Master Thesis

Knowledge development in the Zero Emission Vehicle industry

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Abstract

This study researches the dynamics in knowledge development, knowledge distribution and knowledge transfer patterns among different types of organizations in the battery electric vehicle (BEV) industry and the fuel cell vehicle (FCV) industry during the period 1990-2010. Using patent citation data, license data and component supply contract data we conclude that entry in the FCV industry becomes increasingly difficult in time, while entry and obtaining a first-mover advantage in the BEV industry might still be possible. Furthermore we see that small incumbents and outsiders are catching up in terms of knowledge development in the BEV industry because large incumbents have fallen behind in BEV knowledge development, as they placed their bet on FCV knowledge development. Furthermore, we see a shift to more open models of innovation in the BEV industry. We also found that acquiring licenses and buying components is not straightforward and in many cases depends on agreements for bilateral knowledge transfers. In addition, it seems that licenses are strategically used by incumbent firms.

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1. Introduction

In the last decades, environmental issues have become more evident and environmental challenges have started reaching the top of many political agendas (Pralle, 2009). With respect to the environmental challenges the transportation sector remains a huge problem. In the US, the transportation sector was responsible for over 33% of energy-related carbon dioxide emissions between 1990 and 2008 (U.S. Energy Information Administration, December 8th, 2009). Based on these figures, there are huge opportunities for decarbonising the road transportation sector. In order to decarbonise the road transportation sector, new technologies and fuel chains are needed, for example electricity and hydrogen (Flachsland et al., 2011). The need for these technologies creates opportunities for zero-emission vehicle (ZEV) manufacturers. Currently the most promising technologies for ZEVs are the battery electric vehicle (BEV) and fuel cell vehicle (FCV) (Flachsland et al., 2011). The FCV and BEV are in this research defined as ZEV[1]. These vehicles are needed for a sustainable transition of the road transportation system.

The new fuel technologies induce a need for radical innovation, because the new technologies force manufacturers to draw on new (technical) knowledge[2], capabilities and (commercial) skills, instead of reinforcing their established ones. Based on the need for new knowledge, ZEV manufacturers can be classified as high-tech, as Solberg et al. (2008) state that high-tech industries mostly have a strong focus on intellectual capital. Also from an industry point of view ZEVs are high-tech. Manufacturers are for example building specialized production plants, while internal combustion engine propelled vehicles (ICE) often share production lines with only slight adjustments (Camuffo & Volpato, 1996; Paine, 2011). Frenken et al. (2004) and Oltra & Saint Jean (2009) furthermore noticed an increase in patents for FCVs and BEVs, confirming the importance of intellectual capital for ZEV manufacturers. In conclusion, firms that are developing ZEVs need a lot of intellectual capital, but how do they acquire this?

Manufacturers have various possibilities to obtain knowledge. Knowledge acquisition and transfer can be discussed in the light of the transaction cost approach. This approach discusses transactions that come in various forms (Williamson, 1981). The transaction cost approach makes a trade-off between making and buying, and discusses what option a firm should choose. Also knowledge can be one of these transactions, where making can be translated as internal knowledge development and buying as external knowledge acquisition and transfer via market transactions. This distinction is rather limited, as various intermediary forms of (knowledge) acquisition exist like research collaborations in various forms. In order to identify these intermediary transaction forms, within this study three other literature strands, that fit in the transaction cost framework are addressed. From unilateral knowledge acquisition via bilateral knowledge acquisition to multilateral knowledge acquisition, dominated by external knowledge acquisition and transfer, these are addressed by the Resource Based View, Resource Dependence view and Open Innovation approach (Chesbrough, 2005; Mahoney & Pandian, 1992; Pfeffer & Salancik, 1978). The unilateral knowledge acquisition approach focuses on the internal organization and expects firms to develop and adapt their resources and capabilities (including knowledge) internally by accessing external complementary

[1] The most promising technologies FCV and BEV are studied in this research, (plug-in) hybrid vehicles are excluded due to the fact that they are equipped with an internal combustion engine and thus are not emission-free.

[2] The terms knowledge and intellectual capital are used interchangeably.

resources (Mahoney & Pandian, 1992; Teece et al., 1997). The multilateral knowledge acquisition approach, open innovation, focuses on the environment and adds that firms should to a larger extent look outside their boundaries for knowledge if they do not own it (Chesbrough, 2005). Furthermore, a central aspect within this theory is that *"…intellectual property represents a new class of assets that can deliver additional revenues…"* (Chesbrough, 2005 p.5), as firms should also profit from others' use of their intellectual property (Chesbrough, 2011). Furthermore, most industrial firms are used to exploit technological knowledge and apply it exclusively to their own products (Lichtenthaler & Ernst, 2012). In addition, due to an increasing innovation and cost pressure – consumers increasingly want more for less - manufacturers also look outside their organizational boundaries for complementary knowledge (Ili et al., 2010). This indicates that 'multilateral knowledge transfer' and collaborations are becoming more likely and are also important for developing radical innovations in the high-tech ZEV industry. Access to external knowledge is thus important, but what possibilities does a firm have to access external knowledge?

Besides internal knowledge development, there are various possibilities to access external knowledge, of which licensing is a prominent one (Lichtenthaler & Ernst, 2012). According to Lichtenthaler & Ernst (2012) and Arora & Ceccagnoli (2006) there is an increase visible in active technology licensing in many industries. It is therefore likely that this also applies to the ZEV industry. Also the acquisition of components, and with it knowledge, is a possibility. Data on licenses and data on component supply agreements are therefore used as indicators for examining knowledge development and transfer patterns within the ZEV industry. Furthermore patent citation data is used as an indicator for internal knowledge development and its quality. Pilkington & Dyerson (2006) and Pilkington et al. (2002) use patent citation data in order to study the development of ZEVs. However, they only study the interactions between different types of organizations within an outdated (up to 2002) and limited (268 patents) sample and do not exclude hybrid electric vehicles. The first study (Pilkington & Dyerson, 2006) does only use citations to identify key patents. In order to contribute to these limitations of the literature, this study maps the knowledge network between different types of organizations (incumbent firms, new entrants and public research organizations) and studies how it changes over time. By mapping the knowledge network it also becomes clear what types of knowledge development/acquisition strategies different types of organizations choose. Furthermore, it shows what types of organizations own important knowledge and play a central role in the network. The ZEV industry its knowledge network and knowledge transfers are studied for the years 1990 – 2010. The first year of observation is chosen to be 1990 because in the beginning of the 90s the California Air Resources Board law became active, forcing manufacturers to produce cleaner cars and spurring the development of ZEVs. The end year is the last full year of observation with patent data available, ensuring up to date results.

In order to uncover the knowledge network it is important to distinguish between different types of organizations. Within the ZEV industry, there are various types of organizations with different interests and strategies. We distinguish amongst other types, incumbent firms, new entrant firms, outsiders and public research organizations (PROs)[3]. Incumbent firms already receive rents from existing products and already serve customers. Therefore they might not directly have the willingness, need and possibility to introduce radical innovations (Chandy & Tellis, 2000). New

[3] E.g. universities and public research institutes such as the Dutch TNO. The term public is used in order to indicate that these organizations are publicly funded.

entrants on the other hand are more dependent on the success of the innovation. Furthermore, new entrants are in general better in doing research while incumbents are better in the exploitation of innovations (Teece, 1986). Within the types of organizations, several roles can be identified, such as car assemblers (CAs), and suppliers (Geuna & Nesta, 2006; Lee & Veloso, 2008). Each type of organization is expected to base its strategy on its strengths and weaknesses. In order to identify what types of organizations are engaged in the development of the ZEV, this study distinguishes the different types of organizations involved in ZEV knowledge development and transfer.

Accordingly, the following research questions are formulated for the ZEV industry:

RQ1: *What dynamics in knowledge development can be identified in the ZEV industry during the period 1990-2010?*

RQ2: *How is knowledge distributed among the ZEV participants during the period 1990-2010?*

RQ3: *What knowledge transfer patterns can be distinguished between different types of organizations during the period 1990-2010?*

Since this study shows which types of organizations develop knowledge and transfer knowledge, this study indicates what types of organizations need to be stimulated in order to accelerate knowledge production in the ZEV industry. Furthermore, this study gives an overview of the most innovative types of organizations. Answering the research questions therefore offers benefits for firms, as they can adjust their strategies based on the innovativeness and position of their competitors. Since this study does compare two technologies (BEV and FCV), it becomes clear on which technology a firm can best bet.

This thesis is organized as follows: the next section (section 2) discusses the theoretical implications of the discussed problem. Section 3 discusses ZEV industry specific theory and section 4 describes the method of analyses to be applied in this study in order to answer the research questions. Section 5 discusses the results and is followed by the conclusions and discussion (section 6).

2. Theoretical framework

In this section, the literature on the development and transfer of resources is discussed with an emphasis on knowledge as a resource. Knowledge is an important resource in gaining a competitive advantage and can therefore be related to the innovation strategy of firms. Subsequently, the possibilities of knowledge development and transfer, as well as the possible innovation strategies of firms are discussed for different types of organizations in the ZEV network. The resulting theoretical findings are translated into hypotheses.

2.1. Knowledge as a resource within transaction cost economics

There are several streams of literature that deal with the development and acquisition of resources. Three prominent streams are the resource-based view (RBV), the resource dependence view (RDV) and open innovation (OI). Within these theories knowledge is seen as a resource. Important is that knowledge is not homogeneously, but heterogeneously distributed over firms meaning that different firms own different knowledge assets (Mahoney & Pandian, 1992; Teece et al., 1997). It is therefore likely that the organizations involved in radical innovation have a strong need for knowledge, but that they do not own all needed knowledge. All three theoretical approaches of external knowledge acquisition can be placed in the transaction cost economics framework (TCE). TCE regards transactions as the basic unit of analysis for the study of organizations (Williamson, 1981) and it defines a transaction as a good or service that is transferred across a technologically separable border (Williamson, 1981). In this respect, knowledge acquisitions and transfers can be seen as transactions. A central aspect of TCE is the make or buy decision. This decision depends on the involved transaction costs and advantages (e.g. enjoying economies of scale when buying) and disadvantages (e.g. leakage of information when buying) of a transaction. Williamson (1981) argues that if assets become more specific, transactions will have a stronger bilateral character. This indicates that TCE is applicable, both in the case of bilateral knowledge transfers as well as for unilateral acquisitions. When using TCE for analyzing knowledge transactions it is not specific enough and it does only to a limited extend view the intermediary possibilities between 'make' and 'buy'. Therefore, the RBV, RDV and OI are integrated in the TCE framework between the 'make' and 'buy' decision. The integration in the TCE framework is displayed in Figure 1. All three theories deal with the development and the acquisition of resources (and thus knowledge) in another way and are discussed next.

