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Commitment to fuel cell technology? How to interpret carmakers' efforts in this radical technology

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Abstract

Since the early 1990s, fuel cell (FC) technology has received a great deal of attention from the automotive industry. Its high efficiency and low emissions have made the technology become one of the dominant technological opportunities to achieve more sustainable mobility. Under pressure of ever-increasing regulatory standards, the automotive industry has spent billions of dollars on researching and developing fuel cell vehicles (FCVs), with the objective of starting commercialization in 5–10 years time. Industry experts evaluate the industry's apparent commitment to FC technology optimistically as well as critically. *Optimists* see carmakers' efforts as a sign of change in the industry, necessitated by regulation and societal needs of a cleaner environment. *Skeptics* see carmakers' efforts in FC technology as 'window dressing', investing minimal amounts of resources (with maximum public exposure) while being limitedly committed to commercialize FCVs. This paper makes an attempt to nuance both views by assessing levels of R&D commitments carmakers. Based on an analysis of patenting behavior, this paper concludes that automotive activities go beyond window dressing, but fall short of portraying full commitment to this radical technology.

Keywords: Fuel cell technology; R&D strategies; Automotive industry; Technology commitment; Future assessment

1. Introduction

Since Daimler-Benz showed its first fuel cell vehicles (FCVs) in 1994 and 1996 (Necar I and II), there has been a dramatic increase in activities by the complete automotive industry in fuel cell (FC) technology. This has translated in major expenditures by the industry, which suggests significant commitment by the industry in this technology. Already in 1998 automotive expenditures in FCVs have accumulated to approximately $1.5–2 billions [1]. Until 2000, DaimlerChrysler has invested approximately $1 billion on FCVs, and in the same year announces to invest another $1.4 billions on bringing FCVs to market by 2004.[1] By then, between 400 and 600 DaimlerChrysler employees alone are engaged in FCV development;[2] similar-sized programs are projected by GM and Toyota [2]. Also smaller carmakers such as Renault, PSA and Nissan collectively announce to invest $714 millions between 2001 and 2005 on FC technology.[3] By 2004, an estimated $6–10 billions has been spent by the auto industry alone to research and develop FCVs [3].

Despite these massive resources, industry experts are divided into optimists and skeptics. *Optimists* see carmakers' efforts as a sign of change in the industry, where environmental problems and potential oil crises necessitate the industry to develop alternatives. Optimists also argue that FCVs may form a competitive opportunity for carmakers to acquire crucial competences, set the standards, and pick the fruits as first movers in FCVs.

Conversely *skeptics* argue that carmakers' efforts in FC technology are best described as 'window dressing'. Nine-

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[1] DaimlerChrysler press release, June 2000.

[2] Based on interviews with DaimlerChrysler executives in May 2001.

[3] http://www.fuelcells.org, June 2001.

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digit investment levels may sound impressive, but are minor compared to the massive annual R&D budgets of the automotive industry. According to skeptics, carmakers use FC technology as a way of obtaining a greener image, or as a strategy to prevent regulators to set more stringent standards for current internal combustion engines (ICEs), rather than being committed to in fact commercialize FCVs. This paper examines both hypotheses, leading to an interpretation of the actual automotive commitment to FCVs. Such an assessment is relevant from the perspective of regulators, entrepreneurs in the field of FCVs and hydrogen and investors, given their possible dependence on the commercial success of the FCV.

2. Assessing automotive activities in FC technology

How can automotive R&D activities in FC technology be assessed in an objective way? Confidentiality issues and the potential political nature of automotive announcements regarding environmental technologies hamper the use of press releases, year reports and company interviews. In the last decades, *patent analysis* has become increasingly popular among scientists studying R&D behavior of firms, industries and counties, to get more objective information on R&D activities [4]: patents form a realistic indicator for ongoing R&D activities within a firm, and it can be argued that the benefits of obtaining patents outweigh the costs and time required to obtain them. A practical advantage of patent research is its public availability.

Nevertheless, patent analysis has its pitfalls. The propensity to patent inventions varies across time, firms, industries, technologies and countries [5]. For instance, Japanese firms tend to patent more than their European and US competitors. Furthermore, not all inventions are patentable (e.g. software [4]), while not all inventions are patented for secrecy reasons. And thus patents tend to differ in quality and value. Therefore, patent analysis is more suited for historical reconstruction of R&D activities (start/acceleration/termination of R&D programs, and priority setting among different R&D programs) rather than to assess relative strength of R&D activities of individual companies [5,6].

