

Understanding the automotive industry: German OEM behaviour during the last 20 years and its implications

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Abstract

This work presents a study of how the automotive industry has responded in the last 20 years to pressures driven by economic and environmental issues, and by the transition towards electric mobility. Timelines for the major German automotive OEMs are presented to understand the industry's behaviour in the past in order to design suitable policies that are appropriate to reach future goals around the electrification of road transport. Based upon a comparison of the pressures arising in the automotive sector and the companies' behaviour with regard to technology choice and R&D, a set of hypotheses concerning this behaviour is then presented.

Keywords: low emission vehicles, regulation, Germany, vehicle manufacturers

1 Introduction

The automotive industry continues to experience a number of pressures. Not only are the automobile producers increasingly perceiving oil scarcity, as a potential future issue, but, more and more, these companies are aware of changing customer expectations and behaviour, and are challenged by governmental and regional policies driven by climate change and local air quality issues. As a result, the on-going discussion on emissions has led, and will lead, to a variety of changes in behaviour, responses in strategies and products in the automotive industry; especially as automobiles are responsible for a high amount of energy-related GHG emissions (26% in OECD countries). So the last years' were dominated by discussions concerning fuel efficiency and emission reduction goals and efforts [1, 2].

One way of addressing those pressures is the introduction of technologies such as hybrid, battery or fuel cell electric vehicles [1, 3] as it is argued that the whole spectrum of those electric power train technologies are likely to be needed in a future decarbonised road transport system, each playing a different role [1, 4]. Scenarios, such as those analysed by the IEA and World Energy Council, highlight futures with a fast rapid diffusion of those different drive trains [1, 2].

The study presented here has the aim to illustrate how major German automotive OEMs have responded to pressures and events in the automotive sector, including national and international policies, technology hypes or economic developments. The goal is to understand the decisions that have been taken in the past by the automotive industry in order derive

behavioural patterns with regard to the focus on technologies (such as drive trains). Understanding how the automotive industry responds to different events or pressures, shall allow to understand what policies are most effective at driving the transition towards electric mobility.

In the long run, this work has the aim to provide insights that could be used to explore the effects of transitions towards electric transport on the automotive sector with the help of modelling. Information on the proposed model can be found in [5].

The current structure of the model requires a description and formalization of the automotive industry's behaviour including:

- the pressures that lead to changes,
- the companies characteristics
- and the way the sector responds to those pressures such as the choice of vehicle propulsion technologies.

The work here presents qualitative insights that have been obtained on the path towards the creation of the model.

2 Understanding the Transition and OEM's technology choices

2.1 Past research

There have been a number of studies that explore the role of the automotive industry in the transition towards alternative vehicle propulsion technologies.

Mainly qualitative studies such as [6-16], outline the challenges as well as relationships between the various actors (such as car manufacturers, suppliers, policy makers, etc.), and describe their roles and significance, in the diffusion of electric mobility. In this context, studies such as [17, 18] describe and formalize transition systems with the help of innovation management; mainly based on [19-21].

A number of works point out the challenges for the industry, which is facing uncertainty with regard to future technologies and strategies [22-24]. The automotive industries activities are interpreted as a response against pressures from external actors, like regulators, consumers or

competitors. Other findings describe how short-term strategies of the industry lock it into using combustion engines, avoiding extensive investments into alternative propulsion technologies, as they anticipate and wait for spillovers from other companies executing this research [10, 25].

However, these papers discuss the role of the automotive manufacturers only in a broader context. They outline in a qualitative way how the industry is part of or is affecting the transition towards low emission vehicles. For the purpose of quantification and a robust linking of causes and consequences of the industry's behaviour, they are not sufficient and therefore this work (building upon those presented here) has the aim to present an extensive study of the automotive industry.

3 Methodology

In this study, an analysis on the German automotive sector and the institutions as well as relevant events on the period of the last 20 years is presented. The major German OEMs, BMW, Daimler and Volkswagen are analysed.

Based upon the multi-level perspective approach within transition science [19, 21], the system is classified into three levels, the landscape, the regime and niches. While the landscape and regime describe and define the socio-technical system and the established set of rules OEMs are embedded in, niches can be alternatives, such as the upcoming of TESLA Motors. First, the landscape and regime are discussed in section 4.1, describing events that are expected to have influence on the automotive sector. This is then followed by a description of how the three major German players responded to those changes. Those stories are then put into time lines (see Annex) for comparability reasons.

The study includes aspects that have been identified to have major impact on strategies in the automotive industry. Extracted from a number of studies [14, 26-32] those aspects include technology trends and hypes, national and international policies, competitors, economic pressures, fuel prices and infrastructures, as well as insights on future expectations [33, 34]. But it also has the aim to identify further links between causes and consequences with regard to technology choices and changes in the automotive industry.

