering the introduction of other powertrains in the past, it does seem that FCVs will need to offer performance similar to that of ICEVs if the former are to capture a substantial share of the market. In fact, the increased performance of diesel engines in the early nineties has been one of the reasons responsible for their increased penetration in the market (Cowan et al 2003). According to Christidis (2003), with the exception of the limitations related to the number of models available, there does not seem to be any other difference between gasoline and diesel cars of comparable performance, apart from cost. Although consumers are likely to be interested in the vehicles performance and not in the type of powertrain or fuel (Christidis (2003), FCVs with on-board methanol and petrol are likely to be heavier, more complex and more importantly less responsive to immediate power demand, therefore offering lower performance to consumers. Advanced configurations of petrol or diesel ICEVs or hybrids are more likely to offer performance comparable with current powertrains. Electric Vehicles powered by batteries might be of interest to drivers, provided that longer ranges are achieved.

In terms of marketing, the implications of FCVs matching the performance of ICEVs are rather interesting. Stressing the power, speed and acceleration, i.e. the strategy so far adopted in most advertising campaigns, will not be appropriate for FCVs as at best they will match the performance of ICEVs. Another selling point of cars, big trunk space, will also not be of much prominence in the adverts of FCVs, which at best will have as much passenger space as ICEVs. It is also worth mentioning that for some time after the commercialization of FCVs, automakers are also likely to introduce only a limited number of models on the market, therefore constraining consumers' choice (Bevilacqua Knight 2001, US DoE 2002). An attribute of FCVs that might heavily feature in the advertising campaigns is innovative design. Fuel cell technology provides developers and designers a great deal of flexibility because of the removal of the front engine transmission block typical of ICEVs. The components of the fuel cell system can be installed horizontally on the vehicle floor while four electric motors can be placed in the hub of the wheels (Oertel and Fleischer 2003). General Motors has already presented a concept vehicle, AUTOnomy, implementing this approach (Burns et al. 2002).

Efficiency and Simplicity

Potential adopters are not likely to be attracted by the higher efficiency of energy use in FCVs, when measured from the tank to the wheels. In fact, drivers are more likely to be interested in the fuel cost to travel a certain distance rather than in the fuel consumption. While increased simplicity of FCVs when compared to ICES might be not very appealing to customers, the smaller amount of vibrations and noise could be of interest. However, considering that today's cars are rather silent and that radios and CD players often cover the noise from the engine, the lack of noise arising from the vibrations in ICEVs is likely to be only a small advantage for FCVs. More interestingly, if the increased mechanical simplicity of FCVs translates into lower maintenance costs, cost conscious customers or those driving a high mileage per year could be attracted by FCVs. Like in the case of fuel efficiency this can give an economic advantage to FCVs and will be discussed below.

On-board Energy Supply

A potential benefit of FCVs could be the efficient on-board supply of energy and voltage for comfort load. In terms of entertainment and comfort it is fair to say that current vehicles are still relatively basic, with the former limited to CD players and the latter to air conditioning and heating. Electronic appliances are either restricted to systems helping drivers (e.g. maps and GPS) or present on specialist or luxury vehicles, although electric systems have recently substituted a number of mechanical and hydraulic subsystems (Lutsey et al 2003). Although at the height of the dotcom bubble some vehicles showcased dashboards with computer screen, user-based programmable performances and internet connection, carmakers have now gone back to more mundane issues such as design, speed, handling, ride and comfort (Anon 2004). Very advanced electronic equipments will probably be considered indispensable only by a small number of buyers.

Even if advanced electronic equipments become extremely popular, it is not clear whether ICEVs will not be able to accommodate these types of demands. Meissner and Richter (2001) are sceptical about the need for new power sources as several of the new functions, especially those aiming at improved reliability and comfort, can be satisfied by existing 14V electrical systems. Although higher electrical loads are being supplied when the engine is off or on idle, the authors are confident that modifications will be introduced in a stepwise fashion. In particular, energy management systems can keep the batteries in their best operational window so as to assure that critical components are supplied with power. It also seems likely that the need for FC APUs would be weakened by the diffusion of diesel or gasoline hybrids, as these vehicles will have large batteries able to supply power when idle. The introduction in a limited number of European markets, e.g. in Italy (www.forfour.it), of the Smart ForFour DVD, i.e. an ordinary model with DVD reader and two 7’’ screens shows that ICEVs can still compete with FCVs even when entertainment and comfort on-board load increase.