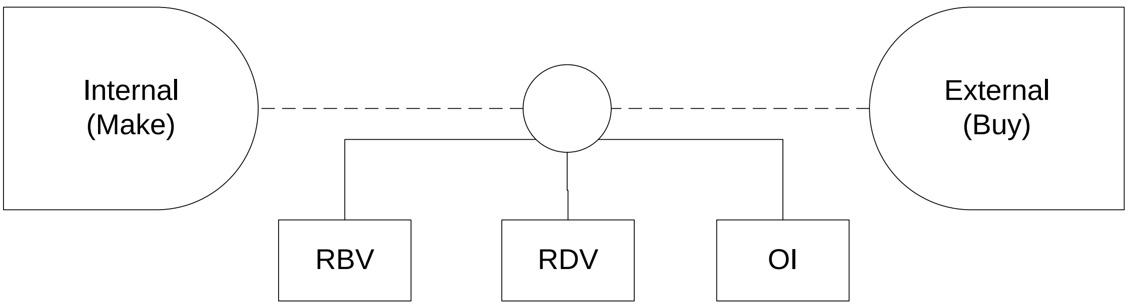


Figure 1 RBV, RDV and OI within the TCE

2.1.1. The resource-based view

The 'resource-based view' emphasizes diversification through firm-specific (rent-generating) resources (e.g. capabilities and assets) and the existence of isolating mechanisms (e.g. entry barriers) as the fundamental determinants of firm performance (Mahoney & Pandian, 1992). From a 'resource-based perspective', knowledge can be seen as an important resource of a firm. Firm specific resources such as knowledge are important in order to create rents and to sustain a competitive advantage (Mahoney & Pandian, 1992; Teece, 1986; Teece et al., 1997). Important for a competitive advantage is that the resources should be difficult to imitate, valuable, unique and non-substitutable (Teece, 1986). The RBV mainly focuses on the firm level and argues the importance of accessing needed complementary resources. A shortcoming is that it neglects the environment.

2.1.2. The resource dependence view

The RDV can be seen as an extension of the RBV (Rijnsoever et al., 2012). The RDV broadens the focus of the RBV as it focuses on the firm and its environment. The RDV argues the importance of acquiring and maintaining resources for firm survival (Pfeffer & Salancik, 1978). A central aspect in the RDV is that organizations are dependent on bilateral transactions with other participants in their environment in order to acquire needed resources (Pfeffer & Salancik, 1978).

2.1.3. Open innovation

OI incorporates both the acquisition of knowledge for internal exploitation and the external exploitation of knowledge (Torkkeli et al., 2009). Furthermore, OI goes a step further compared to the RDV and sees research and development as an open system (Chesbrough, 2005). OI discusses the acceleration of innovation by purposively using knowledge from inside and outside the firm (Chesbrough, 2005). Generating additional value by bringing internal ideas (knowledge) of the firm to the market is another pillar of OI (Chesbrough, 2005). This pillar even extents the TCE approach as the TCE approach stops at buying in. In short, OI is much more focused on getting value from knowledge in all possible ways compared to the other models and considers the entire environment to do so.

2.2. Degree of internal knowledge development

Depending on the degree of internal knowledge development firms choose different ways to develop and acquire their knowledge. Firms that develop their knowledge internally, mainly develop the knowledge themselves, while firms that rely on knowledge developed externally mainly acquire/transfer knowledge from their environment. Note that these are two extremes, and it is expected that often combinations of internal development and external acquisition/transfer can be found.

2.3. Innovation strategy

Depending on the degree of internal knowledge development, firms seek for, and acquire external knowledge. In the most internal form of knowledge development, firms are the least dependent on their environment and this enables them to bring their product unexpectedly and fast to the market, giving them a first-mover advantage. In order to obtain this first-mover advantage, firms need to be technological leaders: own important patents or knowledge (Lieberman & Montgomery, 1987). Furthermore, being a first mover indicates that a firm has confidence in a technology (Bakker, 2011). Besides becoming a first-mover, firms have more options for their strategy when it comes to introducing new technologies to the market; more importantly, the possibilities of knowledge development that go with it. Besides first-movers, firms can also be fast followers or late followers (Sung & Ho, 2010). Fast followers respond to the actions of the first movers, while late followers can be seen as imitators that enter a path when the first-movers proved it as feasible (Bakker, 2011).

Lieberman & Montgomery (1987) argue that imitators (late followers) can imitate patented innovations, only at about 65% of the innovators cost, imposing a 'free-rider' threat to the innovator. In short, there exists a prominent risk that competing firms seek ways to circumvent patents of an innovator. The new patents of the imitator (late follower) then build to a large extend upon the knowledge of the original innovator. Furthermore, innovation mainly is a cumulative activity (Dosi, 1988); therefore, firms will build upon existing technologies and knowledge if they are available.

When a firm chooses an external form of knowledge development, it is no longer possible to speak of a first-mover. These firms need to acquire knowledge from their environment. This does not mean that firms are fully dependent on their environment, they can also choose to develop part of their knowledge internally and acquire another part from others external to their own firm (Torkkeli et al., 2009). Depending on the type of organization in the industry, knowledge development patterns will differ. Therefore, different types of organizations are introduced and discussed in the context of their strengths and weaknesses in knowledge development, knowledge acquisition and knowledge transfer.

2.4. Types of organizations

Within the ZEV industry, different types of organizations all have their own incentives, advantages and disadvantages with respect to knowledge development, acquisition and transfer. Below an overview of the in general active types of organizations is given.

2.4.1. Incumbent firms[4] versus New Entrants

Incumbent firms are established firms that already have their own product portfolios. A difficulty for the incumbent firms is that they receive rents from existing products and that they already serve a group of customers. Chandy & Tellis (2000) call these constraining factors perceived incentives, organizational filters and organizational routines. Incumbents do therefore not directly have the willingness, need and possibility to introduce radical innovations (Chandy & Tellis, 2000; Lieberman & Montgomery, 1987). Cans & Stern (2000) furthermore state that incumbents have a strategic incentive to develop a R&D capability and that they are able to do more intensive research compared to new entrants. In addition, R&D becomes more and more expensive and the pressure on product prices is high (Ili et al., 2010). This problem means that internal knowledge development is becoming increasingly more expensive and therefore less affordable for smaller firms compared to larger firms (assuming that larger firms have more financial resources). Interesting here is that the automotive industry is primarily dominated by large incumbent firms (Klepper, 2007). It is thus likely that these large incumbents have the possibility to choose for a more internal approach of knowledge development due to their firm size and financial resources. A more external approach of knowledge development is likely for new entrants, based on cost and risk sharing as motives (Ili et al., 2010; Mowery et al., 1996).

H1: Large incumbent firms adopt a more internal approach for knowledge development compared to new entrants.

These new entrants are firms new to the industry. New entrants are more flexible in new markets compared to incumbents who have to transform their technology portfolio radically (in this research: the transformation from internal combustion engine vehicles (ICEVs) to ZEVs) (Leten et al., 2010). For

[4] The terms incumbent firms and incumbents are used interchangeably.

incumbents, radical innovation can have competence destroying consequences (e.g. in R&D) (Leten et al., 2010), while new entrants do not face this problem. This flexibility of new entrants is mainly expressed in the exploration phase (research), while incumbents are better in commercializing. This can be explained by, amongst others, complementary assets that are already owned by incumbents (Teece, 1986), like production facilities, distribution channels and customer relations/market knowledge. These resources are important in order to commercialize an innovation and are in general exclusively available to incumbents (Colombo et al., 2006). Despite the lack of complementary assets, new entrants have the advantage of no existing products and customers, what makes radical innovation more easily for new entrants compared to incumbent firms. New entrants can thus be a threat to inert incumbent firms. In terms of knowledge transfer firms have different options. They can opt for an open (external) approach such as two-way exchange of knowledge, or restricted approaches where knowledge only flows one way, or where knowledge transfers are strategically used. Due to incumbent inertia and an expected internal approach of knowledge development, it is expected that the incumbent firms will carefully handle their knowledge to protect it from leaking to other firms. This means that incumbents, in the case of acquisition and transfer of knowledge, choose for restrictive approaches of knowledge acquisition and transfer. The associated reason for this behavior is that incumbents are slowing down the development of the radical innovation by resisting it and with resisting it protect their existing product portfolios (Chandy & Tellis, 2000). It is thus possible that incumbents do not want to sell the radical innovation or foster the development of its underlying knowledge, but that they, as Van den Hoed (2005) calls it – are 'window dressing' or - as Johnson (1999) calls it – are doing no more than 'changing their image in the minds of consumers'? Due to the more external knowledge development approach, which is expected for the new entrants, new entrants are more likely to engage in open knowledge exchange approaches.

H2a: Incumbent firms will choose for a restrictive approach of knowledge exchange.

H2b: New entrants will choose for more open forms of knowledge exchange.

2.4.2. Outsiders

Outsiders are firms that are not active in the automotive industry, but established in other industries. These firms can have relevant and/or key knowledge and technologies for the development of a radical innovation. They may have important knowledge on components, or they may supply components. In short, if a firms' core business is not the automotive industry, but the firm does own unique knowledge, the firms' best option is to sell/transfer the knowledge (Teece, 1986). Teece (1986) described this problem using the case of the EMI cat scanner. EMI was not able to grab the profits of the innovation, simply because they came from outside the market and lacked the complementary assets. For outsiders an open approach on knowledge exchange is thus most likely.

H2c: Outsiders will choose for open forms of knowledge exchange.

2.4.3. Public research organizations

Public Research Organizations (PROs) do research that might be relevant for organizations engaged in ZEV development. PROs absorb and accumulate knowledge, and through their own research they generate new knowledge. They diffuse knowledge in various ways (Fritsch & Schwirten, 1999). PROs like universities have always had an emphasis on publishing research (Geuna & Nesta, 2006). Despite this emphasis on publishing, universities have started patenting in the course of time (Adam B, 2000), and with it commercializing their knowledge. Given that the PROs are to commercialize their knowledge, an open approach on knowledge exchange is most likely.

H2d: PROs will choose for open forms of knowledge exchange.

2.5. BEV vs FCV

In this study, knowledge development in the ZEV industry is studied. Within the ZEV industry, there are two radical vehicle types, the BEV and the FCV. Due to different theoretical implications for both of these two vehicle types, it is important to separate them theoretically. A difference between the BEV and FCV is expressed in the degree of uncertainty of the innovation. A BEV consists of electrical components that often exist on the market[5], while FCVs often rely on specially developed powertrains. Therefore, a FCV could be perceived as a more radical innovation compared to a BEV. Furthermore, Wesseling et al. (forthcoming: 2012) found that the big 15 incumbents have a large share of FCV patents, indicating their dominance on FCV knowledge. In addition, when looking at the 30 most contributing firms, most BEV patents come from outside the automotive industry (Wesseling et al., Forthcoming 2012). This indicates lower entry barriers for firms in the BEV industry compared to firms in the FCV industry. It is therefore obvious that more new entrants are expected in the BEV industry compared to the FCV industry.

Furthermore, due to the less radical nature of the BEV industry it is possible that components are an important and accessible source of knowledge (firms can assemble a car by combining components). Especially for laggards (firms with little innovative knowledge and a late entry timing) simply buying components can be important in order to build their ZEVs and to acquire knowledge. Accordingly, the following hypotheses can be formulated:

H3a: There are more new entrants active in the BEV industry compared to the FCV industry.

H3b: Acquisition of components is a more important source of knowledge in the BEV industry than in the FCV industry.

The theory as presented in this section is mainly a general theory and the specific ZEV industry aspects are elaborated in section 3. The hypotheses specified in this section will be operationalized as discussed in section 4 and empirically tested as discussed in section 5. Finally, the conclusions and discussion are presented in section 6.

[5] E.g. laptop battery technology and normal a/c and d/c motor technology can be converted for use in BEVs.

3. Background: The Zero Emission Vehicle industry

In this study, knowledge development in the ZEV industry is studied. In order to do so, knowledge development, knowledge transfers and knowledge acquisitions within the ZEV participant network are mapped. This section briefly discusses the ZEV industry.