The approach we follow in this study is the following: First, the automotive sector and aspects such as relevant regulations and developments are discussed from 1990 on until 2013. Then, as a second step, each company has been examined during this period. The focus is put on the research and development and the choice of propulsion technologies, including technologies surrounding petrol, diesel, hybrid, battery or hydrogen based power trains. Those are then summarized in timelines.

Those timelines are then put (in a qualitative way) into relation and the comparison is used to derive recurring links and patterns in the behaviour of the automotive industry.

The summaries and timelines are derived from those works and are significantly further supplemented with actual data on economic growth and fuel prices as well as the insights provided by media, mainly drawing from articles of major established journals such as Spiegel, Handelsblatt, Focus, FAZ, ...) or For examples, articles around major exhibitions such as the International Automobile Exhibition IAA in Frankfurt and Detroit Motor Show), were reviewed to check the mood of the whole sector and the trends and fashions at those times. The information on the automotive companies are then additionally supplemented by an analysis of company annual reports.

4 The German OEMs since 1990

This section describes the German OEMs' power train activities since 1990. 4.1 describes what had happened worldwide while 4.2-4.4 focus on the manufacturers themselves. For each of these an illustration of the timeline can be found in the Annex.

4.1 The automotive regime & landscape

The Zero Emissions Vehicle (ZEV) initiative that outlined a number of emission targets and limits as well as diffusion goals for zero emission vehicles in California in 1990 was one of the first policy measures pushing towards low carbon transport. Although limited to California, it had a huge signalling effect as around 25% of the US vehicle market was in California, and developments in California were expected to move to further states. However, though it

triggered a number of EV and FCEV prototypes being presented by the industry, the fact that those goals were not expected to be met meant it was relaxed in 1996, and a key regulatory pressure on the automotive industry was relaxed. While until then hydrogen vehicles had been seen as a solution for future transport, suddenly the mood changed and interest switched towards other technologies such as the development of battery electric drive trains. Around 1996/97, at a time when hydrogen was not seen as a winner anymore, major OEMs in Germany and Japan presented their respective solutions to deal with arising discussions on CO₂ emissions. While Daimler's launch of the NecarII hydrogen demonstrator surprisingly triggered a new hydrogen/fuel cell hype (especially in Germany), Toyota's and Honda's launch of hybrid electric vehicles (Prius and Insight) directly into the Japanese and USA markets was acknowledged by the automotive sector without having initially any disruptive effects. While the early 2000s were dominated by an economic world crisis it was not until 2004/05 that major changes were triggered in the automotive sector. The success of Toyota Prius HEV and the launch of its second generation, as well as rising fuel prices, lead to a change in the perception of the hybrid technology, that until now lead to a 'hybrid race' illustrated by the significant increase in hybrid patents, HEV/PHEV prototypes being presented at various automobile exhibitions as well as numerous announcements of HEV release dates. During that time, hydrogen technology research, still enjoyed support from various governments (for example the US Department of Energy Hydrogen Program). However, with the inauguration of Steven Chu as new US Secretary under President Obama in 2009 and a reassessment of all technology options, the perception and expectations concerning that technology completely changed. Only the intervention of the Congress and the Hydrogen lobby prevented USA hydrogen R&D funding being completely cancelled. During that time (a time where the financial crisis hit) governments such as the German or the UK launched national programs, the "Nationale Plattform Elektromobilität" and "Ultra Low Emission Vehicles initiative" respectively, supporting the uptake of electromobility in order to reach environmental or industrial targets. Since then, HEV/PHEVs and BEVs have dominated current discussions (hydrogen has a minor role in the US White House Blueprint for a Secure Energy Future), and the presence of TESLA in the media, the introduction of many EV demonstrator projects

(SmartEV, MiniE, and many more) as well as the recent introduction of the Chevrolet Volt, Nissan Leaf or Mitsubishi iMiEV support that impression. While the financial crisis as well as rising fuel prices in the late 2000s put the focus on the development of small and highly efficient vehicles, the current (2012/13) focus has switched again slowly but steadily towards bigger cars such as SUVs. However, PHEVs and EVs currently figure in technology portfolios as short- or medium-term solutions more than they ever did before.

4.2 BMW

BMW is an automotive car manufacturer with more than 1.6 million cars sold per year, a profit of more than € 7 billion and more than 100,000 employees (2011). During the last 20 years BMW has increased its output in vehicles from less than 900,000 per year and increased profits nearly tenfold. Since then BMW has had some experience with hydrogen (both internal combustion and fuel cells), battery electric Minis and is currently launching its first hybrid vehicles, and especially its i-series (BMW i3). While it has been always seen as the smaller premium automobile manufacturer, its sales numbers overtook those of Daimler a few years ago. BMW's image is located around medium/large luxury and performance segment cars, a fact that is reflected in the average fleet emissions (145 gCO₂/km in 2011).