Mobile Power Station

Another advantage of FCVs could be their ability of working as mobile power generators, which can be plugged into grid to sell back electricity produced from FCVs. Among the four segments of the vehicle-to-grid (V2G) market, Kempton and Tomic (2005a) discovered that plug-in vehicles are not competitive for baseload power and are suitable for peak power only in some instances. On the other hand, plug-in vehicles are competitive for spinning reserves and highly competitive for regulation[1]. By using their vehicles as mobile power stations drivers can make a more efficient use of electricity storage and production system purchased for transportation. The benefit plug-in vehicles to grid operators consist in substituting expensive generating capacity which is currently used for spinning reserve and generation but sits unused most of the time. Owners of fleet vehicles are one of the most likely beneficiaries of the V2G market. As pointed out by Kempton and Tomic (2005b), fleet vehicles have the advantage of normally being used according to fixed schedules. In other words it would be relatively easy for fleet owners

[1] Baseload power is the “bulk” power generation that is running most of the time. Peak power is used during times of predictable highest demand. Spinning reserves are supplied by generators set-up and ready to respond quickly in case of failures. They would typically be called, say, 20 times per year for about 10 minutes although they must be able to last up to 1 hours. Regulation is used to keep the frequency and voltage steady, they might be called 400 times per day for few minutes at a time. Spinning reserves and regulation are paid in part for just being available; baseload and peak are paid only per kWh generated (Kempton and Tomic 2005b: 282).

to guarantee the availability of their vehicles to grid operators. This is particularly convenient for the introduction of FCVs, as fleet operators are also one of the actors which might easily circumvent the lack of an extensive infrastructure in the first years after the introduction of FCVs. As the spinning reserve and regulation market is much bigger than the capacity provided by fleet vehicles, owners of ordinary vehicles could obtain an interesting income stream from the V2G market. Utilities or other independent parties act as aggregators of individual vehicles, i.e. middlemen between grid operators and a set of dispersed vehicle owners (Kempton and Tomic 2005b). However, doubts regarding the extent to which the V2G can help the diffusion of FCVS are related to the equipment needed to plug-in the cars and to the amount of revenues accruing to the vehicle's owners. If extensive equipment is needed to dispatch and meter the electricity produced from the vehicles, it seems likely that most drivers will not play any role in the V2G market get because of the upfront costs to buy the equipment. However, in case the upfront costs are small, it is likely that competition among drivers will squeeze revenue. Nonetheless, it is fair to conclude that the V2G market is an interesting opportunity for the owners of FCVs and hybrid vehicles. Plug-in vehicles have attracted a great deal of interests, especially in the United States (Anon 2006).

Environmental Benefits

The main benefit from FCVs seems to be the absence of pollutants at the consumption–point in the case of cells fuelled on hydrogen, or the substantial decrease in pollutants in the case of cells fuelled with on-board reformed alcohols or hydrocarbons. In the case of global pollutants different powertrains should be compared taking into account the whole fuel cycle, from the well to the wheels, i.e. comprising the pollution generated when producing hydrogen. Although researchers have analysed pollution from several hydrogen production methods (EUCAR et al 2005, Wang 2003), hydrogen is likely to be produced in the medium term, i.e. up to 2020, from natural gas through a process called steam methane reforming. Carbon can be sequestered only when hydrogen is produced in plants of a considerable size. When produced on-site at filling stations, carbon sequestration is not practicable.

In terms of GHG emissions in the medium term there does not seem to be a great deal of difference between FCVs and a number of options for ICEVs. Some authors have concluded that up to 2020 "the development of alternative drive technologies like fuel cell vehicles or battery-powered electric vehicles is not necessary" from the point of view of transport pollution[2] (Oertel and Fleischer 2003). According to Weiss et al. (2002) in 2020 diesel ICE hybrids and Compressed Natural Gas ICE hybrids will perform better than hydrogen FCVs in terms of life-cycle GHG emissions, i.e. considering also the materials needed to produce the vehicles[3]. By following a strategy aimed at introducing FCVs in 2020 through "progressive and significant CO_2 reduction at lowest cost and risk" for manufacturers, Owen and Gordon (2003) shows that a hybrid ICEV in 2017 is likely to reduce emissions by 49% compared to a 2003 ICEV while the FCV introduced in 2020 is likely to reduce GHG by only an average 43%[4]. Although there does not seem to be much difference between FCVs and ICEVs in terms of GHG emissions, FCVs could be less polluting in terms of local pollutants (NO_X, particulates and SO_X). However, according to Oertel and Fleischer (2003) this is not the case, as "new consumption-optimised vehicles with an internal combustion engine with extra-low exhaust gas emissions also enable local emissions that are nearly zero". Although "further actions would be needed for a reduction of particle emission of diesel drives, [t]he first technical devices for their reduction are already commercially available, even though at the moment there are no clear political efforts to impose these technologies".

