Institutional Change in the Automotive Industry
Or how fuel cell technology is being institutionalised

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In the automotive industry the Fuel Cell Vehicle (FCV) is increasingly seen as the sustainable alternative to internal combustion engine (ICE)-based vehicles. The growing popularity of FC technology in the automotive industry provides an interesting case. Where one would expect the mature automotive industry to dismiss FC technology in order not to jeopardise its ICE technology, several billions of dollars have been spent on the development of FCVs by automotive firms. And, although FCVs are not yet available on the market, the auto industry continues to be optimistic about their prospects. Therefore, we are potentially on the forefront of a major technological change. Given the need for change in order to achieve sustainability, FC technology provides an interesting case to study why the industry has come to adopt this technology, and how FC technology is in the process of becoming institutionalised. Using institutional theory, this paper endeavours to unravel the forces and mechanisms that have shaped the popularity of fuel cell technology in the automotive industry.

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Robert van den Hoed completed his PhD thesis at the Faculty of Industrial Design Engineering, Delft University of Technology, the Netherlands, in May 2004. His thesis was an historical examination of the growing popularity of fuel cell technology in the automotive industry, with a focus on the roles of stringent regulation, competition between automotive companies and competition between technologies. The central research question revolved around how certain technologies become institutionalised while others do not. Robert is now working at Ecofys, a sustainable energy consultancy in Utrecht, with special responsibility for hydrogen, fuel cells and sustainable transport.

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ACK IN 1990, A NUMBER OF CAR-MAKERS SET UP EXTENSIVE BATTERY programmes. The battery electric vehicle (BEV) was generally seen as the most promising technology for achieving zero emissions—the possibility of a battery society was openly discussed and BEVs were expected to hit the market in the mid-1990s (Shnayerson 1996). Several car-makers visited the Vancouver-based pioneering fuel cell company, Ballard. However, they dismissed Ballard’s proton exchange membrane (PEM) fuel cell technology as unrealistic (Motavalli 2000). For years to come, the fuel cell vehicle (FCV) remained inconceivable for the automotive industry.

By 2004, literally every respectable car-maker worldwide has a fuel cell programme. More than 15 car-makers have shown demonstration vehicles, joint estimated annual spending on FCVs by the industry is between US$700 million and US$1 billion\(^1\) and the first fuel cell buses hit the streets in 2002. By the end of this decade, FCVs are projected to be commercially available, bringing the much discussed hydrogen society a step closer.

This dramatic realignment in favour of fuel cell technology demonstrates a seismic shift in the automotive industry’s quest for sustainable mobility. In a period of 12–14 years, fuel cell technology has been transformed from an unrealistic pipe-dream to a credible alternative to the internal combustion engine (ICE). How has this happened and what are factors involved? Furthermore, how is it that BEVs—once considered the design of the future—have been so completely side-lined?

This paper examines the rise in popularity of fuel cell technology in the automotive industry. It provides some insights into the processes by which industries select promising technologies and, more specifically, by which they transform to more sustainable practices. The paper therefore describes an institutionalisation process in which fuel cell technology gains momentum and becomes part of existing institutions. From this perspective, we hope to contribute to institutional theory by including the usually under-exposed treatment of technology. Using institutional theory, the process by which fuel cell technology is institutionalised is described, followed by an analysis of the sources of this technological institutionalisation and the factors which have contributed to the popularity of fuel cell technology. We conclude by considering what might be further expected from this institutionalisation process, in order to shed light on potential barriers for the continuation of this process.

Institutional theory

Institutional theory is traditionally used to describe stability of organisations, industries or societies rather than change (Scott 2001). Institutional theory translates sociological theories to (among others) organisational level, to explain why organisations or industries look so much alike, a phenomenon dubbed isomorphism (DiMaggio and Powell 1983). The source of stability lies in the existence of so-called institutions that shape organisational behaviour. Scott (2001: 48) defines institutions as follows:

Institutions are social structures that have attained a high degree of resilience. Social structures include norms, values, expectations, procedures, standards and routines.

In the case at hand (the automotive industry) institutions include the basic design of the car (e.g. internal combustion engine (ICE), four wheels, metal chassis and bodies), rules in traffic, standards set for safety and protection of cars, and also the network of

\(^{1}\) Based on Kalhammer et al. (1998) complemented with more recent press releases from automotive giants such as Toyota and DaimlerChrysler.
These are social structures that have existed for decades, subject only to small design changes over the years. The extent to which we are conscious of these norms and standards in the automotive industry differs, but a great deal of these institutions are taken for granted.

Using institutional theory to explain organisational behaviour has only gained momentum in the last two decades (Scott 2001). The main premise of institutional theory is that organisations tend to conform to institutions in the (external) institutional context. The institutional context consists of a set of regulations, norms, standards, values, codes and beliefs which prescribe appropriate and legitimate behaviour for an organisation (Scott 2001; DiMaggio and Powell 1983). Firms will tend to conform in order to obtain legitimacy.