The patent data form an indicator of commitment to alternative technologies and FCVs in particular. High patent percentages indicate that carmakers are indeed spending large amount of resources on these technologies, thereby displaying relative strong commitment. Low patent percentages would reflect the skeptical view that carmakers have low commitment in alternative technologies and use their development as window dressing.

In this study, the United States Patent and Trade Office (USPTO[4]) database was used for analyzing automotive R&D activities in alternative technology vehicles (ATVs; alternative to the ICEs), including battery electric vehicles (BEVs), hybrid electric vehicles (HEVs) and fuel cell vehicles (FCVs). Foremost reason to choose the USPTO database (over European or Japanese patent databases) is that California represents the foremost target market for alternative technology vehicles, given its stringent standard setting regarding local emissions. Since 1990, the Californian Air Resources Board (CARB) has mandated the sales of zero emission vehicles in their Zero Emission Vehicle (ZEV) regulation. Although this regulation has been subject to change and postponement, the standard provides an important incentive for carmakers to engage in the development of alternative technologies. Patents in alternatives such as FCVs, BEVs and HEVs[5] are thus most likely patented in the US. Another reason to choose the USPTO relates to the relative high costs of patent applications in the US compared to, for instance, Japan. As a result, Japanese firms are known to patent a great deal in their home country for decoy reasons, but to be more selective in applying patents in the US [7,8]. In order to compensate for patent activities of carmakers not, or limitedly active in the US (particularly European firms such as Renault, BMW) the patent data are complemented by patent search in the European Patent Office.[6]

Table 1
Examples of search queries for searching patents on FCVs, HEVs, BEVs, and total amount of patents per company

Exemplary company ‘General Motors’	Search query
FCV-related patents	SPEC/(‘fuel cell’ or ‘fuel cells’) and AN/(‘General Motors’) and APD/$/$/year
HEV-related patents	SPEC/(‘hybrid vehicle’ or ‘hybrid electric vehicle’ or ‘hybrid propulsion’ and not (‘fuel cell’)) and AN/(‘General Motors’) and APD/$/$/year
BEV-related patents	SPEC/(‘electric vehicle’ or ‘electric car’ or ‘electric automobile’ and not (‘fuel cell’ or hybrid)) and AN/(‘General Motors’) and APD/$/$/year
Total amounts of patents of the company	AN/(‘General Motors’) and APD/$/$/year

Table 1 lists exemplary search queries for assessing patent activity of OEMs in the automotive industry regarding new technologies. Given that FCVs, HEVs and BEVs are sometimes named differently by OEMs individually, different options for describing this technology were taken into account. For BEVs, the patent description (SPEC = specification/description of patent) includes either the term ‘electric vehicle’, ‘electric car’ or ‘electric automobile’, while ‘fuel cell’ (or ‘hybrid’) should be excluded in

4 http://www.uspto.gov/.

5 Although hybrid vehicles (HEVs) are not eligible for zero emission credits, this option has been discussed in the past. With sufficient battery capacity, HEVs would be able to drive with zero emissions on a limited range (up to 50 km), for instance, in city centers, so carmakers argued in the early 1990s. Up till now CARB has resisted to give HEVs ZEV credits, but this is not unthinkable in the future if alternatives prove unviable for commercialization.

6 http://www.european-patent-office.org/.

order to separate 'electric vehicle' patents that actually involves FCV- (or HEV)-related research. Similarly, in order to track HEV patents, patents should include terms as 'hybrid vehicle' or 'hybrid electric' or 'hybrid propulsion', while again excluding 'fuel cell' to separate HEV and FCV patents. Lastly, in order to account for different patent propensities among individual firms, the total number of patents per carmaker was assessed, by combining 'Assignee Name' (AN; individual carmakers[7]) with 'APplication Date' (APD) per year without truncating on specific fields of patents. Application dates refer to the date that new patents are applied for by the patent office, before going in review and being issued: it may take between 2 and 5 years before applied patents are issued. The advantage of using application dates (rather than issue dates) is that it reflects R&D activity historically; the limitation is that patent data of the last 2–4 years are less accurate, due to the large amount of pending patents. As a result, this study can only present patent results until 2001, and not thereafter.