The development of ZEVs is partly encouraged by environmental government policies. One of the most important laws was already established in the 1990s, by the California Air Resources Board (CARB). The CARB forced car manufacturers to introduce zero emission vehicles through the Zero Emission Vehicle mandate (Shaheen et al., 2004). This mandate became less strict over the years and in the end allowed manufacturers to produce internal combustion engine vehicles (ICEVs) with extremely low emissions (Shaheen et al., 2004). Several manufacturers have build demonstration models or limited available ZEVs. In spite of these efforts the ZEV never became a success (Johnson, 1999). Today, ZEVs are making their comeback. Although ZEV sales are still low compared to ICEV sales, there is much movement in the field of electric driving. Firm websites of well-known manufacturers such as GM, Renault, Peugeot, Ford, Toyota, Mitsubishi and Nissan and new entrants such as Tesla show that they have the radical vehicles available for sale. Many other firms such as Audi, Skoda and VW indicate to follow in the coming two years. Of today’s vehicles, the battery electric vehicle (BEV) and fuel cell vehicle (FCV) are the only 100% emission-free vehicles. Therefore, these two vehicle types are considered as the most radical innovations, and developments in the field of these vehicles are studied. Both vehicle types are driven by an electric engine. The main difference between both vehicle types is the way energy is stored, a FCV is equipped with a fuel cell to convert fuel (usually hydrogen) into electricity and a BEV stores electricity in a battery.

3.1. ZEV industry organizations

Within the ZEV industry, different types of organizations are observed (Incumbents, New Entrants, Outsiders and PROs). These organizations can be classified as discussed in section 2.4. Table 1 gives an overview of the different types of organizations. Within the ZEV organizations several roles are identified (Car Assemblers and Suppliers). These roles are found among Incumbents, New Entrants and Outsiders. Only no further roles are discussed for the PROs, as the PROs do have completely different characteristics. (e.g. publicly funded, not commercializing products besides knowledge).

These different types of organizations are used in the subsequent section in order to identify knowledge transfer and knowledge acquisition patterns. In addition, the different roles are discussed subsequently.

Table 1 Classification of different organizations

Incumbents	**New Entrants**	**Outsiders**	**Public Research Organizations**
Car Assemblers Suppliers	Car Assemblers Suppliers	Car Assemblers Suppliers	

3.1.1.1. Car Assemblers

Car Assemblers (CAs) are in this study considered to be firms that sell cars as complete products to end-users (through their distribution and dealer networks)[6].

3.1.1.2. Suppliers

Within this research only 1st tier suppliers are considered, as they, in terms of relationship, are the closest with the CAs and thus mostly are active in the automotive industry. These 1st tier suppliers, directly supply the CAs with their major components and are responsible for the management of 2nd tier suppliers, who deliver the parts for the 1st tier suppliers' components[7]. Suppliers are mainly doing component innovation, while CAs are mainly active in architectural innovation (Lee & Veloso, 2008). To be competitive, research has demonstrated the importance of an overlapping knowledgebase of component and architectural knowledge (Lee & Veloso, 2008). Firms (both assemblers and suppliers) are therefore expected to collaborate in order to complement their own resources (Lee & Veloso, 2008). Important here is that suppliers do have a limited knowledge base regarding architectural innovation, and CAs do have a limited knowledge base regarding component innovation, while both expand their knowledge bases in uncertain times (Lee & Veloso, 2008).

[6] Think of CAs such as the incumbent firms: Renault, Nissan and Honda.

[7] A 1st tier supplier for example sells a battery as a complete component ready to assemble in a car. A 2nd tier supplier delivers the necessary parts in order to build a battery.

4. Methodology

This study is based on a longitudinal research design. During the data collection, data is sorted in different time cohorts to identify possible trends between different groups. Within the data, a distinction is made between the two competing technologies, the BEV and FCV. The distinction between these technologies gives a comparative edge to the research design. Both qualitative data and quantitative data are used to test the hypotheses. This section provides an overview of the corresponding indicators and measures that are used to test the hypotheses and that are used to describe developments over time. For this study the following data sources are used as indicators:

- Quantitative
    - Patent data and patent citation data (for testing hypotheses 1 and 3a)
- Qualitative
    - License data (for testing hypotheses 2a+b+c+d)
    - Component supply contract data (for testing hypothesis 3b)

By combining these three data sources, the strategies on knowledge development, acquisition and exchange can be determined.

Patent citation data is mainly used to determine the degree of internal knowledge development and the innovation strategy. A patent citation also indicates a knowledge transfer, as a new patent builds on the knowledge of the cited patent. Patent citations do also give an indication of the nature of innovation, which can be radical or incremental. Within this study, patent citations are mainly used to identify the key (high quality) patents and therefore citing patents are not examined. License data and component supply contract data are used to determine (external) knowledge transfer and acquisition. Component supply contracts indicate the most extreme possibility for knowledge transfer and acquisition, as it largely eliminates the need for internal knowledge development. Licenses indicate specific knowledge transfers and acquisitions. Although a license can be broad, it is more obvious that firms only obtain a license if they lack specific knowledge themselves. Internal knowledge development will therefore play a more important role in the case of licensing, compared to component supply contracts. These indicators are further elaborated in the following paragraphs and are summarized in Table 2.

Table 2 Indicators and their degree of knowledge integration

Indicator	Degree of internal knowledge development	Type of knowledge development
Patent citations	High	Internal development
Licenses	Medium	Specific knowledge acquisition
Component supply	Low	Integrated knowledge acquisition

4.1. Patent (citation) data

Patent databases are used in order to find all relevant patent entries for ZEVs. The used patent database is PATSTAT of the European Patent Office (EPO). The PATSTAT database contains all data on patent applications of European and international applicants. In order to find the relevant patents, a key-word based search query is used. The key-word based search query is based on title and abstract, and the results for the BEV and FCV are separated. The following search queries are used[8]:

For BEVs:
WORD = (((electric* +2W (vehicle OR car OR automobile)) OR (battery +2W (vehicle OR car OR automobile)))ANDNOT (hybrid OR "fuel cell" OR "fuel cells" OR "internal combustion engine" or hydrogen or H2)) AND PRD [01-01-1990, 31-12-2010] AND APC = "EP"

For FCVs:
WORD = (("fuel cell" +2W (vehicle OR car OR automobile)) OR ("fuel cells" +2W (vehicle OR car OR automobile))) ANDNOT ("internal combustion" OR engine OR hybrid OR gasoline or petrol or diesel or ethanol OR (battery +2W (vehicle OR car OR automobile)) OR (electric* +2W (vehicle OR car OR automobile) ANDNOT "fuel cell*" /5W (vehicle OR car OR automobile))) AND PRD [01-01-1990, 31-12-2010] AND APC = "EP"

Application entries between 1990 and 2010 are included in the analysis. The start in 1990 is based on the US legislation that started to encourage low emission vehicles from the 90s (CARB). The end year is 2010, as including 2011 and 2012 might bias the results as 2012 has not yet ended and it often takes more than 18 months for a patent to be published. A disadvantage of a recent end year is that newer patents almost have had no chance of being cited. In order to circumvent this issue, the sample is corrected for the average number of citations a patent receives per year. Furthermore, although all entries are analyzed, the data is treated as a sample as it is likely that the queries do not return all relevant patent entries. The results are scanned for irrelevant patents using firm names and patent titles (for example electric toy cars are excluded). Furthermore, the sample is limited to applications at the EPO. Entries for national patents, and thus also USPTO patents are excluded. This choice is based on the fact that important knowledge will be at least patented throughout Europe. A national patent application only, would indicate that the patented knowledge is of less importance. Including USPTO patents would thus bias the results, as USPTO patents were until recently only published if they were granted, not when the application was filed (this can cause a delay of over 5 years for publication, as it sometimes takes that amount of time before a patent is granted) (Stoop, 2012).

4.1.1. Patent (citation) data

In this study patent citations are used as a proxy to map the patent quality and importance of patents of the involved types of organizations in ZEV development. Patent citations are often used to determine the value of patents (Bessen, 2008; Hall et al., 2005; Lampe, 2012). Pilkington et al. (2002) and Pilkington & Dyerson (2006) use patent citations as indicator of technological development and to determine key patents in the BEV industry respectively. Pilkington et al. (2002) also used patent citations in order to map the relationships between a limited sample of citing firms and key patents in the BEV industry. However, only citations that were added by the applicants themselves were analyzed. In order to analyze the differences in knowledge development between the involved organizations as completely as possible it is important that all citations (also those added by the patent examiners) are included, as former research suggests that applicants do not always cite all prior patents for strategic reasons (Lampe, 2012).

[8] These search queries are Global patent index (GPI) search queries, the publication numbers found using the GPI are exported and used in PATSTAT.

Patent citations can be added by the patent applicant on the patent application form. The patent examiners will add the other relevant patent citations which the applicant has concealed or was not aware of. There is more than one reason why patents are cited. Patents can be cited whenever a new application builds on it. Patents can also be cited when the new patent uses the technology from an older patent for a new application[9]. Patents which are better than previous patents can also cite the foregoing, even when they do not infringe the foregoing. Furthermore, there is a difference between the patent and its actual application. If a firm owns a patent this does not mean that the firm owns the right to exploit the patent, as the patent can build on knowledge from other patents where the aforementioned firm does not have the intellectual property rights to (Dorr, 2012).

A disadvantage of using patent citations in order to determine the value of patents is that the relationship between citations and actual value is not easily quantifiable (Bessen, 2008). Furthermore, the ratio between value and number of citations differs per technology class (Lampe, 2012). It is more likely that patent citations are a more reliable indicator of the importance and value of the underlying technologies than of the value of the patent itself (Bessen, 2008). In spite of these disadvantages, the use of patent citations as indicator is a relatively reliable approach in this study, as this study does not use patent citations in order to determine the value of patents, but uses patent citations to study the knowledge development of the underlying technologies.

By mapping cited patents, it is possible to identify the first mover firms that tap into new knowledge fields. A first-mover is seen as a firm that owns important (internally developed) knowledge. To identify which types of organizations (e.g. incumbents, new entrants, outsiders or PROs) own this knowledge, a comparison of the proportion cited patents is made for the different types of organizations. Furthermore a comparison is made of the mean number of citations a cited patent receives for the different firm types.

The proportion cited patents of the different types of organizations are compared using Equation 1. Equation 1 is based on the null hypothesis (H0) that there are no significant differences in the proportion cited patents between two groups. The alternative hypothesis (Ha) implies that there are significant differences in the proportion cited patents. Based on the group data, first the Pooled sample proportion (p) is computed, needed to compute the Standard error (SE) of the sampling distribution. Using these values, the t-score can be computed, and by means of the normal distribution (two-tailed) converted into a P-value (see table V, Wonnacott & Wonnacott, 1990). The P-value is the probability that the null hypothesis is wrongly rejected, and makes it possible to interpret the t-score. In this study a 0.10 level of significance is used, due to the small sample size. A P-value lower than 0.10 is taken to reject the null hypothesis and to accept the alternative hypothesis, implying that a significant difference in the proportion cited patents between two groups is confirmed.

[9] For example the application of a laptop battery in a car.

$p=(p_1*n_1+p_2*n_2)/(n_1+n_2-2)$ $SE=\sqrt{\{p*(1-p)*(n_1+n_2-2)\}}$ $t=(p_1-p_2)/SE$ $d.f.=(n_1+n_2-2)$ *With the following hypotheses:* H0:P1=P2 Ha:P1≠P2	$t=(\overline{X}_1-\overline{X}_2)/\{S_p*\sqrt{[(1/n_1)+(1/n_2)]}\}$ $S^2_p=\{\sum(X_1-\overline{X}_1)^2+\sum(X_2-\overline{X}_2)^2\}/(n_1+n_2-2)$ $d.f.=(n_1+n_2-2)$ *With the following hypotheses:* H0: $\overline{X}_1=\overline{X}_2$ Ha: $\overline{X}_1\neq\overline{X}_2$

Equation 1 Comparing proportions (left) **Equation 2 Independent samples T-test (right)**

The mean number of citations per cited patent is compared for all types of organizations. In order to compare the different types of organizations, the mean number of citations per cited patent is compared using an independent-samples T-test (see Equation 2). Equation 2 is based on the null hypothesis (H0) that there are no significant differences in the mean number of citations per cited patent between two groups. The alternative hypothesis (Ha) implies that there are significant differences in the mean number of citations per cited patent between two groups. Based on the group data, first the pooled variance (S^2_p) is computed, needed to compute the t-value. Also the degrees of freedom (d.f.) are computed, combined with the t-value, these values can be converted into a P-value (see table V, Wonnacott & Wonnacott, 1990). For the P-value, the same holds as discussed for Equation 1.