Institutions can be categorised into three pillars (Scott 2001) leading to three types of pressures on organisations:

- **Regulative/coercive pressures**: these originate from powerful actors in the organisation’s environment, and take the form of standards, mandates or rules. A central element is the fact that the actors can use their power to enforce these standards (which gives it their coercive character). Organisations comply out of expedience. Examples include regulations or mandates.

- **Mimetic pressures**: these take the form of taken-for-granted practices or generally-accepted appropriate behaviour for firms. Mimetic pressures originate from credible industry players, (traditional) role models and competitors with large resources, capabilities or a strong network. Firms comply out of social obligation and a fear of lagging behind. Examples may include particular car-makers proposing a new practice or technology.

- **Normative pressures**: these take the form of beliefs, expectations, norms and values held by a larger community than the car industry itself (such as societal groups, regulators, consumers, suppliers). Firms’ compliance is based on the taken-for-granted nature of normative pressures. Examples include the taken-for-granted nature of gasoline as car fuel.

The three pillars are relatively stable; they apply external pressures on organisations that are not likely to change and tend to look alike.

Underexposed in institutional theory is the role of technology. We propose that, as with other sets of practices, technology can be described in institutional terms of norms, standards and values. Compare for instance with typical technology dynamics terms of design rules, technological expectations, dominant designs, path dependencies, vested interests and regimes (Dosi 1982; Nelson and Winter 1982; Schot, Hoogma and Elzen 1994; Geels 2002). All emphasise stability and the continued use of this technology over technological innovations. Green, McMeekin and Irwin (1994: 1056) use the term technological institutions as being:

sustained, not through any internal logic or intrinsic superiority to other institutions, but because of the interests that develops in its continuance and the belief that it will continue. Its continuance becomes embedded in technologists’ and managers’ frameworks of calculation and routines behaviour, and it continues because it is thus embedded.

The authors (1994: 1056) add:

The (technological) regime will therefore constitute a set of ‘socially’ agreed objectives, as to what the parameters of an industry’s products will be, how they would be typically made and, crucially for R&D, on which features of the product and process technological development should focus: in other words, on which performance characteristics’ will serve as a heuristic for R&D attention.
We can thus consider technology as an institution (consisting of norms, beliefs, search heuristics and expectations): technological innovation can thus be seen as institutional change. Along these lines, radical innovation may be conceptualised both as a de-institutionalisation of the dominant trajectory and as an institutionalisation of a radically new technology located outside the current trajectory.

Institutional theory is useful in explaining stability and dominant paradigms. However it is less suitable for explaining (technical) change (Fligstein 1991; Greenwood and Hinings 1996). In recent years, several authors have argued that change does occur and that institutional theory should be altered to include these phenomena (Ventresca and Hoffman 2002; Brint and Karabel 1991; Levy and Rosenberg <Rothenberg in ref list>2002). One way to explain the process of change is by looking at the sources of institutional change.

Institutional change refers to the phenomenon of institutionalisation (Scott 2001) defined as (Oliver 1996: 166):

The process by which activities come to be socially accepted as ‘right’ or ‘proper’, or come to be viewed as the only conceivable reality.

This definition indicates how formerly unaccepted behaviour becomes accepted and internalised. A simple example is the airbag. Until 20 years ago airbags were not a part of the car, but now every new car has one. Airbags have become standard in the same way as seat belts, windscreen wipers, air conditioning and low emission engines.

Parallel to the institutionalisation process, certain practices may become out-dated, not applicable or out of line with changed regulatory standards. These practices can then become de-institutionalised (Scott 2001; Oliver 1992: 563):

De-institutionalisation refers to the erosion or discontinuity of an institutionalised organisational activity or practice.

Where the former highlights the continuous process by which new routine legitimate behaviour is developed, the latter emphasises the replacing of old rules and routines by new ones.

Here, both institutionalisation and de-institutionalisation are at play. With regard to fuel cell technology, new rules, routines, beliefs and expectations are constructed and supported by regulatory institutions, reflecting the institutionalisation process. At the same time, the legitimacy of the current dominant design—the ICE—is increasingly undermined, with the rules and standards surrounding it starting to be questioned in a process of de-institutionalisation. Indicators of de-institutionalisation range from weakened beliefs or changed interpretations of current practices (Greenwood and Hinings 1996) to outright abandonment of these practices (Scott 2001).

But what are the origins of (de-)institutionalisation? What factors make institutions change, and under which conditions? Recent institutional theorists propose that institutionalisation is a result of discourse and negotiation in the organisational field (Scott 2001: 56):

A community of organisations that partakes of a common meaning system and whose participants interact more frequently and fatefuly with one another than with other actors outside the field.