[2] The performance of diesel hybrids and FCVs fuelled by hydrogen from natural gas reformed at a central location are virtually the same, i.e. -28% emissions than a petrol ICEV. ICEVs fuelled on hydrogen emit more GHGs than a petrol ICE if hydrogen is not produced from renewables. Decentralized pathways based on compressed hydrogen from fossil fuels produces only about half GHG reduction of the centralized ones maybe because of lower efficiency of small reformers (Oertel and Fleischer 2003).

[3] Compared to a 2020 gasoline ICEV, an advanced gasoline ICEV will emit 89% of the GHGs, an advanced diesel ICEV 76%, a hybrid gasoline ICE 65%, an hybrid petrol diesel ICE 55%, an hybrid CNG ICE 62% and an hybrid F-T diesel 86%. A hybrid hydrogen FCV will emit 72%, while a hybrid gasoline FCV and a hybrid methanol FCV will emit a disappointing 104% and 99%, respectively. A battery electric car will emit 80% (Weiss et al. 2002: p1-22).

[4] GHG emissions for three vehicles in Owen and Gordon (2003) are 170 g/km for the 2003 vehicle, 86 g/km for the 2017 Advanced Diesel Parallel Hybrid with Heat Recovery. The upper and lower bounds for the 2020 Hydrogen FCV are 119 and 74 g/km.

It should be mentioned that comparisons of pollutants from different powertrains are normally performed using regulated official driving cycles. As these cycles have been found to be a relatively mild representation of real world driving (e.g. Azkarate and Pelkmans 2003), real world emissions would tend to be higher than those obtained by these studies. In particular, the increase in emissions of FCVs in real-world setting is likely to be lower than the increase in emission from ICEVs because of the higher fuel efficiency of the former powertrain. In addition, when comparing different powertrains it is rarely mentioned whether the vehicles are tested with or without comfort loads, i.e. air conditioning or heating. Azkarate and Pelkmans (2003) have showed that air conditioning increases fuel consumption although the effect on other emissions depends on the type of engine[5]. Once again, the use of air conditioning and other comfort load will influence also the fuel consumption of FCVs, although probably to a less extent because of the higher efficiency. Finally, some comparisons have adopted optimistic assumptions regarding the weight of vehicles, i.e. lightweight vehicles, despite the existence of a trend in increased weight both in Europe and USA (Azkarate and Pelkmans (2003).However, both Owen and Gordon (2003) and Weiss et al. (2002) refrain from this practice.

3 Infrastructure Requirements

The features of the infrastructure that are most likely to affect the consumers' choice among competing powertrains are the cost and the density of filling stations. The former is important insofar as it influences the price of the fuel, an economic factor which will be discussed in the following section. It is interesting to notice that the density of filling stations in the early years after the introduction of FCVs could vary for different types of FCVs. In fact, petrol FCVs with on-board reformers would still be able to fill up at the current petrol stations, even though the fuel will be slightly different from the petrol used today. In the case of methanol, current petrol stations would need to undergo some

[5] Pelkmans et al. (2003) discovered a 20% increase in CO_2 from gasoline cars and a 20-30% increase in NO_X, PM and CO_2 from diesel engine due to use of air conditioning. However, the authors conclude that there remain too many uncertainties to propose quantitative factors to correct for air conditioning on vehicles' emissions. The figures above relate only to a single legislative cycle (the European test cycle), and are from a small number of tests (Pelkmans et al. 2003, 143).

refurbishment due to the corrosive properties of methanol. As conversion of petrol stations to methanol can cost about £30,000 (Hart et al. 2000), it is likely that the number of methanol stations could increase relatively rapidly, if demand arises. As the conversion of petrol station to dispense hydrogen is reportedly much more expensive (Wang 1998) hydrogen fuel infrastructure (without on-board reformation) "is likely to be deployed gradually and be severely limited in the early years" (US DoE 2002), early adopters of FCVs will have to drive out of their way to reach the nearest fuel station. Considering that the range might be about 500 km with full tank, FCVs are unlikely to limit drivers' mobility in absolute terms. However, drivers will have to change the current casual approach to tanking vehicles, i.e. stopping when they see one. While driving to the closest filling station can be not very inconvenient in one's own neighbourhood, driving in areas where the location of hydrogen station is not known will be more challenging. As pointed out by Bevilacqua Knight (2001) and E4Tech (2006), the diffusion of on-board GIS-based station locating system could easily tackle this issue.