Translating hypothesis 1 (Large incumbent firms adopt a more internal approach for knowledge development compared to new entrants) in terms of patent citations, large incumbent[10] firms should own a large part of the highly cited patents compared to new entrants, as large incumbents must own high-quality knowledge in order to obtain a first-mover advantage. This knowledge is expected to be developed internally, which reflects itself in cited patents. This means that large incumbents should have a significantly higher proportion cited patents and/or more citations per cited patent compared to new entrants. If only one of these two conditions is fulfilled, the new entrants and large incumbent need to score equal on the other condition. If the large incumbents score significant lower on the other condition, the hypothesis cannot be confirmed.

Hypothesis 3a (There are more new entrants active in the BEV industry compared to the FCV industry) can be tested using patent data. To test hypothesis 3a, the patent applicants from the data sample are divided in new entrants and other types of organizations. By doing this for both the BEV and FCV sample it becomes clear what proportion of applicants can be classified as new entrant. These proportions are then compared using Equation 1 and hypothesis 3a is confirmed if the proportion new entrants is significantly higher in the BEV industry than in the FCV industry.

4.2. Knowledge transfer/acquisition

In order to map knowledge transfers and acquisition, license data and component supply contract data are used. License data is used to test hypothesis 2 (H2a: Incumbent firms will choose for a restrictive approach of knowledge exchange; H2b: New entrants will choose for more open forms of knowledge exchange; H2c: Outsiders will choose for open forms of knowledge exchange; H2d: PROs will choose for open forms of knowledge exchange).

[10] The distinction between small and large incumbent is made as discussed in paragraph 4.3.1.

In order to make a comparison between the forms of knowledge exchange for incumbents, new entrants, outsiders and PROs, all license agreements are qualitatively assessed. A clear distinction is made between the types of organizations that issue a license and the types of organizations that receive a license. As additional explanatory factor, the components included in the license agreement are distinguished. This analysis is done on the basis of all licenses, where a distinction is made between licenses indicating open forms of knowledge exchange/acquisition and licenses indicating restricted forms of knowledge exchange/acquisition[11]. In order to confirm hypothesis 2a, incumbent firms mainly need to have licenses that indicate restricted forms of knowledge exchange/acquisition. In order to confirm hypothesis 2b, new entrants mainly need to have licenses that indicate open forms of knowledge exchange/acquisition. The same holds for hypothesis 2c and 2d, where outsiders and respectively PROs mainly need to have licenses that indicate open forms of knowledge exchange/acquisition.

To test hypothesis 3b (Acquisition of components is a more important source of knowledge in the BEV industry than in the FCV industry), a similar qualitative analysis as performed for testing hypothesis 2 is applied. In this case the component supply contracts of BEV participants are compared with the component supply contracts of FCV participants. Also the components included in the supply contracts are distinguished, as additional explanatory factor. Hypothesis 3b is confirmed when components are more often and easier acquired in the BEV industry compared to the FCV industry.

Section 4.2.1 describes the collection of license data, and the separation of open and restricted forms of knowledge exchange/acquisition for use as indicator, and section 4.2.2 describes the use of component supply contract data as indicator.

4.2.1. Licenses

Licenses are an important indicator of knowledge transfer/acquisition. A difficulty in indentifying licensees is that licenses are not always recorded in patent databases (Dykeman & Kopko, 2004 ,for the USPTO). Patent assignees are not required to record a license in the patent database. For example confidentiality could be a reason. A license agreement becomes public once it is registered in the database. A license can merely be seen as an agreement to not sue each other. A patent database search will therefore only return a limited number of patents with licenses. In order to work around this issue, online news items on licensing in the ZEV industry are used. Using Google, several relevant news websites were found, these websites are recorded in Table 3.

Table 3 Relevant websites on licenses

Websites	
Cars21.com	Autoblog.com
Electric-vehiclenews,com	Evworld.com
Treehugger.com	Fuelcelltoday.com
Greencarcongress.com	Autoweek.com

[11] The distinction between the different types of license agreements is discussed in paragraph 4.2.1.

These websites/items provide a good picture of the license activities in the industry. Google is used to search within the websites (using the SITE: string), as the search engines of the sites are often limited. The following queries are used[12]:

For BEVs:
License OR agreement OR electric license OR electric agreement

For FCVs:
Hydrogen license OR cell license OR agreement OR license

The results of these search queries are recorded in Appendix 1: License Agreements. In order to use the data as indicators, the firm names need to be translated in types of organizations and their corresponding roles. This classification is performed as discussed in paragraph 4.3. Using this classification, the found knowledge transfers are used to test hypothesis 2. For this purpose it is important to distinguish between external (open) and internal (restrictive) forms of knowledge exchange. In the remainder of this page an overview is given of how different license types are distinguished.

4.2.1.1. Open (external) forms

The literature on licensing discusses several types of licensing. These types are further elaborated in Table 4 below.

Table 4 Licensing types: open

• One-sided licensing (Chesbrough, 2005; Fosfuri, 2006; Teece, 1986)	Licensing your intellectual property to another party as a form of income. The knowledge-transfer is in this form only one-sided (the other side only captures an income).
• Cooperative standard setting (Lichtenthaler, 2011; Shapiro, 2001)/ Transfer for adoption (Lichtenthaler, 2011)	Setting a standard (or dominant design) by licensing knowledge or by pooling with others' IP rights. And/or parties licensing their patents with reasonable terms to each other in order to have complete access to knowledge in order to promote a new technology and to increase the adoption speed. Parties can influence this trajectory and push their own technologies by licensing.
• Cross licensing (Cohen, 2004; Shapiro, 2001; Ziedonis, 2004)	Two or more parties giving each other access to their IP, they use their patents in negotiations with owners of other patents. The parties may only license restrictive parts of their intellectual property (Shapiro, 2001).

In principle, these licensing strategies are positive for the development of ZEVs since all strategies ensure that knowledge is transferred. Cross licensing and cooperative standard setting/transfer for adoption are treated as one concept, since the data do not give the possibility to separate these concepts.

[12] Many items are found on special ZEV websites, therefore electric is not always used in the search queries, as all news already is about electric vehicles. Furthermore the BEV and FCV contain a few equal terms. This way lots of articles were found and distinguished in a manual analysis.

4.2.1.2. Restrictive (internal) forms

Based on hypothesis 2, firms might inhibit a restrictive knowledge transfer strategy, which has a negative effect on the technological development of ZEVs. Table 5 below elaborates these restrictive types.

Table 5 Licensing types: restrictive

• Restrictive (cross) licensing	The same as cross-licensing, with the difference that when parties decide to (cross) license, they only license to restricted partners. This expectation is based on the fact that firms also in other forms of collaboration carefully choose their partners (Gulati, 1998).

Section 4.2.1.3 describes how a distinction is made between the licenses found in the data.

4.2.1.3. Distinguishing different types of licensing

One-sided licensing

One-sided licenses are licenses that are issued without receiving a license in return. These licenses are issued without an obvious restriction regarding to whom the license is issued. Obviously, a financial return is likely.

Cross licensing[13]

Cross licenses are not always recorded. To overcome this shortcoming, cross-licensing can be identified and controlled for by searching the found license entries in the data for mutual transactions between two or more organizations in the same period of time.

Restrictive cross licensing

In order to check the results for instances of restrictive cross licensing, the results for cross licensing are analyzed based on the organizations that are involved in the transaction. For the types of organizations, the classification as in section 4.3 is used. When there are relatively many cross licenses between the same organizations, this might indicate restrictive cross-licensing.

4.2.2. Component supply contracts

In addition to licenses as an important means of acquiring knowledge, buying components is another important means of acquire knowledge. Furthermore, as discussed in the theory section it is the most external way of knowledge development. In order to map component supply contracts and in order to test hypothesis 3b, news websites are consulted. Both the relevant news websites used to map licenses and other relevant websites, found by using Google, are also used to map component supply contracts. These websites are recorded in Table 6.

Table 6 Relevant websites on component supply contracts

Websites	
Cars21.com	Thegreencarwebsite.co.uk
Evworld.com	Just-auto.com
Autoblog.com	Greencarcongress.com
Torquenews.com	

[13] Cooperative standard setting/Transfer for adoption are included in Cross licensing.

Also here Google is used to search within the websites (using the SITE: string). The following queries are used:

For BEVs:
contract OR agreement OR supply contract OR electric supply contract

For FCVs:
cell supply contract OR contract OR agreement

4.3. Types of organizations

For the testing of all hypotheses it is important that the linkages between different types of organizations are determined. These linkages are used in order to determine patterns of types of organizations active in knowledge transactions. In order to determine these linkages, the different organizations need to be classified. Based on the theory the types of organizations and roles as summarized in Table 1 are used. This paragraph describes how the different types of organizations and roles are distinguished.

The different organizations are classified based on internet searches on organization name. By analyzing organization profiles, it is possible to classify the organizations into one of the types. In addition, the following characteristics are important in the classification:

4.3.1. Incumbents

Incumbent firms are firms that are already active in the automotive industry. In order to make a distinction between incumbent firms and new entrants, the definitions of Van Praag & Versloot (2007) are used, where incumbents are older than 7 years old. Especially due to the fact that the automotive industry is dominated by large incumbent firms for years (Klepper, 2007), this age definition seems suitable. Per patent is checked whether the difference between the year of establishment of the corresponding firm and the priority date of a patent application differ 7 or more years. This method ensures a reliable classification, as a firm may be an incumbent at the date of the second patent application, but a new entrant at the date of the first patent application.

To test the hypotheses, also a distinction is made between small incumbents (SI) and large incumbents (LI). This distinction is based on annual sales figures, gathered from Hoovers.com. Hoovers is a firm that offers business information about over 85 million firms. Hoovers' database contains annual sales figures for many firms and estimated sales figures for firms that do not publish their figures. These estimates are based on firms with known figures that have similar characteristics, such as industry type, business age, number of employees and sales. The use of these estimates is therefore relatively reliable.

The median of the sales figures is calculated and used as the distinction between small and large incumbents. The median is used instead of the mean, because both the BEV and FCV samples are unevenly distributed. It appears that the BEV sample is right skewed distributed, while the FCV sample is left skewed distributed. It seems that the BEV sample is characterized by all kinds of firms from small to large, while the FCV sample is dominated by large firms. The BEV sample is more representative in this respect, as a left skewed distributed sample is representative for all sorts of industries, therefore the median of the BEV sample is also used for the FCV sample. For the BEV sample the median is $4.210.000.000.

4.3.2. New Entrants

New entrants are new businesses that are younger than 7 years based on the definitions of Van Praag & Versloot (2007).

An exception here are new entrant firms formed by a joint venture of incumbents, or firms stemming from older firms after mergers, acquisitions, name changes etc. The principle here is that these firms are on the same level as incumbents in terms of knowledge development. These firms are therefore classified as incumbents.[14]

4.3.3. Outsiders

Firms that are already active, in other industries than the automotive industry.

4.3.4. PROs

Public research organizations such as universities and federal laboratories.