The organisational field can be seen as a network of organisations with different power positions and engaged in several coalitions with other field members. According to Hoffman (1999), an organisational field meets (or arises) around issues. Here, the issue is sustainable mobility. This comprises the ongoing discussion concerning the un-sustainability of the ICE car and the problems associated with energy efficiency, carbon dioxide and local emissions, use of fossil fuels and the like. But the issue also encompasses discussions about available technologies and scrutiny of established technologies or
practices. Field members negotiate over the dominant problem definition as well as dominant solution directions (Hoffman 1999; Vergragt 1988). It is within the organisational field that rules, regulations and norms are decided upon, and technologies become accepted or dismissed. Note that this is a social process between field members in different power positions—(de-)institutionalisation is, therefore, inherently a political process (Ventresca and Hoffman 2002). An example of the organisational field at work is the dominant focus on technological solutions in order to attain sustainable mobility, largely as a result of corporate interests in the automotive industry. This is similar to the process by which the oil industry got gasoline accepted over methanol as the intermediate fuel for FCVs, through the building of coalitions with General Motors and Toyota, nicely illustrating how the organisational field works and how it results in changed institutions (van den Hoed and Vergragt 2003).

In the case of the automotive industry, apart from car-makers and oil companies, other field members include automotive suppliers, governmental agencies, research institutes, consumer groups and environmental organisations. With regard to sustainable mobility, other actors such as battery manufacturers, the chemical industry, hydrogen-related companies and fuel cell manufacturers are also part of the organisational field.

Based on this model of the organisational field, five factors are likely to induce institutional change:

- **Exits and new entries**: exits and entries can change the power structure in the field, leading to new coalitions and changed supported codes of conduct (Hoffman 1999; Oliver 1996)

- **External shocks or crises**: Fligstein (1991) argues that shocks are important mechanisms, lead to instability. According to Hoffman (1999), shocks provide the opportunity to reflect on established practices. Meyer (1982) shows how shocks can lead to uncertainty which in turn result in unorthodox experiments. Moors (2000) shows how a crisis, or the expectation of a crisis, puts pressure on a system and induces (radical) innovations.

- **New technologies**: new technologies can provide answers to problems or performance crises (Oliver 1992) associated with the established technology or practice.

- **New practices by established members**: rather than being constrained by institutional pressures, organisations themselves are capable of influencing institutions by proposing new practices (Oliver 1992; Scott 2001; Ventresca and Hoffman 2002). This is often referred to as the institutional entrepreneur (Ventresca and Hoffman 2002).

- **Market changes**: changes in the market can change demands for new practices, so putting pressure on current practice (Oliver 1992).

The above five factors influence the negotiation process in the organisational field and the resulting outcomes of this process, namely the institutions. An analysis of institutionalisation of fuel cell technology thus requires analysis of the above five factors and their influence on the organisational field. In the next section, the changed fuel cell technology institutions (divided into coercive/regulative, mimetic and normative) will be assessed for the period 1990–2003. The data are gathered from governmental agencies (e.g. CARB), press releases from automotive companies and influential research papers.

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2 See www.fuelcells.org.
Institutionalisation of FC technology

In this section, we try to establish the extent to which fuel cell technology has been institutionalised. This requires an analysis of coercive pressures, mimetic pressures and normative pressures.

Regulative institutions

Coercive pressures refer to strong forces mandating certain practices. In the case of the automotive industry, regulation is the strongest coercive force. To what extent have carmakers been coerced or even forced into developing FCVs?

Since the 1970s, environmental problems associated with the car have been increasingly regulated; for example, greenhouse gas emissions, energy efficiency, end-of-life scenarios and alternative fuels have been subject to regulation. However, none of these regulations have threatened ICE as the dominant technology or questioned its value to society. The only serious challenge to the ICE dominant design is the Californian zero-emission vehicle (ZEV) regulation (CARB 1996).

In 1990, the CARB included a passage in the ZEV regulation that mandated car-makers to sell ZEVs. Large car-makers were required to achieve 2% of their total sales in ZEVs by 1998, rising to 10% in 2003. Given that ICE vehicles cannot achieve zero emissions, alternatives were required. The only viable alternative at the time, according to the industry, was the BEV.

The ZEV regulation has been subject to change over the years. In 1996, the pre-2003 ZEV requirements were dropped in exchange for an industry commitment to bring a limited number of BEVs to the Californian market (CARB 1996). By 1998, the 10% target was lowered to 4%, with the remaining 6% to be achieved with extremely clean vehicles (CARB 1998). In 2001, the 4% was further reduced to 2% and another a new category was added, the ZEV alternative technology (ZEV–AT). ZEV–AT was set up to stimulate new technologies with very low emission levels, such as: natural gas vehicles (NGVs), hybrid electric vehicles (HEVs) and FCVs with an onboard reformer. The last change, made in 2003, allowed car-makers to sell FCVs, so giving them an alternative compliance route.