While in the early 1990s ZEV regulation driven experiences with alternative vehicle power technologies were disappointing, it was not until 1996 that BMW established serious hydrogen research activities. Though it was in a time of hydrogen disappointment in the automotive sector, the decision was mainly motivated by a hydrogen vehicle demonstration by its main competitor, Daimler. Though the work focused on PEM fuel cells and later SOFC fuel cells as well, BMW presented in 1998 the BMW 750hL, a large segment vehicle with a hydrogen combustion engine and a 5kW PEM APU. Since then, BMW built more than 100 hydrogen combustion vehicles that were used at various events (such as the EXPO 2000 in Germany) and a number of demonstrator programs where those vehicles proved themselves in over more than 4,000,000 kilometres driven. Also, a petrol fuelled vehicle using a SOFC APU with a fuel processor instead of an alternator was introduced. Though BMW announced it would bring its

hydrogen combustion vehicle to market in 2002, those vehicles did not go beyond the status of demonstrator fleet programs.

While the average fleet emissions of BMW had been stable (though at a relatively a high level), emission target discussions at the European level had led in the late 90's and the beginning of the 2000's to an introduction of a variety of engine efficiency improvements as well as the higher use of diesel in the fleet, leading to a slow but steady decrease in average fleet emissions. However, hybrid or electric vehicle development was not intensified in this period of time. The acquisition of Rover brought in Range Rover SUV technology, leading to the design and production of BMW's X5 SUVs. Also, the early 2000's were more focused on the world economic crisis, the new emerging Chinese market and the opening of BMW's new production facility in Leipzig in 2005. This changed in 2005/06, mainly with the success of Toyota's Prius and rising fuel prices, causing customers to demand similar solutions. Until then, only hydrogen technology featured in the annual reports as a future solution for low emission vehicles while, from 2005/06 onwards hybrid vehicle technology was included in the annual reports as well. Around that time a collaboration with GM and Daimler-Chrysler was announced in order to develop a hybrid system to compete with the Japanese manufacturers. Also, in 2006/2007 BMW intensified its hydrogen combustion vehicle activities by leasing out 100 vehicles. In this period, BMW's average fleet emissions were increasingly dropping (approx. 170 gCO₂/km), however, discussions on regulations in the European Union on a limit of 130gCO₂/km increasingly created pressure. Apart from recuperating energy to its lead acid battery with the help of the alternator, BMW had not provided any hybrid vehicle solution so far.

In 2007, a successful year for BMW, with no signs of the financial crisis yet to come, BMW initiated a project called 'project i' (under the 'Number ONE strategy) that reviewed the technology future options. This led to a significant change in the technology strategy of BMW. Shortly after the review had finished, BMW stopped its combustion hydrogen vehicle program and announced the launch of a Mini EV trial fleet, a battery collaboration with SB LiMotive and the creation of a Joint Venture with PSA (Peugeot/Citroen). In 2010, it also announced plans to develop and produce a BEV for the mass market, while also a

hydrogen and petrol hybrid vehicle prototype (using a 5kW PEM Fuel Cell, see above for APU) was presented drawing upon the experience available in house.

Today, in the early 2010's, after a number of competitors have brought their PHEVs or BEVs to market, BMW has presented its Megacity Vehicle (BMW i3), a small lightweight BEV vehicle that is expected to reach the mass market in the end of 2013 (built in Leipzig). During that phase the acquisition of SGL Carbon, the supplier of lightweight materials for the i3 was announced. 2012/2013, in a time, where the amount of HEVs/PHEVs in BMW's portfolio is limited, BMW and Toyota have agreed to collaborate on fuel-cell systems, lithium-air batteries, lightweight technologies and electric power trains.

Currently BMW is selling more vehicles than ever and has the highest profits it has ever made.

4.3 Daimler

Daimler (at times DaimlerChrysler) is a car manufacturers with more than 1.4 million cars sold per annum, a profit of more than € 4 billion and around 100,000 employees (2012). During the last 20 years Daimler gradually has increased its output in vehicles from less than 500,000 per annum. This does not include its heavy duty vehicles, trucks or buses, where Daimler has significant market share. Daimler has introduced the Smart brand, has presented a number of FCEVs and is currently preparing the launch of Smart EVs. While it has always been seen as the bigger German premium automobile manufacturer, its sales numbers were overtaken few years ago by BMW. Its image is located around medium/large luxury and performance segment cars, a fact that is well reflected in the average fleet emissions (150 gCO₂/km in 2011). However, with its brands Smart and Car2Go it is penetrating the market of smaller vehicles as well.