Furthermore, among the incumbents, new entrants and outsiders, two roles are distinguished, CAs and suppliers.

4.3.4.1. CAs

Firms that sell assembled, ready-to-drive cars to their customer base.

4.3.4.2. Suppliers

Firms that sell components to the CAs. Only 1st tier suppliers are considered in this study.

[14] During this study, the year of establishment has been changed for 8 firms, for example for ZF Lenksysteme, a joint venture between Bosch and ZF, where the year of establishment of ZF is used (1915) instead of 1999.

5. Results

In this section, the results are presented in the order of the collected data. First, the results derived from the patent data and patent citation data are presented. Subsequently, the results derived from license and component supply data are presented.

5.1. Patent (citation) data

The BEV search query returned 1138 patents, of which 861 patents are relevant and classified as displayed in Table 7. The FCV search query returned 83 patents that are all relevant and classified as displayed in Table 8. The irrelevant patents include: Individual Inventor, Industrial application (military application, lawnmowers, quads, ships, excavator, forklift etc.), (motor)bikes, rail, patent agent and trucks. These classes are excluded from the analysis. It was found that a distinction between CAs and suppliers was not sufficient. Besides CAs and suppliers, also firms on infrastructure (e.g. charging technology), non-public research organizations (NPROs), and other firms with relevant technology were found in the sample, therefore additional classes are added.

Table 7 and Table 8 also give an overview of the cited patents and the total amount of firms with patents in the sample.

Using the "Total patents" and "Total firms" in Table 7 and Table 8, hypothesis 3a is tested. New Entrants have a 4,07% (35/861) share in patents in the BEV sample, compared to a 0% share in the FCV sample. Furthermore, of the firms in the BEV sample, 8,11% (15/185) are new entrants, compared to 0% in the FCV sample. Using Equation 1 the proportion new entrants in the BEV and FCV industry are compared. Both the share of new entrant patents and new entrant firms is significantly higher in the BEV industry (P>99%). This confirms hypothesis 3a *(There are more new entrants active in the BEV industry compared to the FCV industry)*.

Table 7 BEV patent classification

Type of organization	**Large Incumbent**		**Small Incumbent**		**New Entrant**		**Outsider**		**PRO**		**Total**	
Patents	**Cited**	**Total**	**Cited**	**Total**	**Cited**	**Total**	**Cited**	**Total**	**Cited**	**Total**	**Cited**	**Total**
CA	97	279	6	10	1	11	3	5	0	0	107	305
Supplier	105	257	34	77	7	16	53	125	0	0	199	475
Infrastructure	0	0	0	0	0	8	3	21	0	0	3	29
NPRO	0	0	4	7	0	0	0	2	0	0	4	9
Other	0	0	0	0	0	0	7	21	6	22	7	21
Total patents	202	536	44	94	8	35	66	174	6	22	326	861
Total firms	38	57	29	57	3	15	22	45	3	11	95	185
Pat. per firm	5,3158	9,4035	1,5172	1,6491	2,6667	2,3333	3	3,8667	2	2	3,4316	4,6541

Table 8 FCV patent classification

Type of organization	Large Incumbent		Small Incumbent		Outsider		Total	
Patents	Cited	Total	Cited	Total	Cited	Total	Cited	Total
CA	22	60	3	4	0	0	25	64
Supplier	3	5	6	7	0	1	9	13
Infrastructure	0	0	0	0	0	5	0	5
Other	0	0	0	0	0	1	0	1
Total patents	25	65	9	11	0	7	34	83
Total firms	7	10	3	4	0	7	11	22
Pat. per firm	3,5714	6,5	3	2,75	0	1	3,0909	3,7727

5.1.1. Proportion cited patents

For the BEV sample, the NEs have the smallest proportion cited patents (22,86%), followed by the PROs (27,27%), LIs (37,69%), Outsiders (37,93%) and SIs (46,81%). For the FCV sample, the outsiders have the smallest proportion cited patents (0,00%) followed by the LIs (38,46%) and the SIs (81,82%). There is no data for PROs and NEs as there are no PROs and NEs in the FCV sample. Table 9 shows the proportion cited patents per type of organization (total patents/total cited patents) and the mean number of citations per cited patent for each type of organization.

Table 9 Proportion cited patents and mean number of citations per cited patent for all groups

Type of organization	Proportion cited patents BEV	Mean number of citations BEV	Proportion cited patents FCV	Mean number of citations FCV
NE	22,86%	3,97	na	na
SI	46,81%	5,40	81,82%	3,23
LI	37,69%	5,14	38,46%	3,84
Outsiders	37,93%	5,17	0,00%	0,00
PRO	27,27%	5,04	na	na

Table 10 shows the P-values per two types of organizations, for both the comparison of the proportion cited patents and the comparison of the mean number of citations per cited patent.

Table 10 Comparison proportion cited patents and difference in mean between all groups (P-values)

Type of organization	Compared to	Proportion cited patents BEV	Difference in mean BEV	Proportion cited patents FCV	Difference in mean FCV
SI	**LI**	0,102	0,779	0,000*	0,475
SI	**NE**	0,006*	0,143	na	na
SI	**Outsiders**	0,160	0,807	0,000*	na
LI	**NE**	0,046*	0,550	na	na
LI	**Outsiders**	0,960	0,971	0,000*	na
NE	**Outsiders**	0,060*	0,169	na	na
PRO	**LI**	0,284	0,963	na	na
PRO	**NE**	0,712	0,331	na	na
PRO	**Outsiders**	0,296	0,945	na	na
PRO	**SI**	0,072*	0,857	na	na
*significant on a 90% confidence-interval					

Equation 1 is used to check if the above differences in the proportion cited patents are significant. If the P-value is lower than 0.10, it is assumed that the difference in the proportion cited patents is significant for two types of organizations. In the BEV sample, the proportion cited patents of the NEs (22,86%) is significantly smaller than the proportion cited patents of the SIs, LIs and outsiders. There do not seem to be significant differences between the proportion cited patents of the SIs, LIs and outsiders. The proportion cited patents of the PROs is only significant lower compared to the proportion cited patents of the SIs. There are no significant differences between the PROs and the LIs, NEs or outsiders. In the FCV sample, the differences in the proportion cited patents between all types of organizations are significant. Apparently, the patents of the SIs are of the highest quality, followed by patents of the LIs and outsiders.

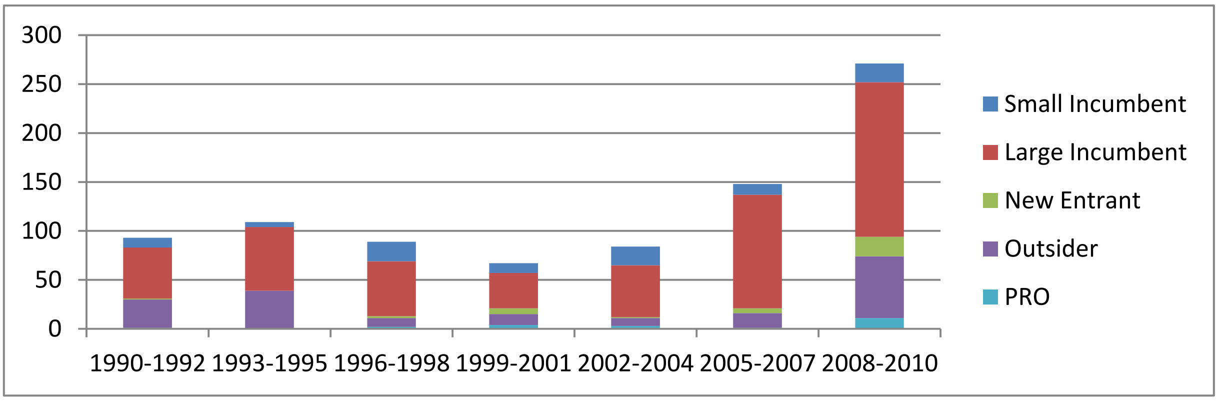
5.1.2. Mean number of citations per cited patent

The mean number of citations per cited patent is also shown in Table 9 for all types of organizations in the BEV and FCV sample. In the BEV sample, the cited patents of the SIs on average receive the most citations (5,40), followed by the outsiders (5,17), LIs (5,14), PROs (5,04) and NEs (3,97). In the FCV sample, the LIs on average receive the most citations per cited patent (3,84) followed by the SIs (3,23) and outsiders (0,00). The NEs are not shown as they do not have any patent.

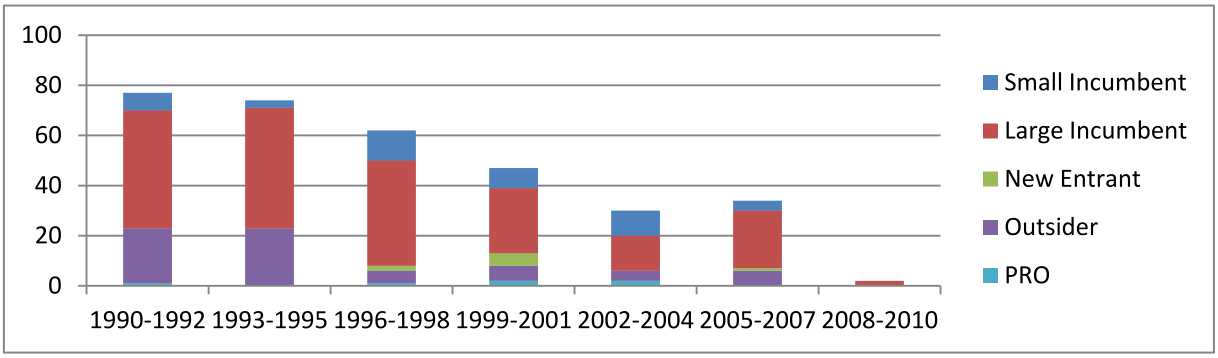
A T-test is used to check if the above differences in the mean number of citations per cited patent are significant. The P-values of these tests are also shown in Table 10 for the BEV and FCV sample. Also here a P-value lower than 0.10 means that a significant difference is assumed. The mean number of citations per cited patent do not show significant differences between any types of organizations in both the BEV and the FCV sample. This means that the cited patents of all groups do not differ in quality. However, the share of high quality patents (proportion cited patents) is much lower for NEs compared to the other groups. It appears that LIs indeed have a larger share cited (high quality) patents compared to NEs, indicating more internal knowledge development, and at least giving them the opportunity to gain a first mover advantage. These findings confirm hypothesis 1 *(Large incumbent firms adopt a more internal approach for knowledge development compared to new entrants).*

5.1.3. Trend

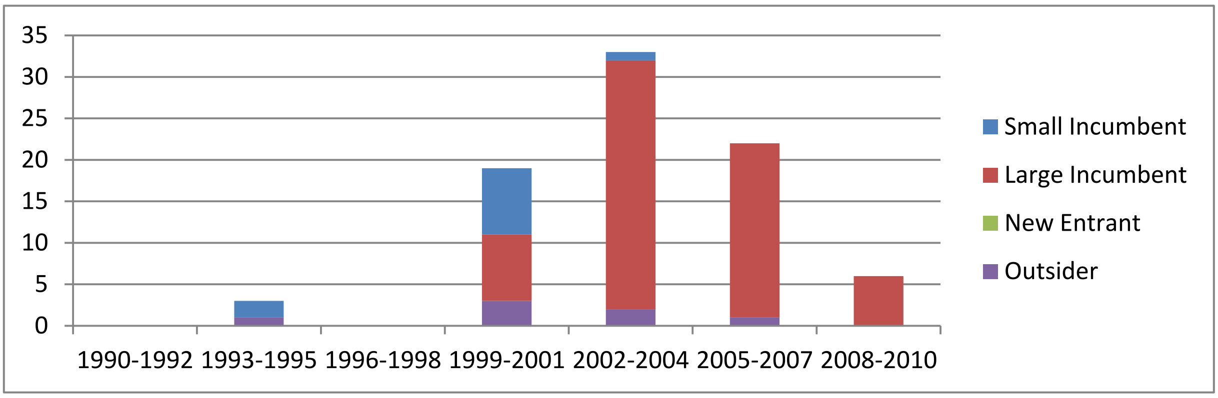
In order to map trends in the knowledge development of the FCV and BEV, the number of patents and number of cited patents are plotted for periods of three years for the FCV and BEV. Graph 1 to 4 give an overview of the development of the number of patents and the number of cited patents over time.