Comparing the 1990 and the 2003 regulatory requirements, it is striking that the percentage of ZEVs that car-makers must sell has fallen significantly. Nevertheless, there is still an obligation to deliver vehicles with no emissions. Although car-makers have the option to fulfil the ZEV requirements with BEVs, the technical development of this vehicle has been so disappointing that FCVs are largely preferred by most car-makers, and this preference is being reinforced by the ZEV regulation.

Normative institutions

Normative institutions refer to the beliefs, expectations, norms and values associated with technology. To what extent does a consensus exist concerning the future of FCVs? How has the attractiveness of the FCV option changed through the years?

In the early 1990s, fuel cell technology was not seen as a viable option for ZEVs. At that time, although technology was considered potentially suitable for stationary appli-

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3 These vehicles would need to achieve SULEV (super ultra low emission levels) emission standards, which are the equivalent of the emissions produced by utilities for generating electricity (CARB 1998).
4 FCVs fuelled by direct hydrogen fall in the ‘gold’ ZEV–AT category.
5 The number of required sales is based on sales volume, but averages out at around 250 FCVs <per year> until 2008.
cations, mobile applications required much higher energy densities and cheaper fuel cell stacks. Thus, the dominant alternative car design in the early 1990s was the BEV.

This paradigm began to change when, in 1994 and 1996, DaimlerChrysler (then called DaimlerBenz\(^6\)) revealed two fuel cell demonstration vehicles and expressed its commitment to pursue this technology. These events proved crucial in putting FCVs on the agenda of the automotive industry (Kalhammer et al. 1998; Maruo 1998). From the industry’s perspective, fuel cell technology has a number of attractions:

- In comparison to BEV technology, fuel cells offer greater future potential once obstacles such as the need for higher energy densities, lower weight and volume requirements, longer range and easier refuelling have been overcome. Cost issues remain a potential difficulty, but are not thought to be insurmountable (Kalhammer et al. 1998).

- Fuel cell technology has a certain ‘sex’ appeal. The principle behind it is almost too simple for words (reverse electrolysis); its promise of maintenance-free and silent vehicles is very appealing, as is its flexible design potential (Nieuwenhuis and Wells 1997).

- The most important attraction of the FCV, however, lies in its environmental potential—it is energy efficient, has low greenhouse gas emissions and is non-polluting. It represents the ‘holy grail’ of sustainable mobility (Hoogers 2003).

Thus, between 1996 and 1998, fuel cell technology in vehicles generated a great deal of excitement, not only among car-makers, but also fuel cell manufacturers, hydrogen companies (storage technology), oil companies (hydrogen infrastructure), chemical industry (catalysts and membranes for fuel cells) and governments (stimulation programmes, testing programmes). By the late 1990s, with the BEV market continuing to disappoint, fuel cell technology became the new zero emission alternative. The only question was: ‘Could it be done?’

By 2003, the technology’s technical viability was not in doubt. Test programmes with fuel cell buses and cars had been under way for several years, the first FCVs had been sold and most of the critical technical problems had been solved (particularly cold start, water management and reforming technology), although it was acknowledged that further work was needed (Hoogers 2003).

Moreover, there is increasing international consensus among car-makers, oil industry, governments, environmental groups and research institutes on the viability of a future hydrogen society. The debate focuses on ‘when’ this transition will occur, rather than ‘if’. Illustrative is Iceland’s efforts to become the world’s first hydrogen society in the next decade.

According to Dr Alan Lloyd, chair of CARB: ‘Fuel cells offer our nation the double benefit of clean air and energy independence.’\(^7\) The long-term vision of FCVs and hydrogen (generated by photovoltaics or wind) remains a strong one, to which a growing fuel cell community adheres. By the early 2000s, oil companies had set up extensive hydrogen programmes, stock prices of fuel cell manufacturers were booming and fuel cell stimulation programmes by governments were too numerous to mention.\(^8\)

In recent years, however, the rosy hydrogen–FCV picture has developed some cracks. Energy efficiency and emission levels are not as favourable as once thought (Weiss et al. 2004).

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\(^6\) DaimlerBenz and Chrysler merged in 1998 to form DaimlerChrysler. Throughout this chapter, the company will be referred to as DaimlerChrysler.


\(^8\) Kalhammer estimates investments until 1998 in fuel cell technology to be US$1.5–2 billion. Based on press releases, the programmes of DaimlerChrysler and Toyota had annual investments of more than US$200 million in fuel cell technology.\(<\text{when}\>\)
2003; see also Vergragt in this issue), while the safety of hydrogen–FCV buses operating in Amsterdam has been called into question. Thus, the vision of a gleaming hydrogen society still exists, but its sheen has been slightly tarnished.