Daimler was at the forefront of fuel cell research for automotive application. First trials had been executed with FC buses, but it was the change of the company's internal FC group from Dornier to the car section in the early 90's that allowed Daimler to develop a number of FC prototype and demonstrator vehicles. A few years later, in 1994 Daimler presented its first FC prototype

Necar I (New Electric Car I), but it was the Necar II that raised the profile for FC vehicles at those times. Since then Daimler has presented a variety of FC vehicles, including versions with methanol reformers or hybrid drive trains. The FCs were provided by Ballard, a Canadian company that had already provided FCs for trials with FC buses. In that domain, as well as in the segment of vans and trucks, Daimler undertook various demonstrator projects with FCEV. The collaboration with Ballard led to a purchase of a stake in Ballard by Daimler (together with Ford) in 1997, and to the total acquisition of the Ballard's automotive FC division in 2007. This means that Daimler has had significant know-how in the application of FC since the early 90's. Around the year 2000 there was high expectations with regards to the commercial launch of FCEVs. However, although Daimler announced in 1999 that there would be 100,000 FCEV in 2004, until 2013 the application of FCEV did not go beyond demonstrator programs or small series applications.

In 1994 Daimler took over Volkswagen's engagement in Nicolas G. Hayek's micro compact vehicle project that had the aim to provide a small city vehicle. The smart fortwo, a small two seater vehicle was brought to market in 1998. However, as Hayek's vision of a small and energy efficient vehicle that could be used for car sharing had not been satisfied by Daimler, Hayek decided to leave the joint venture and Daimler became sole owner of Smart. And although Daimler launched a number of vehicles under the Smart brand, such as a roadster, it only had generated losses. On the other hand the Smart brand led to a decrease in Daimler's average fleet emissions, down to around 180gCO₂/km in 2005 from 230gCO₂/km in 1995.

The year 2005 brought significant changes, not only for the Smart brand. In a time where the merger with Chrysler had not led to the expected results, where Smart was generating losses, as well as the whole automotive branch of Daimler, and in a time where Toyota presented the second generation of its successful Prius, Daimler changed its CEO and launched its CORE restructuring program. All Smart models but the fortwo were scrapped and nearly 10,000 workers laid off. But 2005/06 also brought changes in terms of efficient vehicle drive trains. While consumers were affected by rising petrol prices, Daimler introduced together with Volkswagen and GM its Bluetec Diesel branding, especially as an answer to the 2nd generation of the Prius HEV that received positive

coverage, especially in the US. A number of mild-hybrid vehicles were launched as well. However, the announcement that Daimler was collaborating with Zytek, a British powertrain and vehicle specialist in 2006 with the aim to retrofit and electrify 100 Smarts, that have been then tested in London, was even more significant. At the same time the car sharing scheme Car2Go had been launched using Smarts. Since then Daimler has build more than 2000 smart EVs that are being tested before the vehicle is expected to be brought to market in 2014.

While the first Smarts' electric drive trains had been provided by Zytek, the newest generations were using batteries, battery systems and motors from subsidiaries, that Daimler created in the late 2000's. Together with Evonik (specialist in chemicals) it formed joint ventures for batteries (Li-tec) and battery management systems (ACCUmotive) and with Bosch it formed a JV on electric motors (hubject GmbH). Before that, in 2009 Daimler bought stakes in TESLA that provided the batteries for the 2nd generation of electric smarts. To ensure economies of scale for the JVs with Evonik, the batteries were also offered to other OEMs such as Renault/Nissan. Furthermore, in the early 2010's Daimler has announced a collaboration with Toyota in the domain of FCs and collaborations with carbon and composite manufacturers.

With regard to the Mercedes brand, Daimler has slowly introduced hybrid drive trains. First in their sports car SLS (2008), then their premium vehicles S class (2009) and recently in their E class. Furthermore the A and B class with their sandwich floor have been used as basis for a number of BEV and FCEV trials. The B class is expected to reach the mass market in 2014. However, FCEVs are seen as the long-term solution.

4.4 Volkswagen

Volkswagen is the biggest of the German car manufacturers with more than 9 million cars sold per annum, a profit of more than € 4 billion and more than 500,000 employees (2012). The Volkswagen family includes brands such as Audi, Skoda, Seat and Porsche as well as Scania and MAN in the domain of heavy trucks. In comparison to BMW and Daimler, Volkswagen does offer a wider variety of smaller vehicles which is well reflected in its average fleet

emissions of 134gCO₂/km in 2012, which is in-line with EU limits. While the focus in the past years has been put on efficient diesel engines, Volkswagen has recently launched a number of Hybrid Audi vehicles and is preparing the introduction of BEVs in 2013/2014.