It is interesting to analyse which users might be less sensitive to the lack of an extensive hydrogen infrastructure. The most obvious candidates are fleet (delivery firms, ambulances, police cars etc.) and bus vehicles which return to depot every night. If a tank full of hydrogen is enough for the mileage driven daily, hydrogen infrastructure is relatively superfluous to these types of vehicles, provided that hydrogen can be produced at the depot. Other potential early adopters are taxi drivers. As in this profession it is not uncommon to have social facilities visited by drivers once a day or more to enjoy a break, one could conveniently locate a hydrogen station near these premises. Company cars, which are normally driven within a certain area, are another potential early adopter because they can easily plan the refuelling and know the location of hydrogen stations. A vehicle which is used as a city car in a family would be in a similar position, although it might be subject to a more flexible use. The vehicles mentioned above are important for the diffusion of a hydrogen infrastructure as their geographical concentration can guarantee an acceptable utilization rate of re-fuelling stations therefore avoiding lengthy loss-making periods with under-utilized capacity. On the other hand, owners of the main family car may be particular reluctant to buy FCVs as long as the infrastructure is not reasonably diffused as they would not wish to be limited in where they were able to drive their vehicle.

4 Economic Factors

As discussed in Section 2, FCVs advocates aim at matching the performance of the new powertrain to that of ICEVs. Not surprisingly the same approach has been proposed in terms of price. Setting this price target seems to implicitly acknowledge that FCVs can offer few benefits compared to ICEVs; otherwise a price premium would be justifiable. The same matching strategy has been proposed with regard to the operating costs of FCVs. As mentioned above, the FCVs' higher fuel efficiency has an important role in decreasing the fuel cost per mile, especially considering the price of hydrogen and in the owners' expenditure for maintenance costs.

Looking at the experience from the introduction of diesel powertrain, however, the targets set by FCVs advocates seems appropriate. In fact, the price difference between diesel and gasoline ICEVs is considered one of the reasons hindering the penetration of diesels in the market (Cowan et al., 2003; Greene 1996). According to Oertel and Fleischer (2003), the costs of purchasing and operating vehicles are very important in determining their competitiveness. On the other hand, there is not conclusive evidence on the extent to which fuel economy influences purchasing decisions. According to US DoE (2002) consumers rank fuel economy relatively low on the list of desired attributes for automobiles. Considering that for the average 1999 American car, fuel costs amounted to only 10% of the annualized costs (Azkarate and Pelkmans), drivers' lack of interest is quite understandable. Perhaps, FCVs efficiency could be more appreciated in Europe where higher fuel taxes make diesel and petrol more than twice as expensive as in the US (Davis and Diegel 2004). On the other hand, efficiency of European cars is higher therefore reducing the improvement that can be delivered by FCVs.

Although lower running costs are likely to be important in explaining the penetration of alternative fuels, they are not certainly the only or the determinant factor, as shown by the diffusion of diesel in the market. Compared to petrol, the price of diesel has been increasing in the last decade in most European countries while the fuel economy of the engine has been more or less constant (Cowan et al. 2003). However, diesel sales have constantly increased. The recent surge of SUVs shares in the United States and their more contained increase in Europe is another example of the limited importance of economic factors in the decision of purchasing a car. In fact, according to Hulten (2003) SUV owners found fuel economy and price the least important attributes in a car. Considering the low fuel economy of SUVs, pick-ups and bigger hatchbacks (Azkarate and Pelkmans 2003), the introductions of FCVs would be most beneficial in these models, although this is likely not be particularly highly valued by potential buyers.