Mimetic institutions

What are the mimetic institutions for the automotive industry? What are considered good and legitimate practices for the industry to adopt? One relatively objective method of assessing company R&D activities is by analysing patents. A study was carried out using patent data from the US Patent Office complemented with that from the European Data Office. Figure 1 shows the dominant role of BEV technology in R&D priorities until 1997 (this was in line with disappointing BEV sales at around this time) with a shift from BEV to FCV (and HEV) taking place around 1997. In 1998, there were more patents for FCV and HEV technologies than for BEV. By 2000, the number of FCV and HEV patent applications were, respectively, two and a half to three times higher than BEV applications. Figure 2 reveals that, by 2000, nearly 35% of all alternative fuel vehicle (AFV)-related patents were FCV-related, 50% were HEV-related and just 15% were BEV-related. Figure 3 shows that, by 2000, close to 9% of all patent applications were related to AFVs. More than 3% of all patents in 2000 were FCV-related (compared to no more than 0.4% in 1994)—in other words, one out of every 33 patent applications made by car-makers was fuel cell related in 2000.

These data include all large car-makers worldwide: DaimlerBenz/Chrysler, General Motors, Honda, Toyota, Ford, Nissan, Mitsubishi, BMW, Volkswagen, Fiat, Renault, PSA (Peugeot, Citroen), Daihatsu, Daewoo and Hyundai.

**Figure 1** PATENTS IN EVs, FCVs AND HEVs APPLIED FOR BY CAR FIRMS (1990–2000: MOVING AVERAGE 2)

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9 RTL-4 News 10 September 2003, 7:30 pm.
10 See www.uspto.gov, gb.espacenet.com. As a main data source the US Patent Office was used, given the size of the US market (propensity to patent in the US is high), the presence of ZEV regulation in California (the US thus provides an important market to secure ZEV related patents) and the high costs for having US patents (thereby securing the quality of patents; in comparison in Japan costs for patenting are much lower leading to high patent activity for decoy purposes). Nevertheless, European companies such as DaimlerBenz, BMW, Volkswagen, Renault and Peugeot-Citroen are not active in the US (and thus show little patent activity there); to compensate patents of the EPO complement the US data.
The patent study shows the increased R&D activities in fuel cell technology, and the integral place fuel cell research has captured in automotive R&D. The institutionalisation of FCV as common practice in the auto industry is further illustrated by an analysis of the introduction of demonstration FCVs. Figure 4 shows how, for nearly two years (1994–96), DaimlerChrysler was the only car-maker with a FCV model. Then, in less than three years (late 1996 until early 1999), seven other firms issued their first demonstration FCV. Another two years later, 14 (most of the industry) had demonstrated a FCV arising from an in-house fuel cell programme. This majority reflects the consensus on this technology.

As the world’s leading car-makers initiated fuel cell programmes, so they terminated BEV programmes. Fuel cell programmes are now an integral element in auto R&D, as demonstrated by the following statements:

> B. McCormick, co-director of General Motors’ Global Alternative Propulsion Cen-
tre (GAPC) states that fuel cell technology is: ‘no longer a science project; the fuel cell is getting to be real’\textsuperscript{11}

- Dr E. Shubert, co-director of General Motors’ GAPC notes: ‘Hydrogen is the only energy carrier that will satisfy the need for a lasting reduction in carbon dioxide emissions despite a steady increase in the number of motor vehicles on the road’\textsuperscript{12}

- Ford states: ‘We believe fuel cells are the only technology today with the potential to someday replace the internal combustion engine’ (Wallace 2001<not in ref list>)\textsuperscript{13}

Thus, in the last decade, fuel cell technology has gained remarkable momentum and has been accepted by a wide range of societal groups (including the oil/automotive sectors) as the future car propulsion system with hydrogen as the fuel. How can this popularity be explained?

**Sources of institutionalisation of FCVs**

Using the five change factors described earlier, the sources of the institutionalisation of FCV technology will be examined.

**Exits and new entries in the organisational field**

The organisational field is not a stable set of organisations and coalitions—exits and entries occur which impact on progress towards sustainable mobility, leading to different norms, beliefs and expectations (in other words, to different institutions).