Although VW executed some trials on EVs, PHEVs and FC vehicles in the 1990s, its power train research was focussed on highly efficient combustion engines and especially diesel engines, as well as the use of bio fuels. While BMW and Daimler had presented their solutions for low emission transport, VW presented its Polo 3L with a fuel consumption of 3l/100km in 1998 which was followed in 2002 by the announcement of a 1 litre vehicle. However, those were soon scrapped due to low demands (same happened for Audi A2) before 2005. However, during that year, the success of the Prius and rising fuel prices lead to the creation of the collaborative brand Bluetec for Diesel combustion engine vehicles (together with Daimler and GM).

In 2007 VW collaborated with Porsche on hybrid drive trains, with Sanyo in Li-ion batteries and Continental for the delivery of hybrid drive trains. Towards the end of the 2000's VW launched a number of collaborations on batteries and power electronics including Panasonic, Li-tec (Evonik/Daimler), BYD and Toshiba. While VW introduced a number of PHEV SUVs after 2007, it also pursued the development of low emission engines. Its 1.4 litre TSI turbocharged engine has won the Best New Engine Award for 7 consecutive years since 2006. The micro vehicle Up! (similar to the Smart fortwo but a 4 seater) had been introduced in 2009. An electric version is expected in 2013/2014. Furthermore the 1 litre vehicle project has been re-launched again in 2007 leading to a number of prototypes, with the last one in 2013 (XL1 Super Efficient). In addition to that VW pursued the development of bio fuels and launched own production facilities in the early 2010's.

Volkswagen seems to be on track with its plan to become the biggest vehicle manufacturer. Furthermore it aims to decrease average fleet emissions to 120 gCO₂/km by 2015 and 95gCO₂/km by 2020. Like BMW it also has a stake in SGL Carbon, and recently VW has signed a deal with Ballard to deliver FC for HyMotion (\$56 million). Apart from this a wide introduction

of hybrid and battery electric vehicles is announced for the next years to come.

5 Findings

This section has the aim of outlining a number of patterns in the behaviour of the German automotive OEMs that has been derived from a brief analysis of the respective timelines. For that the timeline of the landscape has been put in relation to the timelines of the individual companies to find out what events lead to reactions in the automotive industry. Furthermore the observed changes, their extent and their consequences were taken into account as well as the characteristics of the company at a specific time. So, for example were the skills of the company at the point of a change relevant as well. As the sample is small the findings here in this section are of a qualitative nature.

The following hypotheses are proposed by this work based upon the analysis of the German automotive manufacturers since 1990:

- **Without significant external pressures OEMs do not pursue significant changes:** During the early 90's as well as in the early 2000's there had been no significant external pressures, leading to business as usual. Daimler focused on FCEV, VW on diesel engines and BMW on the hydrogen combustion engines. Only in the existence of pressures such as policies or customers perception due to rising fuel prices did OEMs review their technology choices.
- **Regulations and consumer pressure are main drivers for technology change while economic indicators not.** Regulations such as the Zero Emission Vehicle initiative in California and the European tailpipe CO₂ emission standards have led to intensified efforts in the automotive industries. The same effect could be observed when competitors' solutions received significant attention such as Daimler's Necar II, that led to hydrogen research at BMW, or the launch of the 2nd generation of the Toyota Prius HEV that led to a rethinking in the German automotive industry. Also does the customer response to rising fuel cost play a significant role. The temporarily increase in the demand for low emission vehicles around 2005 had lead to adjustments of technology portfolios. In contrast to that, did low sales or the perception of economic crisis not trigger changes in

technology strategies or did not lead to a decrease of R&D expenditures.

- **New solutions are created through combinations of available internal solutions:**

As expected, the automotive OEMs develop solutions that resolve the pressures from outside based on the knowledge available in house, i.e. they tend to focus on, and continue research in, what they are good at. As mentioned before Daimler focused on FCs, VW on diesel drive trains and BMW on the combustion of hydrogen. For example, when BMW presented its first hybrid concepts, the range extender was based upon a small fuel cell that had been used as Auxiliary Power Unit (APU) in the hydrogen combustion vehicles, while Daimler used the smart platform for the provision of small city EVs.