3. Findings

In the following, the results of the patent study are presented. First, the absolute number of patents of OEMs in ATVs is shown, followed by the relative number of patents (relative to total amount of patents of carmakers).

3.1. Patenting behavior of the car industry (absolute numbers)

Fig. 1 shows the development of patent applications for BEVs, FCVs and HEVs by large automotive firms in the period 1990–2000. Overall it shows how BEV, HEV and FCV patents all have their origin in the early 1990s; not more than five patent applications were found on either three of these technologies for the complete automotive industry in 1990; since 1991–1992, a structural increase in patent behavior in these ATVs can be observed at least until 2000.

The data also show how priorities have shifted in the industry regarding to preferred technology: until 1996, a majority of ATV patents are related to BEVs (see Fig. 2). However, since 1994 BEV's share shows a steady decline in favor of FCV- and HEV-related patents; by 2000, a mere 15% of all ATV patents are related to BEV. The peak years for BEV lie in 1995, in which 56 patents are applied for by the industry; in 2000 this number has fallen to 40.

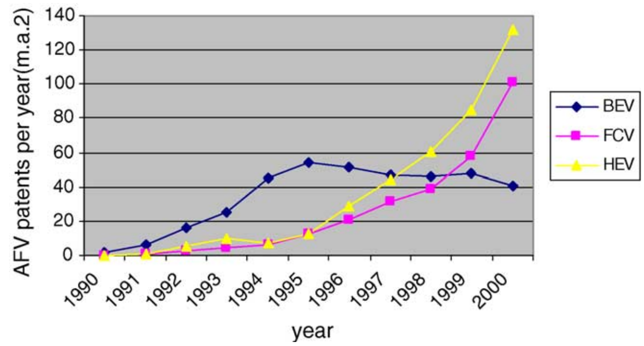

Fig. 1. Patents in BEV, FCV and HEV, applied for by car firms (1990–2000 – moving average 2).[8]

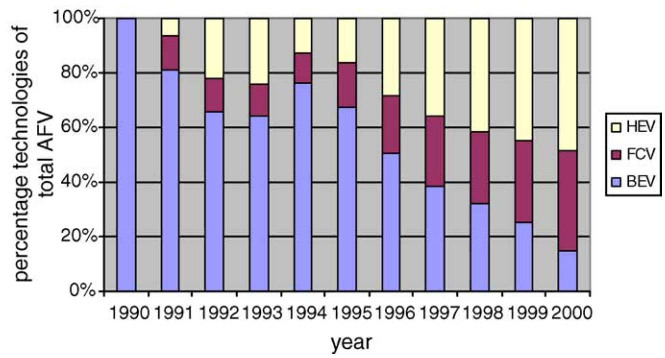

Fig. 2. Patents in BEV, FCV and HEV as percentage of total ATV,[9] applied for by car firms (1990–2000 – moving average 2).

The number of both FCV- and HEV-related patents start to climb in the period 1994–1995. HEV and FCV overtake BEV in 1998–1999, which reflects the shift in industry prioritization regarding the particular technologies. In 2000, more than 100 FCV patents are applied for by carmakers alone (not including FC manufacturers), and more than 120 HEV-related patents. This is a factor 2.5–3 higher than the number of BEV patents in this year. HEV technology is slightly more patented than FCV technology, which may indicate that these technologies compete with each other in acquiring R&D resources. By 2000, just under 50% of all ATV patents are HEV-related; FCV follows with approximately 35%; BEV is responsible for 15% of all ATV patents.

The patent data are largely in line with more qualitative market assessments of ATVs. In the early 1990s, BEVs formed the most promising technology to achieve the stringent 1990-ZEV-standards in California. The regulation spurred R&D activities in BEV until 1995/1996 after which several BEVs were brought to market. However, disappointing sales (see Fig. 3) led carmakers to shift to more promising alternatives such as FCVs and HEVs.