The most notable new entrant is, of course, Ballard, the leader in fuel cell technology. By increasing energy density combined with more powerful membranes while at the same time reducing platinum load, Ballard has made the PEM fuel cell eligible for applications in cars (Motavalli 2000). In the slipstream of Ballard’s pioneering work, a whole range of new fuel cell companies have flourished, such as International Fuel Cells, Plug

\textsuperscript{12} See www.fuelcells.org, August 2001.
Power, H-Power and DeNora. The competition among these firms has created further momentum. With DaimlerChrysler showcasing its NECAR models and the FCV now well and truly on the map of the auto industry, a range of related industries jumped aboard—hydrogen-related companies for storing and handling hydrogen (e.g. Quantum, General Hydrogen), chemical companies for developing membranes and catalysts (e.g. Johnson Matthey, Dupont, 3M, Hoechst) and, of course, fuel companies (Methanex for methanol, StatOil, BP, Shell). These firms developed their own coalitions, both with each other and with car-makers. Again, momentum increased.

By contrast, and illustrating the working of the organisational field, the late 1990s saw the exit of battery developers, BEV developers and related industries as a result of disappointing sales and the shift to FCVs.

But to what extent did Ballard put fuel cell technology on the map? Remarkably, the crucial inventions Ballard made to the fuel cell originated from 1985 and 1986, years before the ZEV regulation, and more than eight years before the first prototype FCV appeared. In this period Ballard was unable to get fuel cell technology on the agenda. Motavalli (2000) describes how several car-makers tested Ballard stacks in the early 1990s, but dismissed the technology—impractical, too costly, too unwieldy?—.

The ZEV regulation and the early tests (which early tests? Ballard’s?) did not seem to raise Ballard’s profile or get FCVs on the agenda. In fact, it could be argued that this only happened when DaimlerChrysler decided to engage in collaborative research with Ballard.

External shocks or crises

Two external shocks or crises were important factors in the rise of fuel cell technology. First, by challenging the ICE paradigm, the Californian ZEV regulation was a shock to the automotive industry. The central message sent by this regulation was that, in the future, polluting emissions from cars would no longer be tolerated. A zero emission vision, an alternative to ICE, was born. For car-makers, ICE could no longer be taken for granted. So, although auto R&D continued to develop ICE technology, it also started to include non-ICE alternatives. Another impact of the ZEV regulation was to provide a boost for zero-emission technology companies, such as battery developers and pioneers such as Ballard who saw the potential to form fruitful new coalitions with car-makers (Motavalli 2000).

Second, the attack on the World Trade Centre in New York in 2001 had a profound impact on the institutionalisation of fuel cell technology and, in particular, the hydrogen society (see Hekkert and van den Hoed in this issue). As a result of 9/11, the Iraq conflict and continuing instability in the Middle East, oil security and dependency have become important issues for the US government. In his 2003 state of the Union address, President Bush announced US$1.2 billion investments for research into hydrogen for car propulsion, further illustrating the widespread expectation of a hydrogen–FCV society.

New technologies

The performance characteristics of the fuel cell have most definitely contributed to its success. One of its most important characteristics is power density (measured in kW per litre). According to Kalhammer et al. (1998), Ballard’s fuel cell power density showed a factor ten increase between 1990 and 1998. By 1998, 1 kW/litre had been achieved.

14 See www.eere.energy.gov/hydrogenfuel.
This doubled the target of 0.5 kW/litre set by the Partnership for Next Generation Vehicles (PNGV)\(^\text{15}\) in 1994 (see Fig. 5). The Partnership’s 1998 goal of 1.4 kW/litre was nearly achieved in early 2000 with Ballard’s \textit{<correct?>Mark 900 series achieving a 1.3 kW/litre output,\(^\text{16}\)} while its successor reached more than 2.0 kW/litre in 2002.\(^\text{17}\)

With this progress, the power density of fuel cell technology approaches that of the ICE; and whereas, formerly, the fuel cell stacks used the complete compartment space of a vehicle (in NECAR I), the system now fits the floor of the Mercedes A-class, not compromising passenger space. Furthermore, the weight of the stacks has come down by several factors (Hoogers 2003; Kalhammer \textit{et al.} 1998). Similar progress has been made with regard to low temperature operation, dynamic behaviour, and water and heat management (Hoogers 2003).

It is safe to say that without this remarkable technological progress, fuel cell technology would not now be on the agenda of the automotive industry. With the technical aspects under control, more commercial aspects have become important, the key one being cost. Although costs have undoubtedly come down, this remains one of the more difficult challenges.

\textbf{Institutional entrepreneur}

Institutional entrepreneurs are those companies within the institutional context itself that are the source of novel practices. Although car-makers are constrained by their institutional context they can nevertheless influence the institutions in their context by proposing new, unorthodox practices or technologies. History shows how the automotive industry has taken on this role.