Finally, it is quite interesting to evaluate which drivers might find cost savings arising from higher tank-to-wheel fuel efficiency of FCVs more attractive. Considering that 17% of the energy in tank goes wasted in idling (Azkarate and Pelkmans 2003), urban drivers might be more interested in the adoption of FCVs. Among them, the owners of fleet vehicles could also see immediate benefits to the bottom line from reduced operating costs. Quite interestingly for a rapid penetration of FCVs, these users might be not very concerned about the lack of extensive hydrogen infrastructure, as mentioned above. While on one hand reduced fuel consumption could persuade them to adopt FCVs, on the other hand it is imperative that fuel savings translate into lower running costs.

5 Institutional Factors

Institutional factors seem to be not very influential in the consumers' choice between ICEVs and alternative powertrains such as FCVs. In the case of retail lenders, if the price of different types of powertrains is similar, it is not clear why financial institutions should be more inclined to lend money to buy one rather than another. Although banks and loan companies might prefer to lend to buy a certain powertrain because the others are far more expensive, this constraint imposed by financial institutions would be almost irrelevant on the consumers' choice, as it is likely that many users would not buy the more expensive drive anyway. Similarly, if the safety of the new powertrains is not comparable to that of existing ICEVs, the owners would face higher premiums for insurance. However, drivers are unlikely to buy a powertrain if they do not perceive it to be safe. In terms of planning systems, it is not clear whether FCVs' owners will enjoy a mobility comparable to that of ICEVs. As some underground parking facilities do not allow cars running on LPG to use their services, the same constraint might be applied to FCVs.

6 Policy Instruments

If manufactures are successful in introducing FCVs with performance equivalents to ICEVs and at a comparable price; if a hydrogen infrastructure is timely built in with a density of hydrogen stations which is acceptable to the average user; and if the price of hydrogen will make the running costs of FCVs comparable to those of ICEVs, policy instruments will be obviously not needed. In this scenario as the confidence on FCVs increases, more and more drivers will adopt FCVs over ICEVs. However, if any of the conditions above is not met, policy instruments in the form of monetary incentives can help the introduction of FCVs into the market. Possible policy instruments for FCVs include reduced purchase taxes, lower road taxes or reduced sale duties on hydrogen. Because the last two options might be amended as the share of FCVs increases, reduced purchase taxes on vehicles could be more attractive to potential buyers. FCVs could also be given an incentive by being exempted on the fees introduced to access city centers, such as the London Congestion Charge, as local emissions are zero, if FCVs are directly fuelled on hydrogen. The exact nature of the policy instrument that will be introduced will depend on which ICEVs' feature FCVs are unable to match: for example, if FCVs were more expensive, a grant for the purchase of FCVs could be appropriate.

7 Cultural Perceptions

The role of cultural perceptions in the choice between FCVs and ICEVs is not entirely clear. Factors like brand status should be irrelevant as all car manufacturers will produce FCVs if technical and economical hurdles are overcome. In the very early years after the introduction of FCVs a number of potential buyers might have doubts on the performance of FCVs and still buy ICEVs even when the former have an equivalent or slightly superior performance. On the other hand, some drivers could be attracted by FCVs because of the novelty factor or because of the technological-savvy image that driving FCVs might convey. The change in users' practices implied by FCVs might be an obstacle to their diffusion; it seems likely that any widely adopted alternative vehicle will have to meet as much as possible the user habits and expectations developed by the current incumbent. In particular, the penetration of FCVs is likely to be influenced by the time needed to fill up the tank (Oertel and Fleischer 2003). As the handling, transport, storage and retailing of liquid hydrocarbons are all relatively uncomplicated, consumers might be unwilling to adopt FCVs, if hydrogen can be dispensed only slowly or requires complicated handling procedures. Constant availability will be paramount in influencing the users' acceptance of new powertrain. Hulten and Pelkmans (2003) report that an ethanol shortage experienced in 1989 in Brazil reduced the confidence of customers and contributed to a steep reduction of the market share of ethanol vehicles. Dedicated ethanol vehicles were about 85% of the total sales in 1988 but only about 15% in 1990.