7 In this study, patent behavior of the following OEMs was assessed: GM, Ford, Chrysler, Daimler*, BMW, Renault, PSA, Volkswagen, Fiat, Toyota, Honda, Nissan, Mitsubishi, Mazda, Hyundai and Daewoo. OEMs such as Volvo, Saab, Suzuki are not taken into account, given that these companies fall under the umbrella of carmakers such as GM and Ford: search queries for these companies lead to very limited to no patents in ATVs: apparently ATV research is largely carried out at the level of the mother company, or assigned to the mother company. As a result, the selected OEMs account the majority of patents in the car industry regarding FCVs, BEVs, HEVs.

8 A moving average of 2 years is used in order to level out annual fluctuations; the 2000 value represents an average of patent numbers over the years 2000 and 2001.

9 ATV stands for alternative fuel vehicles; for the purpose of the analysis, this only includes technologies such as BEV, HEV or FCV (and, for instance, excludes the hydrogen-fueled ICE).

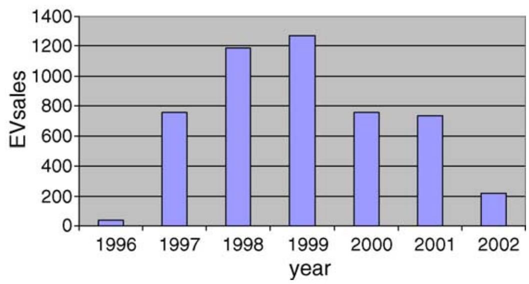

Fig. 3. BEV sales in the US annually (source: EVWorld).

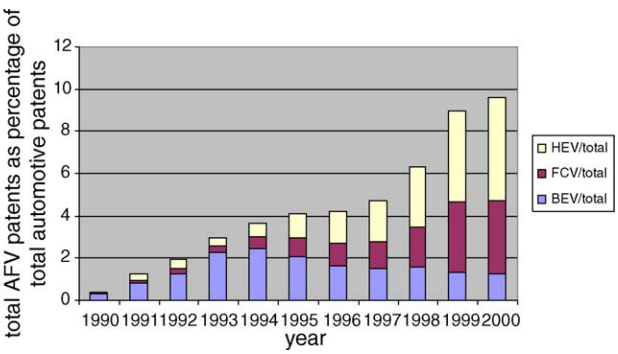

Fig. 4. ATV patents as percentage of total automotive OEM patents (1991–2000 – moving average 2).

The structural increase in patents in ATVs since 1990s suggests that the ZEV has had a strongly supporting effect on carmakers to research and develop alternative technologies with zero emission potential.[10] Although none of these technologies have become a mainstream commercial success (HEVs come closest), such stringent standards setting may prove successful in initiating extensive R&D programs on alternative technologies.

3.2. *ATV patent behavior by the car industry (relative to total patents)*

The increased *number* of patents in the last 10 years in ATVs indicates growth in carmakers' R&D activities in ATV. However, how do the number of patents compare to the total number of patents of the industry. Furthermore, the increase in ATV patent activity may coincide with similar increases in total industry patent applications. In order to account for patenting trends by the car industry, the relative share of ATV patents is calculated compared to the total number of industry patents. Relative patent data reflect the priority ATVs get compared to other R&D activities (see Figs. 4 and 5).

Since 1990, the percentage of HEV/FCV/BEV patents relative to total patents applied for by carmakers have increased

[10] HEVs are not necessarily zero emission vehicles, but have in the past been proposed by carmakers (like Toyota and Mitsubishi) to get ZEV credits, as HEVs may achieve zero emissions for short distances by using the battery only. However, until now the Californian Air Resources Board (CARB) has not provided these credits. Nevertheless, it is not inconceivable that HEVs become the standard in low emissions (Hekkert and Van den Hoed 2003).

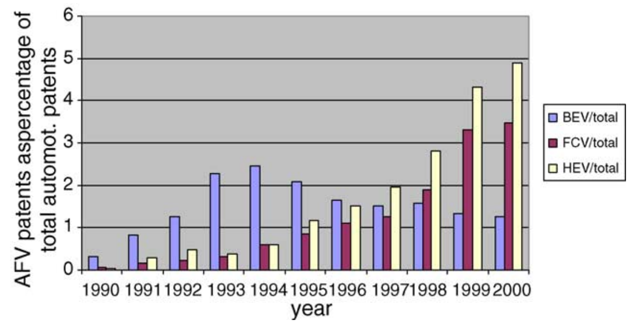

Fig. 5. Patents in BEV, FCV and HEV as percentage of total ATV, applied for by car firms (1990–2000 – moving average 2).

structurally, from a mere 0.5% in 1990 to more than 9% in 2000. And thus by 2000, 1 out of 11 patents applied for by automotive firms is ATV-related. The rise in absolute number of ATV patents is thus congruent to its relative share in total patents.