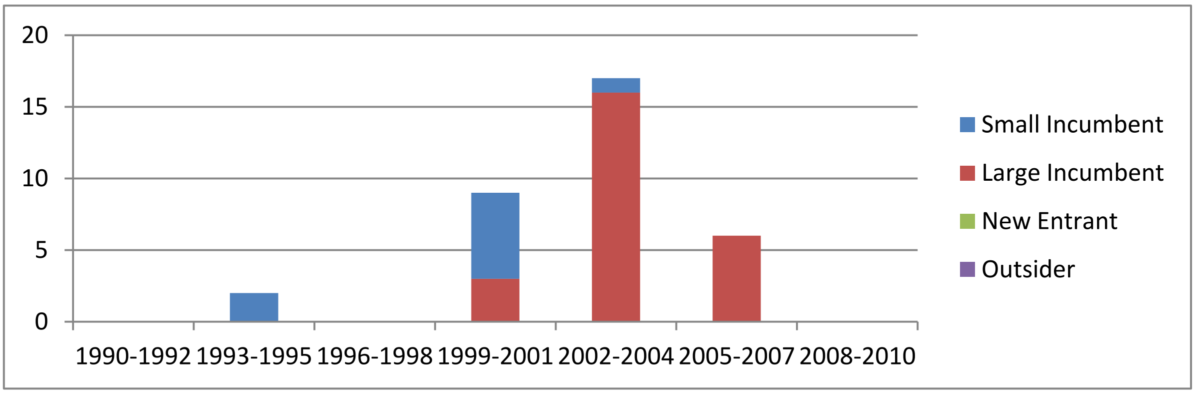
Graph 1 Number of patents BEV



Graph 2 Number of cited patents BEV



Graph 3 Number of patents FCV



Graph 4 Number of cited patents FCV

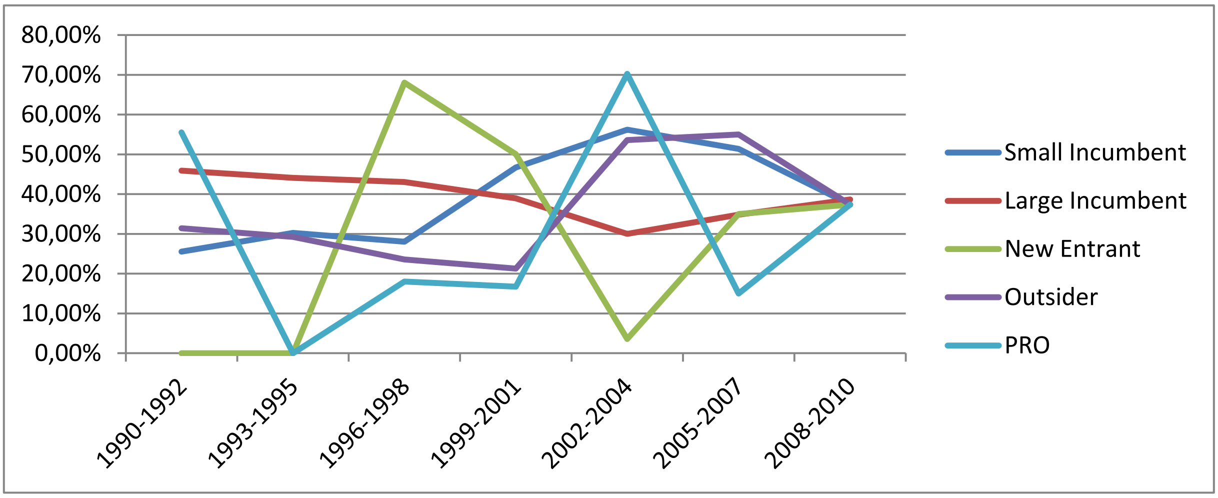
It is striking that the number of patents show an upward trend in the BEV industry from 2002, while they show a downward trend in the FCV sample. In terms of knowledge development, the development declines within the FCV industry, while the BEV seems to become a more popular alternative to be developed. Apparently, firms shift their focus from the FCV to the BEV.

The BEV sample furthermore shows a downward trend for the number of cited patents. This may be caused by the time effect: older patents have had more time to receive citations. Due to missing values in the FCV sample for two periods, it is not possible to determine a trend for the number of (cited) patents in the FCV sample and to give a reliable explanation for the observations. The number of cited patents does follow the curve of the number of patents for the FCV. It thus seems that the time effect is less present in the FCV sample. Looking at the time it takes before a cited patent receives its first citation, BEV patents within the sample need on average 3,4 years, while FCV patents only need 2 years on average. Since the data is shown in periods of three years, the FCV patent citations often are in the same period as the patents. Graph 3 and Graph 4 show this, as the number of patents and the number of cited patents show the same trend. For the BEV, the citations lag a period behind. For the BEV no cited patents are thus expected for the last period of three years. Graph 1 and Graph 2 do show this as there are almost no cited patents in the last period of three years (2008-2010), however in the other periods the cited patents do not follow the trend of the total patents. There is thus a decrease in cited patents, while there is a large increase in the number of patents.

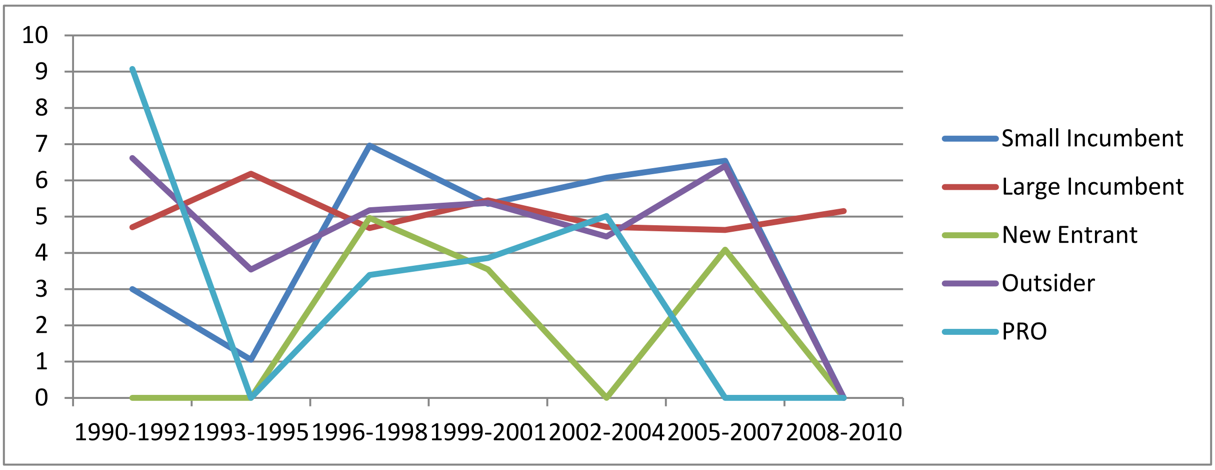
In order to map trends between the different groups over time, the proportion cited patents and the average number of citations per cited patent are plotted in periods of three years for all types of organizations from both the BEV and FCV sample. A correction has been applied in order to make the proportion cited patents comparable. In order to do this, for each firm type, the deviation from each three year average is plotted relative to the overall mean proportion of cited patents for all firm types (38,14% for BEV and 40,96% for FCV). The years 2008-2010 are not discussed in the analysis as most patents have not received any citations is those years yet, as receiving a patent takes 2 to 3,4 years on average, causing the proportion cited patents for all groups to equal on the sample average. The same holds for the average number of citations per cited patent that equals zero, if there are no cited patents in a year, also after a correction. The trends are discussed per sample, first for the BEV sample and subsequently for the FCV sample.

5.1.3.1. BEV

Graph 5 shows the trend of the proportion cited patents for the BEV sample and Graph 6 shows the trend of the average number of citations per cited patent for the BEV sample. LIs show a stable pattern over the years. There are only slight fluctuations visible in the proportion cited patents and the average number of citations per cited patents. This could mean that LIs have always seen the importance of knowledge development on BEV technology, and that the LIs steadily continued (high quality) knowledge development.



Graph 5 Proportion cited patents BEV



Graph 6 Average number of citations per cited patent BEV

The SIs and outsiders show another trend. The knowledge quality of both groups lags behind the knowledge quality of the LIs until approximately 2000. The knowledge quality is measured as a combination of the proportion cited patents and the average number of citations per cited patent. When both are high, it is assumed that the quality of the patents of the corresponding type of organization is high. If the proportion cited patents and/or the average number of citations per cited patent is lower for a type of organization compared to the other types of organizations, it is assumed that the quality of the corresponding type of organizations' patents is lower.

The average number of citations per cited patent is quite stable and shows a similar trend for outsiders and SIs, making the proportion cited patents leading for identifying knowledge quality differences between the SIs and outsiders. Also the proportion cited patents shows a similar trend for both groups.

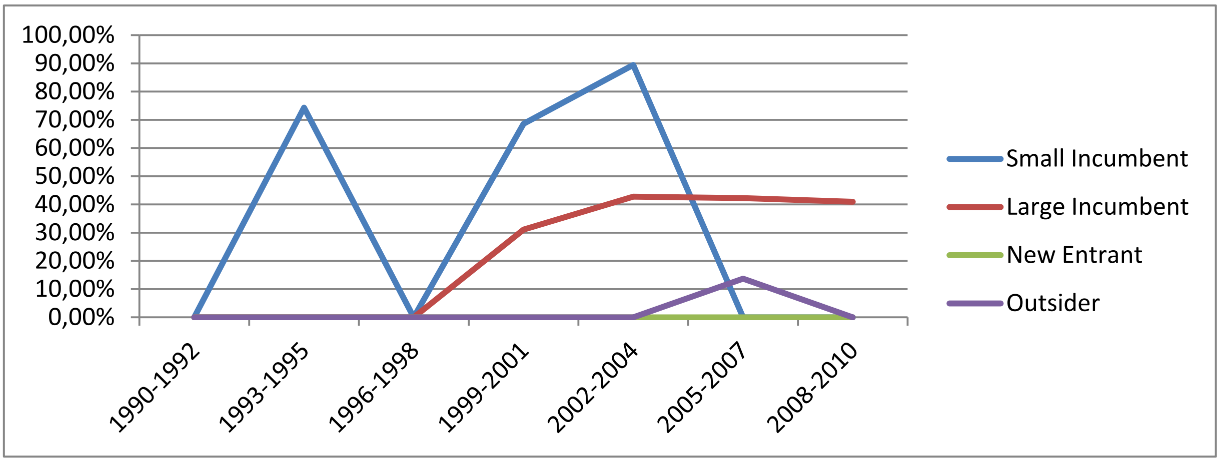
After 2000 the outsiders and SIs seem to have the highest knowledge quality. It seems that the outsiders and SIs started as fast followers, and when the BEV technology started to become more viable (after 2000) started catching up and eventually kept a pole position in high quality knowledge development. The fact that outsiders do approximately show the same trend as the SIs might be explained by the fact that outsiders are in most cases incumbents in other industries, giving them the possibility and incentive to do internal research, also on technologies other than their core technology. Furthermore, the SIs and outsiders do to a lesser degree face incumbent inertia, making them more flexible firms, that can easier switch to new technologies compared to the LIs. This while large incumbents need to continue to invest in their current product portfolios and customer bases.