- **Even if the pressure is there, disruptive changes need to be triggered by disruptive (internal) events:**

Even if there is enough pressure from outside, only when a disruptive event occurs, OEMs tend to adjust their technology choices to resolve the pressures they are facing. BMW's project i that lead to the current focus on BEVs had been launched shortly after a new CEO had arrived. Daimler's disruptive restructuring of Smart towards a focus on the fortwo and electrification (something that Hayek had actually envisioned for Smart) as well as the move towards hybrid and electric vehicles, occurred shortly after the appointment of a new CEO. On the other hand the success of the Prius was also around this time.

- **Knowledge on disruptive or less familiar technologies is obtained from third parties:**

In the case where an OEM has decided to create a solution that is not covered by available knowledge, collaborations, joint ventures or acquisitions are undertaken. For its Smart EV, Daimler collaborated with a small British SME. VW collaborated with Porsche to introduce hybrid power trains into their own vehicles. And even in the case where no change was sought, it was Hayek that brought the concept of small compact vehicle to Daimler, that led to Daimler's entry into the car sharing business (Car2Go).

6 Conclusions

This paper has presented and analyzed the behaviour of the German automotive OEMs with regard to alternative power train technologies. For that it has put the automotive sector and its environment such as regulation or economic

development into relation with the technology choices individual automotive companies did. In brief analysis, this work proposes a number of hypotheses concerning the behaviour of OEMs. These are:

- Without significant external pressures OEMs do not change.
- Regulations and consumer pressure are main drivers for change while economic indicators not.
- New solutions are created through combinations of available internal solutions.
- Even if external pressures are there, disruptive changes need to be triggered by disruptive (internal) events.
- Knowledge on disruptive or less familiar technologies is obtained from third parties.

These are preliminary results that are proposed for discussion.

In the next step our work will concentrate on worldwide operating automotive OEMs to understand the differences in their behaviour as well as to determine whether similar patterns can be observed.

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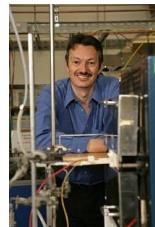
transport and policy making.

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Annex

Figure 1: Timeline of the automotive landscape (regulations, global disruptive development, etc since 1990)