Stagnation in the relative share of ATV patents can be discerned in the period 1995–1996: this can be attributed to the preparation of bringing BEVs to market; as well as the relatively recent demonstrations of viable alternative technologies such as the FCV and the HEV. Particularly, the showcase of Daimler-Benz's FCV-NECAR II in May 1996 (followed by its commercialization projections in January 1997), and the showcase and commercial plans of Toyota's HEV (Prius) in December 1995 put these two technologies on the map. This seems to explain the subsequent increase in patent activities in these technologies since 1996, in which most carmakers set up their own FCV and HEV programs to follow Daimler-Benz's and Toyota's lead.

Fig. 5 splits up the different ATV technologies. Over the period 1990–2000, BEV patents do not reach 3% of the total patents in the car industry, and by 2000 are close to the 1% mark. In 1994, 1 out of every 40 patents applied for by the industry is BEV-related; in 2000 this applies for 1 out of 75 patents. This indicates that BEV programs have remained modest relative to other programs.

The percentage of patents related to FCV rise to over 3% in 1999 and 2000; similarly, HEV percentage of total patents approaches the 5% mark in 2000. Nearly 1 out of every 20 patents of carmakers is related to HEV; 1 out of every 33 to FCV. Both HEV and FCV values are still rising, although FCV patents seem to be leveling off.

The patent data reflect a significant share of patent activity of the car industry going to ATVs, and that FCVs and HEVs have achieved a more dominant position in R&D labs than BEVs ever did, despite the competition for acquiring resources between HEV and FCV. The internal competition for funds is illustrated by GM's announcement (2003) that it dismisses the HEV option as it would slow down the development of the long-term agreed option of FCVs.[11] In that respect, the high patent percentages for FCV and HEV in

[11] Press release GM, September 2003.

2000 (compared to BEV in 1995) are remarkable, and suggest that the commitment for FCVs and HEVs is considerably higher than for BEVs in the mid-1990s. In the coming years, the costs for making HEVs and FCVs market-ready will increase significantly. Given the relatively large share of ATV patents, it is unlikely that a dual strategy of developing both HEVs and FCVs remains viable for the auto industry, and that choices will have to be made which technology is favored over the other.

4. Interpretation of findings

The patent data demonstrate a structural increase in ATV patents between 1990 and 2000 both in absolute as well as in relative (to total patents) terms. How should these values be interpreted? To what extent do the values confirm either a 'window dressing' perspective or rather a 'commitment' perspective?

4.1. Nuancing the skeptical view

There are at least three reasons why the patents do not reflect a 'window dressing' perspective alone. First of all, the relative shares of ATV and FCV patents are too large (9 and 3%, respectively), and consequently the R&D expenditures made on these technologies are too extensive to be simply labeled as 'minimum efforts'. Although 3% FCV patent percentage may seem small, it must be acknowledged that the remaining 97% is not entirely focused on established propulsion-technology ICE, but rather involves all automotive R&D activities regarding safety technology, ICT-related research, paints and coatings, manufacturing technology, nanotechnology and alike. Although carmakers still invest factors more on improving conventional engines than on ATVs [9], the dominance of pure ICE-related research over ATV research is gradually decreasing. From this perspective, 3% can be called significant: ATV technologies in general and FCV technologies in particular have attracted a considerable chunk of the R&D budget that carmakers have at their disposal for innovation at large. Second, the 3% FCV percentage is also remarkable as this technology is in competition with HEV to acquire R&D resources in the industry. Arguably, without this HEV–FCV competition the level of FCV commitments may have even be higher. Third, the ATV and FCV percentages are still rising in 2000 and may well do so in subsequent years, leading to even larger shares of ATV patents.

And thus one can conclude that the auto industry's ATV and FCV activities reflect significant (rather than minimal) efforts to study the opportunities of these technological alternatives. ATV research has obtained an important position on the R&D agenda of carmakers, with resulting resources available for ATV programs. The structural increase in ATV patents indicates that ATV research has become part of their day-to-day activities, in automotive R&D processes. Carmakers' activities in FCV and HEV are beyond the level of mere 'green washing' or 'window dressing' portrayed by the skeptics in the field.