The NEs and PROs show a fluctuating curve due to the small sample size (6 cited patents out of 22 patents for PROs and 8 cited patents out of 35 patents for NEs), causing missing values for a number of years. Due to the small sample sizes it is only possible to discuss the average proportion cited patents and average number of citations per cited patent over the years. Both are lower for the PROs and NEs compared to the other three groups (only significant lower for the NEs).

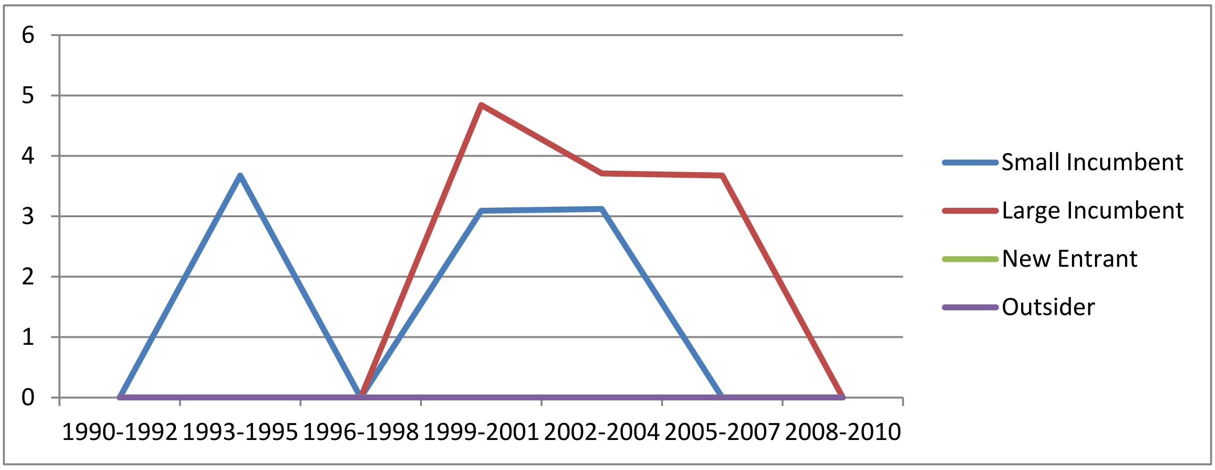
The observations for NEs are consistent with theory, where it is argued that although NEs do not face incumbent inertia it is likely that they do not have the resources available that the other groups have, in order to perform (high quality) internal development.

5.1.3.2. FCV

Graph 7 and Graph 8 show the trends for the FCV sample. Within the FCV sample, no NE patents are present. Furthermore, outsiders do not have cited patents within the sample. SIs do only have 6 cited patents, causing a blurred image. Furthermore, the LIs have their first cited patent in 1999.



Graph 7 Proportion cited patents FCV



Graph 8 Average number of citations per cited patent FCV

The average number of citations per cited patent is slightly higher for the LIs in the years where cited patents are available. The proportion cited patents and the average number of citations per cited patent show, like in the BEV sample, only slight fluctuations for the LIs. The LIs seem to continue their knowledge development steadily, maintaining their quality. The proportion cited patents is in all cases significantly higher for the SIs compared to the LIs, however due to the small sample size of the SIs it is not possible to identify a trend for the SIs.

In general, the data do clearly indicate that the incumbents dominate knowledge development in the FCV industry.

5.1.4. Summary of the results

The results show that there are more NEs active in the BEV industry compared to the FCV industry. The NEs furthermore do not seem to own the highest quality patents, compared to the outsiders, LIs and SIs. PROs also do not seem to own the highest quality patents, although their patent quality is only significantly lower compared to SIs.

The results do not show any significant differences between the SIs and the LIs, theory however argues that LIs have the advantage of more financial resources and that LIs can therefore do more internal development and become a first-mover. Looking at the average number of patents per firm and the average number of cited patents per cited firm (see the last row of Table 7 and Table 8) shows that in both cases LIs (BEV: 9,4 patents per LI and 5,3 cited patents per LI; FCV: 6,5 patents per LI and 3,6 cited patents per LI) own more patents per organization compared to SIs (BEV: 1,6 patents per SI and 1,5 cited patents per SI; FCV: 2,8 patents per SI and 3 cited patents per SI). This confirms that LIs indeed are able to do more research (in quantity), but that it does not affect the quality measured in the proportion cited patents and the mean number of citations per cited patent (the quality measured in patent citations is almost equal for SIs and LIs). The distinction between SIs and LIs thus is useful.

5.1.4.1. BEV vs FCV

In the BEV industry, outsiders and SIs are slowly taking the lead over LIs in terms of the proportion cited patents. In the FCV industry, the incumbent firms dominate knowledge development. Furthermore the number of patents quickly increases in the BEV industry while it decreases in the FCV industry. Strangely, the number of cited patents decreases in the BEV industry, while it follows the trend of the total amount of patents in the FCV industry. Therefore, it appears that the number of cited patents and the proportion cited patent decreases in the BEV industry. Apparently, innovation in the FCV industry is of an incremental nature, while innovation in the BEV industry is of a radical nature.

5.2. License data

Using the search method as discussed in the methodology, 17 licenses are identified (see appendix 1). Table 11 gives an overview of the licenses and makes a distinction in the licensed technologies.

Table 11 Licenses

Technology	BEV	FCV
Battery	9	0
Fuel cell	0	1
Charging	2	0
Powertrain/platform/car	5	0
Total	16	1

A notable proportion of the licenses is on battery technology, where all licenses are issued by PROs (8), or by outsiders (2). The firms that receive licenses are incumbents (4), outsiders (3) and new entrants (3). All 10 licenses are one-sided licenses.

In the case of powertrain, platform and car licenses, 3 out of 5 license agreements are the result of collaborations. One of these 3 licenses is issued by a NE CA to a LI CA, one by a SI Supplier to a LI CA and one by a SI CA to a SI CA. The two remaining license agreements are license agreements between CAs. The first between Fiat and Chrysler, which can be explained by the majority interest of Fiat in Chrysler since 2011. The second license is an agreement on a powertrain between Tesla (NE CA) and Daimler/Mercedes (LI CA). Tesla licenses its powertrain to Daimler/Mercedes. Interesting here is that Tesla is a New Entrant CA, specialized in the development of BEVs, that does contract work for two large incumbents (delivery of powertrain to Toyota for their RAV4 EV, and licensing their powertrain to Daimler for their Smart Fortwo electric). This is a good example of a firm that applies ideas in the open innovation literature, namely by generating value by the external exploitation of knowledge. Oddly enough, Daimler and Toyota are large firms who are expected to be able to develop an EV themselves. In this case Daimler and Toyota are not first movers as discussed in section 2.3, they do not have the knowledge and intellectual capital to introduce the EVs themselves, which makes them fast followers. These firms can at the same time be first movers in other areas, like Toyota with hybrid electric vehicles.

On charging two licenses are found, a PRO licensing technology to a small incumbent CA and an outsider licensing technology to an incumbent infrastructure firm.

On FCV, only 1 license was found, a license that gives Suzuki access to Intelligent Powers' fuel cell systems. Also this license agreement is the result of a collaboration.

Incumbent firms do engage in unilateral knowledge transfers (one-sided licensing), when they are receiving a license. Only in the case of collaborations, such as joint ventures, incumbents (4) do engage in bilateral knowledge transfers or issue a license. This option is not discussed in the theory section, but it does indicate a restrictive approach of knowledge exchange, as firms do carefully choose their partners for collaborations. This confirms hypothesis 2a *(Incumbent firms will choose for a restrictive approach of knowledge exchange).*

Outsiders are in particular found in license agreements on batteries (5). Outsiders issue (4) licenses and receive (3) unilateral licenses. Only in one instance an issued license is based on a cooperation between an outsider and an incumbent. These firms are thus applying open forms of knowledge acquisition and exchange. Based on the available licenses hypothesis 2c *(Outsiders will choose for open forms of knowledge exchange)* is confirmed. Note that battery manufacturers dominate the sample.

All PROs (9) do issue one-sided licenses. This is logical, as PROs do not exploit their knowledge, but try to earn an income by commercializing it. This shows that the PROs do not choose for a restrictive approach of knowledge exchange, as they do license one-sided without the collaborations as observed for the incumbent firms. The PROs thus do choose for an open approach of knowledge exchange. This confirms hypothesis 2d *(PROs will choose for open forms of knowledge exchange)*.

There is insufficient data on new entrants that issue a license to test hypothesis 2b *(New entrants will choose for more open forms of knowledge exchange).* Tesla is the only example of a firm that out-licenses, without cooperating with the firms it licenses to. In three other cases new entrants receive a license, and in one case a new entrant gives a license to an incumbent firm as result of a cooperation.

5.3. Component supply contract data

Using the search methods as discussed in the methodology, 25 component supply contracts are identified (see section 0: Appendix 2). Table 12 gives an overview of the component supply contracts and makes a distinction in the supplied parts.

Table 12 Component supply contracts

Technology	BEV	FCV
Battery	13 (11 to CA)	0
Fuel cell	0	7
Powertrain	3	0
Electric drive unit	1	0
Car	1	0
Total	18	7

As with the licenses, it is notable that a large proportion (13 out of 25) of the supply contracts is on batteries. Eleven of the supply contracts are between battery producers and CAs (3 SI, 7 LI and 1 NE[15]). The battery producers are both new entrants with a specific focus on the automotive industry, as well as producers (outsiders) that are adding the automotive industry to their customer base.

On FCV, 7 supply contracts were found, of which 5 consist of a delivery to a LI, 1 consists of a delivery to a SI and 1 consists of a delivery to a NE. The suppliers of the fuel cells can be regarded as incumbent suppliers. Among the 7 contracts, 3 firms are identified (Ballard, Dynetek and Quantum). These firms are all specialized in automotive applications, while six of the battery suppliers are outsiders that have much larger product portfolios and stem from other industries (power tools, backup power, telecom, military applications).

The supply of batteries and fuel cells can be seen as transactions. Both are not core technologies of the CAs. Thus integration is subject to transaction costs (Williamson, 1981). A fuel cell can be viewed as more asset specific, as the buyer and seller are operating in a bilateral exchange relation. This requires more strict supply contracts and cooperation between selling and buying parties. For the

[15] Note that Tesla is classified as small incumbent within the component supply contracts, while the firm is classified as new entrant in the license data, due to the firm age at the publication date of the supply contracts/licenses.

firms found in the fuel cell supply contracts this is confirmed by for example joint ventures and strict supply and cooperation contracts[16]. A battery is less asset specific, and CAs might even enjoy scale economies by buying batteries on the market.

It seems that batteries and fuel cells are more often purchased by CAs compared to other parts. A possible explanation for this phenomenon is that both technologies are too distant from the CAs core technologies. It seems that these components are the components by which manufacturers can differentiate themselves[17]. A product can therefore stand or fall by picking the right component supplier.

The remaining supply contracts (5) consist of large incumbent CAs that buy complete powertrains (3), a complete car (1) and an (1) electric drive unit. Especially the delivery of complete powertrains and a complete car are striking examples of firms that buy the most important knowledge in components. All these contracts are found in the BEV industry. Two of these contracts represent a strict collaboration between two parties (and involve a stake of both Daimler and Toyota in Tesla).