A factor that is considered particular important by the academic community for the diffusion of FCVs is the perceived safety of the fuel. Although hydrogen can be considered a safe product in the chemical industry, a completely different typology of users will get in contact with hydrogen when used as an energy carrier. The extent of the problem is unclear. Thomas (1997: p.vii-viii) concludes that "in normal operation FCVs should have less potential hazard than either a natural gas vehicle or a gasoline vehicle", while in a tunnel collision "FCV should be nearly as safe as natural gas vehicle, and both should be potentially less hazardous than a gasoline or propane vehicle". The greatest potential risk to the public could occur in case of a slow leak in an enclosed home garage. However, Swain (1998: p. v) concludes that “the use of passive ventilation is sufficient to prevent the accumulation of a flammable mixture of hydrogen”. Although past and current industrial experience with hydrogen cannot fully inform a comprehensive assessment of risks to safety associated with substantially different uses of hydrogen as an energy vector (Ricci 2005), it is very likely that any safety concerns will be tackled by either hydrogen producers or cars manufactures. Also in the case of methanol, safety and toxicity are still under discussion, although it seems that adequate measures and devices can tackle the major problems (Oertel and Fleischer 2003).

8 Conclusions

The discussion in this paper has been summarised in Table 1. It is fair to conclude an “average” consumer is likely show only moderate interest for Fuel Cell Vehicles. The most problematic point is related to the fact that FCVs lack a sharp competitive advantage with regard to the mechanical performance. Many authors in the literature seem to confirm this conclusion by requiring FCVs to match the capital cost and operating cost of current vehicles. In terms of technological performance the competitive advantage of FCVs could consist in higher on-board power supply and the ability of using the vehicles as mobile power stations. The latter would imply the existence of a source of income especially for the first FCVs adopters. Considering their limited need for an extensive infrastructure, it is also particularly convenient that fleet vehicles can be very competitive as mobile power stations because of the reliable despatchment schedule which can be set up around the main use of the vehicle. With regard to the environmental benefits a number of contributions conclude that for a considerable amount of time FCVs will offer very few savings in terms of GHGs evaluated from well-to-wheel terms. Carbon sequestration would change this conclusion radically although it would also constrain the development of the hydrogen system, as carbon can be sequestrated only in centralised plants. Infrastructure requirement could be a serious hurdle especially for Hydrogen fuelled FCVs. Although manufactures are aiming at providing a range similar to that of current ICEVs, the convenience of consumers will be limited in the early years after the introduction of FCVs due to the lower density of hydrogen filling stations. However, GIS–based systems could limit the importance of this factor. It is also worth mentioning that car manufactures would have an interest in providing this technology in all FCVs if they wanted to increase their marketability. It is also true that limited hydrogen infrastructure could be less important for buses, fleet vehicles, taxis and city cars. The cost of FCVs and hydrogen is maybe the most important hurdle for the diffusion of the new drive. After the technological problems have been solved, FCVs are likely to be slightly more expensive than current ICEVs, which are benefiting from massive economies of scale and focused R&D expenditure. This issues of FCVs' cost is particularly important considering that these vehicles seem to have very few competitive advantages compared to future configurations of ICEVs. Although matching the capital and operating cost of ICEVs is a very serious challenge, some authors have shown the steps required to achieve this task. Clearly, focused policy instruments will help the introduction of FCVs. As discussed in the article, the particular type of instrument needed will depend on the evolution of FCVs and on how they compare to future configurations of ICEVs. Finally, in terms of cultural factors, users' practice developed with ICEVs and perceived safety of FCVs might be a disadvantage unless they are matched by the new technology. However, marketing and information campaigns would likely be able to make these issues less important.

	Competitive performance of FCVs	**Implication for marketability**
1) Technological Performance		
a) Mechanical Performance	More flexible design if hydrogen can be stored efficiently	Difficult to market FCVs because lacking clear performance advantages
b) Efficiency and Simplicity	Lack of noise	Advantage for niche markets
c) On-board Energy Supply	Better able to deliver load for comfort and entertainment appliances	Facing competition from on-board APU, hybrid vehicles and ICEVs
d) Mobile Power Station	Providing a source of income for buyers of FCVs; issues related to competition and equipments	Could help uptake of FCVs
e) Environmental Benefits	FCVs have lower well-to-wheel GHG only in a few analyses	No advantages unless GHGs are lower (sequestration?)
2) Infrastructure Requirements	Serious hurdle especially for direct hydrogen FCVs	Varying importance for different consumers; possibility of sequential niche markets
3) Economic Factors	Cheaper than ICEVs only under the most optimistic assumptions	Few features to balance likely cost disadvantage; niche markets seem price sensitive (e.g. fleet vehicles)
4) Institutional Factors	None	None
5) Policy Instruments	The instruments will depend the evolution of FCVs	Useful to speed up the introduction of FCVs
6) Cultural Factors	User practices and perceived safety maybe a disadvantage; might be balanced by novelty lovers	Marketing campaigns could neutralise possible obstacles