A comparison with the oil industry and its activities in hydrogen and renewables further illustrate this point. Where companies like Shell and BP make widespread announcements of these 'green' activities, actual expenditures in these technologies fall under the 1% level of total R&D expenditures [3]. The level of expenditures on ATVs by the auto industry exceeds the levels displayed by the oil industry by several factors.

Company statements make clear why the auto industry cannot suffice with 'window dressing' regarding ATVs and FCVs in particular. The industry is increasingly scrutinized by regulators and consumer groups to 'clear up their act' and develop cleaner and more efficient cars. Particularly the California ZEV regulation has challenged the current ICE paradigm, by mandating cars with no emissions at all: as the ICE would not suffice, developing alternatives became obligatory. Apart from regulatory forces, the quest for technological competences as a source of competitive success plays an important role for carmakers to engage in HEVs and FCVs: although belief in these technologies may lack, companies still engage in these technologies in order not to lag behind. Competitive forces play an important role for carmakers to invest considerably in these alternative technologies. Lastly the industry is also anticipating possible changes in availability of oil, or in particular cheap oil [10]. Although no clear signs of increasing oil prices have emerged, conflicts in the Middle East and the looming oil dependence of Western Countries has increased the awareness of the crucial role of oil in Western society. Changes to oil prices may have massive economic and political consequences, reason for oil companies as well as car companies to develop alternative technologies with increased efficiency (HEVs) or alternative fuels (BEVs, FCVs). Anticipation of oil problems forms an additional driver to engage beyond minimal efforts in these alternative technologies. These regulative, competitive and oil-related factors may explain the relative high investments in FCVs by the automotive industry.

4.2. Nuancing the optimist view

If the patent data do not directly reflect 'window dressing', do they then suggest strong commitment by the car industry to commercialize FCVs? This optimist's view seems hard to justify as well. There are a number of serious question marks concerning carmakers' commitment to commercialize FCVs.

First, the FC patents reflect the car industry's efforts to develop the necessary competences for developing FCVs, but it does not directly reflect commitment to bring FCVs to market in the near future. The costs for FCVs will increase sharply, the closer FCV development comes to market. Particularly building up manufacturing capabilities for large-scale FCVs require massive amounts of resources: at this point carmakers have not been forced to make decisions concerning FCVs; the prototypes and limited amount of sold/leased FCVs are made in series without investing large sums in manufacturing lines. And thus the real commitment to commercialize FCVs remains to be seen, and can be assessed when these hard decisions for manufacturing have to be made. These decisions are likely to be made only around 2005–2007.

Second, despite the activities of nearly all carmakers in FCVs, a great deal of these efforts is explained by risk reduction and copying behavior in the industry. Van den Hoed [3] concludes that carmakers, in order to reduce costs for technology development, choose to develop technologies proposed by automotive opinion leaders. Not always does this go hand in hand with a strong belief that the technology is superior to the established technology (the ICE). Interviews with engineers of several OEMs show how there is considerable skepticism in the chances of FC technology [3]. Therefore, the current strategies of carmakers are better characterized as defensive and risk-reducing, rather than offensive. These defensive strategies will also become clearer once market-focused decisions will have to be made. It seems unlikely for skeptical carmakers to invest in large-scale manufacturing lines and extensive marketing campaigns to sell the FCV.

This relates to a third question mark: the automotive industry follows a dual strategy towards regulators. On the one hand, the industry is actively developing technological alternatives to the ICE; on the other, the ZEV regulation is continually scrutinized as being unattainable, economically unviable, leading to higher costs for the consumer [11]. Furthermore, carmakers' accelerated research to improve the environmental performance of ICEs indicates an effort of carmakers to preempt stringent regulation, thereby preventing a shift from ICEs to FCVs. Given that the ICE forms a key moneymaker for, and major differentiating factor between carmakers, there are little economic incentives to shift to FCVs, unless FCVs provide a competitive alternative to the ICE-based vehicle.