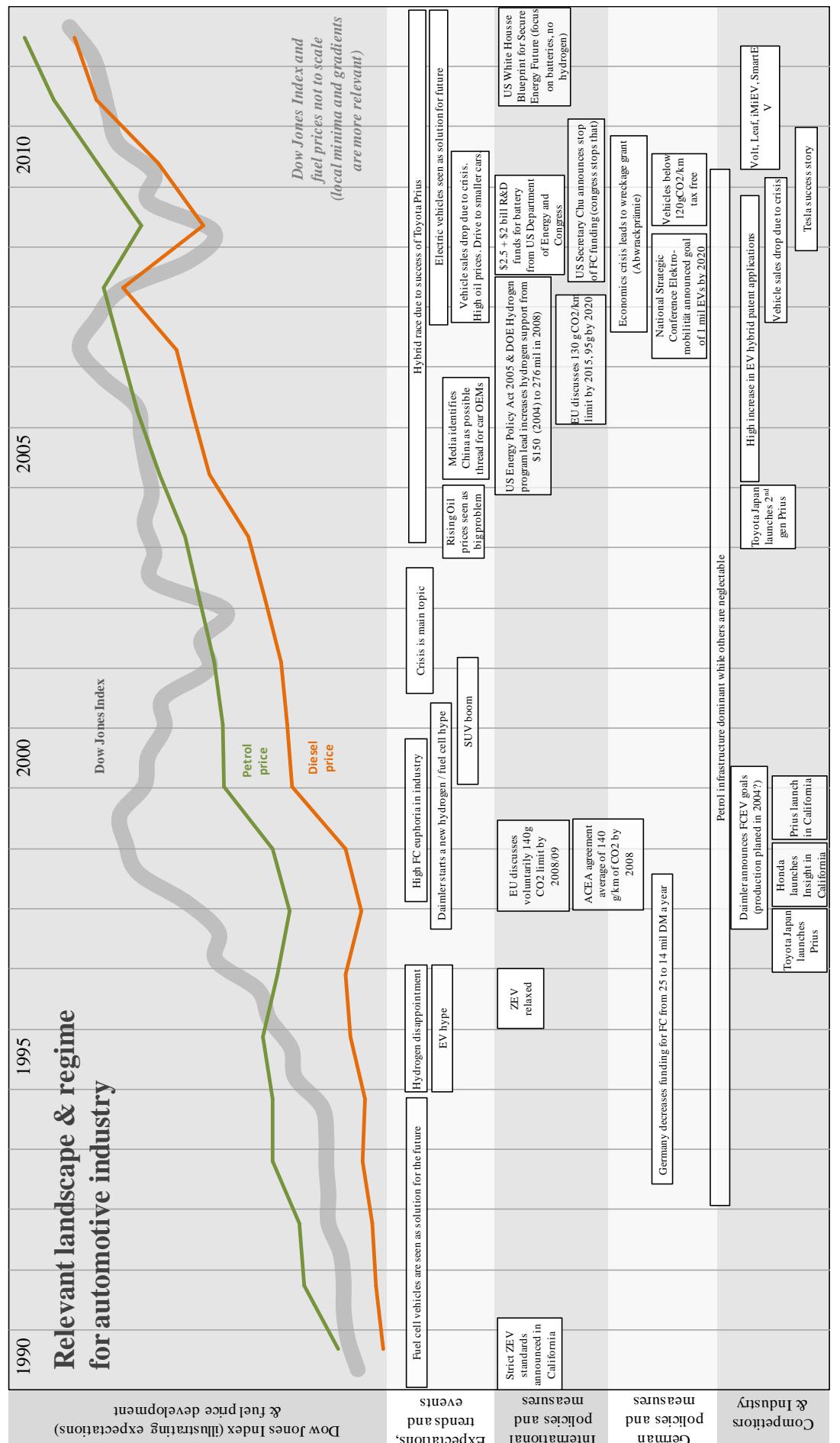


Figure 2: Timeline for BMW (technology focus, research, major developments, etc since 1990)

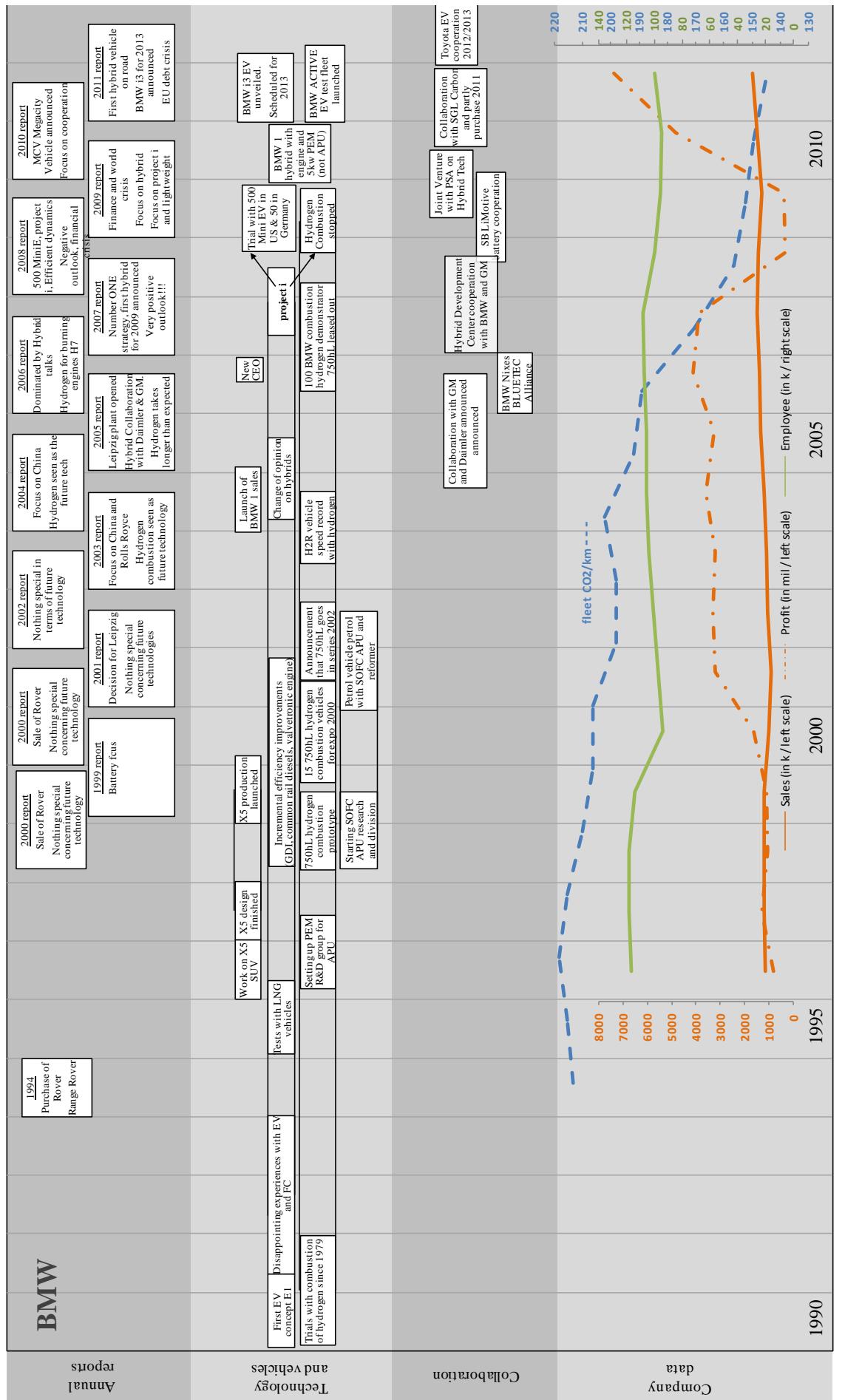


Figure 3: Timeline for Daimler (technology focus, research, major developments, etc since 1990)