A good first example is General Motors’ showcase of its EV1 in 1990 and its simultaneous announcement to commercialise the BEV in 1995. This announcement formed an important push for CARB to adopt the ZEV regulation. General Motors positioned the BEV as a \textit{viable technology} (i.e. one commercially available in the mid to long term). This optimism concerning BEVs was unprecedented (Shnayerson 1996): it illustrated a shift in normative pressures, namely in the commercial beliefs and expectations of BEV. \textit{Where formerly a study project, BEV projects gains perspective with General Motor’s}

\begin{figure}
\centering
\caption{Evolution of Ballard Stack Performance}
\label{fig:ballard}
\end{figure}

\textit{Source: Kalhammer \textit{et al.} 1998}

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\(^{15}\) PNGV was initiated by the Clinton administration with the objective of developing vehicles capable of achieving 80 miles per gallon; see www.pngv.org.

\(^{16}\) See www.hfcletter.com/letter/february00/feature.html.

ambitions, and propel programmes at other car-makers. (unclear, please rephrase)

Similarly, DaimlerChrysler’s showcasing of the NECAR I (in May 1994) and, in particular, the NECAR II (in May 1996) had a similar effect. Before these events, the viability of fuel cell technology as a car propulsion unit had generally been seen by the automotive industry as unrealistic. The progress made by DaimlerChrysler projected fuel cell technology as a viable alternative to ICE. Possibly even more important was the reputation of DaimlerChrysler as a well-known innovator in the industry, with a strong and innovative R&D department and culture. Furthermore, the company’s links with subsidiaries in aerospace (DASA, Dornier) and electronics (AEG) also provided a source of innovative technologies. It was no accident that DaimlerChrysler’s belief in fuel cell technology originated from its aerospace subsidiary Dornier which had experimented with the technology in the late 1980s as part of a space-related project (Motavalli 2000). Thus, DaimlerChrysler was a likely candidate for an institutional entrepreneur, creating normative expectations and beliefs for the industry as a whole.

A final example of the institutional entrepreneur phenomenon is in Toyota’s HEV activities. Although considered by other car-makers, HEV technology was generally seen by the industry as too expensive and too complex for commercial application. With the risky market introduction of the Prius in the late 1990s, Toyota dispelled that myth. The success of the Prius not only provided a role model for the rest of the industry, it also influenced the regulatory institutions—in California the HEV is now classified in the ZEV–AT category, and provides a possible extra push to develop more stringent energy efficiency standards (see Hekkert and van den Hoed in this issue).

General Motors, DaimlerChrysler and Toyota are institutional entrepreneurs proposing new and unorthodox practices. Three technologies previously considered unrealistic or commercially unviable have become serious options to be considered by the rest of the industry. Regulatory standards have also changed as a result of these technological proposals. Thus, these three firms have changed the institutional context in which they operate. They did this, not for altruistic purposes, but for sound business reasons, having built strong foundations for their respective technologies. Further support from others in the sector and from regulators has helped to improve their competitive position. By acting strategically, firms can position themselves in the driver’s seat of innovative practices and technologies.

Innovation and strategic behaviour may not, however, be sufficient, as is shown by BMW whose endeavours to get its hydrogen–ICE vehicle accepted by the industry and regulators have not succeeded (as yet). It stands alone in its approach, as it does in its application of fuel cell technology as a battery replacement. BMW’s relatively small size and lack of resources seem to affect its ability to influence other players. Institutional entrepreneurs need:

▶ Some level of credibility derived from a strong resource position (e.g. General Motors, Toyota)

▶ A strong R&D department (e.g. DaimlerChrysler and, to a lesser extent, General Motors and Toyota)

▶ A strong knowledge position in the technology (e.g. DaimlerChrysler and General Motors)

▶ A strong network (e.g. General Motors and Toyota with Exxon, DaimlerChrysler with Ballard).

Institutional entrepreneurs are a strong force in shaping the institutional environment.
Market changes

Rather than solely looking at technological opportunities or regulatory climates, markets are also subject to change (Christensen 1997). While markets change, ‘old’ technologies can become obsolete or insufficient to fulfil market needs. Consequently, ‘new’ technologies can become more attractive. To what extent could the changing market environment have been the reason for the success of fuel cell technology? Only to a limited extent, so it seems.

On dominant market criteria such as costs and performance, the FCV is unlikely to provide better value than the current ICE (van den Hoed and Brezet 2003). It is more likely that any added value will be derived from the electric nature of FCVs, as conventional batteries can hardly keep up with the increasing energy demands of modern cars. Fuel cell technology not only solves this problem, it can also provide electric power when the motor is not running. Hoogers (2003) and Kalhammer et al. (1998) concede that this application of fuel cell technology is interesting, but suggest that it does not offer sufficient added value to propel FCVs into the market alone. Similarly, silent cars are, at this stage, not a serious market driver.

Furthermore, the history of environmentally benign cars has not been comforting. Several models boasting better efficiency or low emissions, but sold at a price premium, have remained niche markets. The first model to show some market success is the Toyota Prius, despite its price premium. By 2002, more than 100,000 models had been sold, an unprecedented amount for an environmental car. The FCV will have to display qualities other than its environmental performance to gain market acceptance.