Lastly, where FC technology has been touted as the 'holy grail' for achieving sustainable mobility in the late 1990s, in recent years the enthusiasm around FC technology has dimmed somewhat. Given the large number of significant challenges FCVs face in costs, infrastructure and complementary technology (e.g. hydrogen storage), likelihood of commercialization on the short term is limited [12]. On some occasions, the industry has taken an advance on the FCV potential while its technological and economic viability have not been proven as such. Illustrative are the structural postponements in commercialization deadlines of FCVs in the last 5 years. Furthermore, through processes of learning, there are growing question marks concerning the environmental merits of FCVs [13,14], while safety issues of hydrogen are increasingly scrutinized. The very reason for FCVs to become popular in the first place has come under fire. The increasing technological and environmental question marks have weakened the high expectations surrounding FCVs, and will have influenced the ambitions of carmakers to invest heavily in their commercial development. The current patent activities should be seen in the light of the large uncertainties and question marks in this technology, and may reflect long-term expectations rather than short-term belief in a shift towards FCVs.

4.3. Interpretation of patenting behavior: balancing act

And thus both the 'skeptic' and the 'optimist' views on the automotive industry's commitment to FC technology should be nuanced. The automotive strategy can neither be characterized as pure 'commitment' (optimist) or pure 'window dressing' (skeptic). Rather the current FC activities of the car industry seem a balancing act. On the one hand, the car industry is forced to develop technological alternatives by regulators thereby legitimating their actions, but also forced by potential dynamics in oil prices. The quest for more sustainable technologies has become a genuine competition in the industry, as carmakers with solid technology strategies may proof more profitable than their competitors; less tangible are the potential advantages of developing a green image on competitive advantage. Carmakers cannot afford not to compete in FC technology in case technological breakthroughs continue to the point that the technology becomes competitive to the ICE. Carmakers are thus faced with regulative, long-term oil-related and competitive pressures to engage beyond the level of window dressing.

These pressures are balanced with the traditional barriers for radical innovation [15,16]: there are economic motives *not* to shift to alternative (substituting) technologies such as FCVs, particularly with the uncertainties involved in the development of FCVs and the necessary infrastructure. The industry cannot afford to substitute the ICE thereby overthrowing its core technology, knowledge base, and manufacturing capabilities. FC technology is in a pre-commercial development stage, which permits spending considerable R&D resources; however, the real commitment decisions lie in the future when manufacturing lines have to be set up. And thus, the current industry activities in FC technology should be seen in the light of its (relatively inexpensive) development stage: full commitment to commercialize FCVs seems unlikely unless political pressures, technological breakthroughs or oil price increases occur.

5. Conclusions

Based on the patent analysis, this paper concludes that neither an optimist nor a skeptic interpretation of the car industry's activities in FC technology is accurate. FC activities do not represent 'window dressing' given the percentage of FCV patents and industry-wide expenditures in fuel cells and hydrogen-related technology. Carmakers cannot afford to fall behind in this technology, pressured as they are by regulatory and competitive forces, and anticipation of oil price dynamics. However, FC activities also do not present 'commercialization commitment' as the 'hard' investments still have to be made, and carmaker strategies are defensive rather than offensive. Carmakers' commitment to FC technology can thus best be interpreted as balancing the pressures from external stakeholders (regulators, consumers, competitors) and internal barriers for innovation in uncertain technologies.

These conclusions are relevant for a number of stakeholders. First, regulators should be aware that although FCVs are in full development, the hard decisions to commercialize these vehicles occur in 2–4 years time when manufacturing decisions are to be made by the car industry. Until that time regulators should balance their technology-related policies, not only focusing on FCVs, but also on other ATVs such as HEVs. This study further suggests the stimulating effect of stringent regulation (ZEV) on R&D activities in alternative technologies; this regulative pressure should be continued to support the development of alternatives to the ICE. Second, entrepreneurs in FCVs and hydrogen (FC manufacturers as Ballard, or hydrogen technology developers such as General Hydrogen) should diversify their customers, not solely focusing on the auto industry. It is conceivable that FCVs prove to be unrealistic in several years time; too large dependence on this industry will jeopardize the life chance of many entrepreneurs in this new field.

Although the car industry is making its advances in this technology, and taking its responsibility to get FC technology closer to commercialization, developing the much touted hydrogen economy requires a long breath, and sharp monitoring whether the promised environmental advantages of hydrogen will in fact materialize.

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