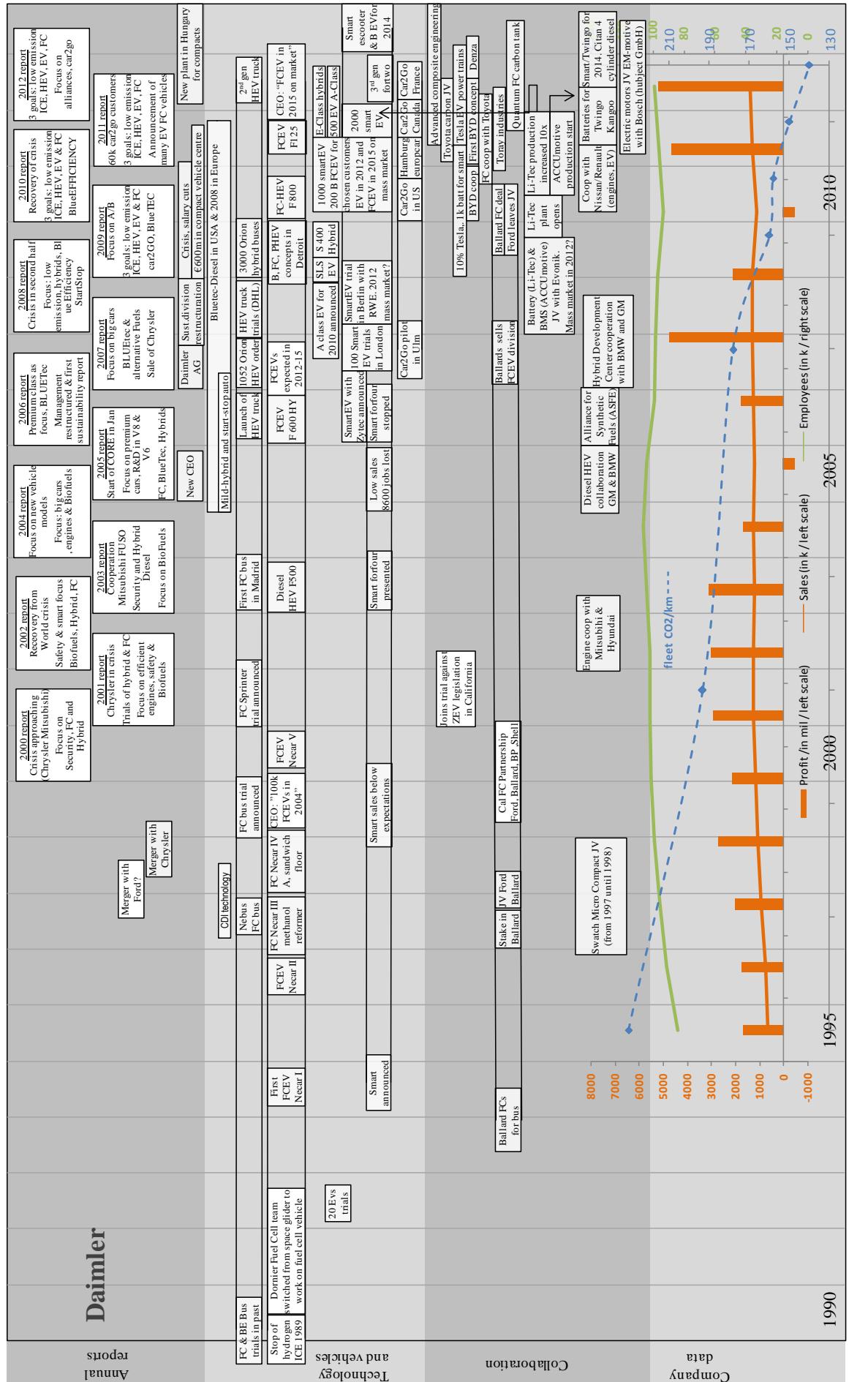


Figure 4: Timeline for Volkswagen (technology focus, research, major developments, etc since 1990)