Table 1 *Competitive performance of Fuel Cell Vehicles and implication for marketability*

References

Adamson K. A. (2005) Calculating the price trajectory of adoption of fuel cell vehicles *International Journal of Hydrogen Energy* 30 p.341–350

Agnolucci P. and P. Ekins (2006) *Technological Transitions and Strategic Niche Management: The Case of the Hydrogen Economy* London: PSI mimeo

Anon (2004) *Clean machine* The Economist, Sep 2nd 2004. London

Anon (2006) Plug-In Partners National PHEV Initiative Austin, TX: Plug-In Partners, available on-lien at www.pluginpartners.org/includes/pdfs/PluginPartnersPacket.pdf

Azkarate G. and L. Pelkmans (2003) New Passenger Cars: Economic Rates Evolution and Trends in Fuel Consumption and Emissions in Pelkmans L. and P. Christidis (eds.) (2003) *Trends in Vehicle and Fuel Technologies: Review of Past Trends* p.93-151 IPTS Technical Report Series EUR 20746 Seville: European Commission Joint Research Centre IPTS - Institute For Prospective Technological Studies

Bevilacqua and Knight (2001) Bringing Fuel Cell Vehicles to Market – Scenarios and Challenges with Fuel Alternatives West Sacramento, CA: California Fuel Cell Partnership, available on-line at http://ntl.bts.gov/lib/24000/24000/24071/ScenarioStudy_v1-1.pdf

Burns L.D., McCormick J.B. and C. E. Borroni-Bird (2002) Vehicle of change *Scientific American* 287(4) p.64-73

Cherry R. S. (2004) A hydrogen utopia? *International Journal of Hydrogen Energy* 29 p.125 – 129

Christidis P. (2003) Driving Factors Affecting the Decisions on the Purchasing, Substituting and Scrapping of Cars in Pelkmans L. and P. Christidis (eds.) (2003) *Trends in Vehicle and Fuel Technologies: Review of Past Trends* p.174-185 IPTS Technical Report Series EUR 20746 Seville: European Commission Joint Research Centre IPTS - Institute For Prospective Technological Studies

Cowan R., S. Hultén and N. Hmimda (2003) The Introduction of Diesel Engines in Cars in Pelkmans L. and P. Christidis (eds.) (2003) *Trends in Vehicle and Fuel Technologies: Review of Past Trends* p.186-197 IPTS Technical Report Series EUR 20746 Seville: European Commission Joint Research Centre IPTS - Institute For Prospective Technological Studies

Davis C., Edelstein B., Evenson B., Brecher A. and D. Cox (2003) *Hydrogen Fuel Cell Vehicle Study* - A Report Prepared for the Panel on Public Affairs (POPA) American Physical Society Ridge, NY: American Physical Society

Davis S. C., and S. W. Diegel (2004) *Transportation Energy Data Book: Edition 24* Washington, D.C: US Department of Energy

E4tech (2005) The Economics of a European Hydrogen Automotive Infrastructure, available on line at http://www.braunschweig.ihk.de/innovation_umwelt/nachrichten/april_05/The%20Economics%20of%20a%20European%20Hydrogen%20Automotive%20Infrastructure.pdf

EUCAR, JRC and CONCAWE (2005) Well-to-Wheels analysis of future automotive fuels and powertrains in the European context, available on line at http://ies.jrc.cec.eu.int/wtw.html

Freeman C. and F. Louça (2001) *As Time Goes By* Oxford: Oxford University Press

Geels F. W. (2002) Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective And A Case-Study *Research Policy* 31 p1257-1274

Greene D. L. (1996) *Transportation and Energy* Washington, D.C.: Eno Transportation Foundation, Inc.