Conclusions

This paper has described how fuel cell technology has become an accepted technological alternative to the ICE. The FCV is in the process of becoming institutionalised, manifested in the form of: regulatory support systems (e.g. ZEV and carbon emissions regulations); expectations/beliefs in a hydrogen–FCV society (normative); and a sense of what is considered appropriate behaviour by car-makers in order to achieve sustainable mobility (mimetic). This process of institutionalisation is described both as a process of gaining momentum and growing acceptance for a technology, and also as a political process through which stakeholders and coalitions of stakeholders try to collect support and achieve consensus for their particular (technological) interests. Based on this assumption, the factors that influence this institutionalisation process have been discussed, using the organisational field as the locus of institutional change.

A combination of change factors is at play in explaining the current popularity of fuel cell technology in the automotive industry. The remarkable technological progress displayed by the technology has been a dominant reason for car-makers to invest in it. Without this progress it is unlikely that the technology would ever have made it to the demonstration stage. However, technological progress alone seems insufficient to explain its success. The ‘shock’ of the Californian ZEV mandate provided car-makers with a powerful incentive to look for, and invest in, alternatives. But ZEV has had another effect: it has attracted new entries with innovative technologies (e.g. battery developers and fuel cell manufacturers) to the organisational field, thereby laying the foundations...
for new coalitions and shifting the power structures. ZEV has been a second crucial condition for the success of fuel cell technology.<add in small bit on 9/11 and oil supply concerns?>

The case also shows how car-makers themselves have been instrumental in getting their own industry to adopt new technologies. Ballard’s technology had been available since the mid 1980s, but only DaimlerChrysler’s investments (in 1993) put the company and its technology on the map. Similarly, General Motors’ adoption of AeroEnvironments’ BEV technology illustrates how large car-makers play a crucial role in technology acceptance.

Thus, we conclude that the combination of an attractive technology, shocks and institutional entrepreneurialism have all played key roles in getting fuel cell technology onto the R&D agenda of the global automotive industry.

Whether this is sufficient to secure the future commercial success of FCVs remains uncertain. Although an institutionalisation process has taken place, we can only conclude that fuel cell technology is only slightly institutionalised. Similarly, and possibly more importantly, the ICE is only slightly de-institutionalised. The case shows how market factors have had a very small role in raising the popularity of FCVs, and might well dampen the potential for future success. This suggests that although the current combination of change factors favours ongoing R&D on fuel cell technology, it does not guarantee its commercialisation. Whereas in the R&D stages, competitive advantage and the acquisition of valuable resources are important drivers for car-makers (in order to safeguard their knowledge positions), commercialisation requires cost-effectiveness as well as significant resources to build manufacturing capacity. A similar scenario to that seen with BEVs is conceivable, in which poor sales lead the industry to retreat from further development and investment. Thus, without significant market incentives the further institutionalisation of FCVs might well be hampered.

This paper shows how institutional change is the result of discussions at organisational field level, with the ZEV regulation providing a good example of how several stakeholders can influence the outcome. Furthermore, the powerful negotiating role of car-makers (as well as the oil industry) is striking. It is the large car-makers, such as DaimlerChrysler and General Motors, who put fuel cell and BEV technologies, respectively, on the agenda, rather than small firms such as Ballard. An estimated US$200–300 million annual budget is available for car-makers such as General Motors and DaimlerChrysler for research on fuel cell technology, providing a strong knowledge resource based in research institutes, academia, pressure groups or regulators. This resource can influence the technological decision-making, technological trajectories and success or failure of technologies in the automotive industry. Given the strong role of the automotive industry, and conflicting economic incentives and sustainable objectives, the existence of a large knowledge gap between the car industry and those who regulate it is undesirable if sustainable mobility solutions are to be achieved.

Based on these assessments, the following recommendations to regulators are made:

- Regulators should continue focusing on long-term desired objectives for sustainable mobility, such as zero emissions. Over time, such objectives may well become institutionalised, so creating normative pressures to adopt new and sustainable practices, and simultaneously attracting new companies with innovative technologies. Furthermore, it will further commit car-makers to the sustainable mobility track.

- Apart from institutionalising new technologies such as fuel cell technology, de-institutionalisation of the ICE should be targeted. As long as the ICE is perceived as an unproblematic technology, it will be very hard to replace it with alternatives.
Progress in fuel cell technology should be fostered, particularly with respect to market criteria such as costs and performance. Currently, the FCV is not yet able to provide market value, and promoting it too soon could endanger its long-term success. Patience should be exercised together with experimentation. Although breakthroughs remain necessary, it seems wise to initiate small-scale experiments to foster learning with respect to consumer acceptance and technological requirements, thereby paving the way towards viable FCVs (Brown et al. 2003).

References