Hart D. Leach M.A., Fouquet R., Pearson P.J. and A. Bauen (2000) Methanol infrastructure - will it affect the introduction of SPFC vehicles *Journal of Power Sources* 86 p.542–547

Hendry C., Harborne P. and J. Brown (2004) Fuel Cell Innovation: A Developing UK Industry? Economic and Social Research Council (ESRC) Working Paper Series Number 2004/3 Swindon: ESRC, available on line at http://www.sustainabletechnologies.ac.uk/PDF/Working%20papers/102a.pdf

Hultén S. (2003) Study on SUV in the USA in Pelkmans L. and P. Christidis (eds.) (2003) *Trends in Vehicle and Fuel Technologies: Review of Past Trends* p.198-206 IPTS Technical Report Series EUR 20746 Seville: European Commission Joint Research Centre IPTS - Institute For Prospective Technological Studies

Hultén S. and Luc Pelkmans (2003) Emission Regulations for Light-Duty Vehicles – A Comparison of the USA and Europe in Pelkmans L. and P. Christidis (eds.) (2003) *Trends in Vehicle and Fuel Technologies: Review of Past Trends* p.152-173 IPTS Technical Report Series EUR 20746 Seville: European Commission Joint Research Centre IPTS - Institute For Prospective Technological Studies

James B. D., Baum G. N., Lomax, Jr. F. D., Thomas C.E. and I. F. Kuhn, Jr. (1996) *Comparison of Onboard Hydrogen Storage for Fuel Cell Vehicles* study prepared for The Ford Motor Company Arlington, VA: Directed Technologies, Inc.

Kempton W. and J. Tomic (2005a) Vehicle-to-Grid Power Fundamentals: Calculating Capacity and Net Revenue *Journal of Power Sources* 144 p.268–279

Kempton W. and J. Tomic (2005b) Vehicle-to-Grid Power Implementation: From Stabilizing the Grid to Supporting Large-Scale Renewable Energy *Journal of Power Sources* 144 p. 280–294

Lutsey N. Brodrick C. Sperling D. and H. A. Dwyer (2003) Markets for Fuel Cell Auxiliary Power Units in Vehicles - A Preliminary Assessment *Transportation Research Record 1842* Paper 03-3443 p.118-126.

MacLean H. L. and L. B. Lave (2003) Evaluating automobile fuel - propulsion system technologies *Progress in Energy and Combustion Science* 29 p.1–69

Meissner E. and G. Richter (2001) Vehicle electric power systems are under change! Implications for design, monitoring and management of automotive batteries *Journal of Power Sources* 95 p.13-23

Oertel D. and T. Fleischer (2003) *Fuel Cells Impact and consequences of Fuel Cells technology on sustainable development IPTS* Technical Report Series EUR 20681 Seville: European Commission Joint Research Centre IPTS - Institute for Prospective Technological Studies

Owen N. J. and R. L. Gordon (2003) *Carbon to Hydrogen Roadmaps for passenger Cars; Update of the Study for the Department of Transport and the Department of Trade and Industry* Shoreham by Sea: Ricardo Consulting Engineers

Pelkmans L. and P. Christidis (eds.) (2003) *Trends in Vehicle and Fuel Technologies: Review of Past Trends* IPTS Technical Report Series EUR 20746 Seville: European Commission Joint Research Centre IPTS - Institute For Prospective Technological Studies

Rifkin J. (2002) *The Hydrogen Economy: the Creation of the Worldwide Energy Web and The Redistribution of Power on Earth* Oxford: Polity

Rip A. and R. Kemp (1998) Technological change in Rayner S. and E. L. Malone (eds) *Human Choice and Climate Change Vol.2* p.327–399 Columbus, OH: Battelle Press

Swain M. R. (1998) *Addendum to Hydrogen Vehicle Safety Report: Residential Garage Safety Assessment* study prepared for The Ford Motor Company Coral Gables, Florida: University of Miami

Thomas E. (1997) *Direct-Hydrogen-Fueled Proton-Exchange-Membrane Fuel Cell System for Transportation Application - Hydrogen Vehicle Safety Report* study prepared by Ford Motor Company for US Department of Energy Office of Transportation Technologies Arlington, VA: Directed Technologies, Inc.

US Department of Energy (DoE) (2002) *National Hydrogen Energy Roadmap* based on the results of the National Hydrogen Energy Roadmap Workshop Washington, D.C.

April 2-3, 2002 Washington, D.C.: US DOE, available on-line at http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/national_h2_roadmap.pdf

Wang (2003) *Well-to-Wheels Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions - Hybrid Electric and Fuel-Cell Vehicles*, Center for Transportation Research, Argonne National Laboratory

Weiss M. A., Heywood J. B., Drake E. M., Schafer A. and F. F. AuYeung (2000) *On the Road in 2020 A Life-Cycle Analysis of New Automobile Technologies* Energy Laboratory Report # MIT EL 00-003 Cambridge, Massachusetts: Energy Laboratory Massachusetts Institute of Technology