To wrap up, acquisition of components seems important and happens in both industries. Dependent on the component, cooperation on development can be important in both industries. Due to the needed cooperation it is not easy to simply buy a component as a source of knowledge. Only batteries are more universal in the BEV industry, and do not, or to a lesser degree require the bilateral knowledge exchange as needed for the other components. Acquisition of components is an important source of knowledge in both industries, and on the basis of the data it is not possible to argue in which industry this phenomenon is more important. Accordingly, hypothesis 3b *(Acquisition of components is a more important source of knowledge in the BEV industry than in the FCV industry)* cannot be confirmed now.

[16] For the supply contracts in the sample for example the joint venture AFCC (Daimler, Ford and Ballard Power Systems), a memorandum of understanding for supply and cooperation between Ballard and Tata, and a memorandum of understanding between Ballard and Shanghai Fuel Cell Vehicle Powertrain. Furthermore manufacturers also develop customized products, requiring a high degree of cooperation, for example a custom build Quantum fuel cell for Daimler.

[17] These components determine important characteristics of vehicles, such as the range and charge times.

6. Discussion & Conclusions

In this section, the results of this study are discussed. With it, also the theoretical and managerial implications of this study are discussed, as well as recommendations for further research and the limitations of this study.

6.1. Patent citations

Patent citations were used to test hypothesis 1 *(Large incumbent firms adopt a more internal approach for knowledge development compared to new entrants).* The knowledge quality of PROs and new entrants seems remarkably low. For new entrants this is significant lower compared to the other types of organizations including large incumbent firms, and this is in line with hypothesis 1. The theoretical assumption that internal knowledge development is less affordable for smaller firms does not reflect itself in the quality of the knowledge produced as measured by patent citations. Large incumbents however do quantitatively have more important knowledge.

The resulting data for testing hypothesis 1 offered a good basis for answering RQ2 *(How is knowledge distributed among the ZEV participants during the period 1990-2010?).* The data shows that there are gradual changes visible in knowledge development. Where large incumbents dominated BEV knowledge development in quantity and quality until 2000, small incumbent and outsiders slowly overtake the large incumbents on patent quality after 2000. Although no statistically significant differences are discovered (yet), large incumbent should start to consider to invest more in knowledge development on the new technologies as outsiders and small incumbents might become leaders of high quality knowledge development if the found trend continues[18].

Within the different types of organizations, PROs stand out. It seems that PROs only play a minor role in the development of FCV and BEV knowledge, both in the light of the number of patents as well as in the light of the quality of the patents. Apparently, PROs do only make a little contribution. Contributions of PROs might even be unnecessary as firms seem to find their way anyway. But PROs appear to play an important role in the development of batteries. The role of PROs in BEV and FCV development is thus a good subject for further research.

Hypothesis 3a *(There are more new entrants active in the BEV industry compared to the FCV industry)* furthermore helps, in combination with hypothesis 1, answering *RQ1 (What dynamics in knowledge development can be identified in the ZEV industry during the period 1990-2010?).* Large differences are found between the BEV and FCV industry. There are significantly less new entrants present in the FCV industry compared to the BEV industry. This is in line with theory and hypothesis 3a. Apparently, entry barriers are indeed higher for new entrants in the FCV industry. Incumbent dominance is also reflected by the fact that we mainly found incumbent firms in the FCV sample. This finding is in line with the findings of Wesseling et al. (forthcoming: 2012), who found that the big 15 incumbents have a very large share of FCV patents over time.

Frenken et al. (2004) and Oltra & Saint Jean (2009) found an increase in BEV and FCV patents over 1980-2001 and respectively 1990-2005. In this study, the number of BEV patents is stable until 2002, after which it shows an upward trend, while the number of FCV patents shows a downward trend after 2004. There seems to be a shift that was not yet visible in the years studied by Frenken et al.

[18] See section 6.3 for additional insights.

(2004) and Oltra & Saint Jean (2009). In terms of knowledge development, knowledge development declines in the FCV industry, while the BEV seems to become a more popular alternative to be developed. Apparently, firms shift their focus from FCVs to BEVs. Furthermore, Frenken et al. (2004) found that FCV development requires a longer time horizon. This finding, suggests that entry in the FCV industry slowly becomes pointless, because of the (too long) time FCV development takes and the increasing attention for BEVs. This finding does not only apply to new entrants, but to all participants that are not (yet) active in the FCV industry. In terms of innovation strategy, it is much harder for late entrants in the FCV industry to gain a first-mover advantage because of the long time horizon, as knowledge might become obsolete because of a shift to another technology (e.g. BEV) or because of the advantages of the first-movers that were already active in the FCV industry. This while gaining a first mover advantage in the BEV industry is still possible, because of the more radical nature of innovation in the BEV industry, the shorter time horizon required for BEV development and the popularity of the BEV. Entry barriers are thus lower in the BEV industry. It seems that knowledge development in the FCV industry is of a more incremental nature. Incremental innovation might be inevitable, because of the high costs and long time horizon of knowledge development in the FCV industry.

6.2. Licenses and component supply contracts

The theory as presented on knowledge exchange and acquisition applies also to the ZEV industry. The discussed possibilities for knowledge exchange and acquisition correspond with the strategies of the different types of organizations. Only, buying components as a means of acquiring knowledge is not as straightforward as presented in theory. It seems that bilateral knowledge exchanges are in most cases needed in order to achieve a successful integration of components. In order to test hypothesis 3b *(Acquisition of components is a more important source of knowledge in the BEV industry than in the FCV industry),* more research is needed on the bilateral exchanges that are needed for the integration of components, as the data in this study do not allow to conclude in which industry the acquisition of components is a more important source of knowledge. Only when bilateral exchanges needed for component integration are studied more extensively it becomes possible to test whether or not the acquisition of components is of higher importance either in the BEV industry or in the FCV industry.

Interestingly, the component supply contracts as well as the licenses mainly stem from 2006 to 2012. This while at least a part of the websites consulted are from 'older' magazines that go further back than 2006. There is thus an increase visible in active technology licensing in the BEV industry, and in component supply contracts in both the BEV and FCV industry. Lichtenthaler & Ernst (2012) and Arora & Ceccagnoli (2006) already found an increase in active technology licensing for other industries. Furthermore, Lichtenthaler & Ernst (2012) found that technology licensing is not a substitute for development, and that a balance between own development and licensing is sought for. In the BEV industry firms do seem to keep this balance, because in most cases firms only obtain licenses on specific parts only and thus need to develop the largest part of their products themselves. For the FCV industry only one license is found. An increase in licensing is thus not visible for the FCV industry. It therefore seems that the importance of own knowledge (development) is much higher in the FCV industry. Possibly this is caused by the long time horizon, that causes out-licensing for firms that also use their technologies themselves to be riskier in the FCV industry than in the BEV industry as out-licensing might significantly reduce their (leading) position. In this case a firm will not generate additional value out of its knowledge, but only endanger its own position. It therefore does not seem wise (for any incumbent firm) to out-license knowledge in the FCV industry if it is capable of (financing) internal development and bringing its products to the market.

It seems that just as for licensing, a good balance of own knowledge is also needed for buying components and that buying components is not a substitute for development either. For example for the delivery of a fuel cell or a powertrain the delivery of a component is not enough, because knowledge development and transfer is also needed for the integration of a component.

The increase in active BEV technology licensing might furthermore be explained by a shift from mainly internal knowledge development to more open models of innovation. A shift to open models of innovation seems especially likely for PROs and Outsiders. For the PROs, open knowledge development seems logical as it creates a way to generate an income out of their knowledge. In the case of outsiders theory suggested that open forms of knowledge exchange were likely if outsiders do not own the complementary assets that incumbent firms have to exploit new technologies.

An important finding for the incumbent firms is that incumbent firms only license to restricted partners. One might thus wonder to what extent incumbent firms are really making a shift to more open forms of knowledge development. Incumbent firms thus seem to use technology licensing more strategically. Gulati (1998) found that, in general, firms carefully choose their partners for a collaboration. Technology licensing can in this respect be seen as such a type of collaboration. More specifically, Kim & Vonortas (2006) found that a firm will easier issue a license if the licensee is closer to their own technical profile, market profile, and if the firms are more familiar with each other through prior agreements. This seems to correspond with the licenses found in this study, as incumbents mainly seem to license to incumbents. Eswaran (1994) furthermore found a strategic incentive for firms to out-license to weaker firms with little viable technology, namely to crowd the market and to deter entry of a stronger competitor. This could explain why incumbents do not license to new entrant firms as they might be a threat. But it does contradict the fact that incumbent firms license to other incumbent firms, as it is found in this study that the incumbent firms do seem to own viable technology (at least not less viable than other organization types' knowledge).

Hypothesis 2 *(2a: Incumbent firms will choose for a restrictive approach of knowledge exchange; 2b: New entrants will choose for more open forms of knowledge exchange; 2c: Outsiders will choose for open forms of knowledge exchange; 2d: PROs will choose for open forms of knowledge exchange)* proved to be a good basis for distinguishing different types of knowledge transfers. Hypothesis 2 was primarily based on strengths and weaknesses of different types of organizations, such as incumbent inertia and the lack or ownership of complementary assets. Based on the results it seems that besides these strengths and weaknesses it is important to take the types of organizations and strategies into account. For example incumbent firms strategically license to other incumbents and not to outsiders and new entrants.

The hypotheses furthermore helped answering RQ3 *(What knowledge transfer patterns can be distinguished between different types of organizations during the period 1990-2010?)*. The results show that PROs and outsiders choose for open approaches of knowledge transfer, while incumbent firms choose for more restricted approaches of knowledge transfer. A clear increase in knowledge transfers is visible after 2005, indicating a possible shift to more open innovation by outsiders and PROs. It was not possible to identify a knowledge transfer pattern for new entrants, as there is a lack of data on new entrant licenses. Although, the knowledge quality of the new entrants is low compared to the knowledge quality of the other types of organizations. New entrants do therefore have two options, if possible invest more in R&D, or make more use of open models of innovation to increase the quality of their knowledge development, but at the same time reduce risks and costs.

6.3. Theoretical implications

The trends in the ZEV industry provide new theoretical insights. Wesseling et al. (forthcoming: 2012) identified a discontinued wave of hydrogen FCV development in the annual portfolio share of the fifteen largest CAs from 1998 to 2007. Here, the annual portfolio share of hydrogen FCV patents almost reaches 7% of all patents hold by the 15 largest CAs. For BEV patents this share is less than 1%. In almost the same period, we find that small incumbents and outsiders are starting to outperform large incumbents on BEV patent quality. Strikingly, theory argued that the development, exchange and acquisition of knowledge is important for gaining a competitive advantage. It seems however that small incumbents and outsiders are given space by the large incumbents, because the large incumbents shifted their focus to (H)FCV development instead of that small incumbents and outsiders transformed their asset position by increasing knowledge development.

Knowledge development in the BEV industry is characterized by a fast increase in non-incremental (radical) innovation, as the amount of cited patents remains low (even decreases), while the amount of patents is increasing rapidly. These are possible symptoms of the emergence of niche markets (Anderson & Tushman, 1990; Geels, 2002). Here we see that the knowledge on batteries and infrastructure is owned in particular by outsiders. Partly because of this, it is possible for the small incumbents and outsiders to offer their products as niche products (including the arrangement of infrastructure etc.) and influence standards. At the same time the political landscape is changing, encouraging radical innovation. The large incumbents have this same political advantage. They are, however, betting on another technology (FCV) that is much harder to offer as a niche product, making a breakthrough much more difficult. Infrastructure (e.g. hydrogen fuelling stations) for FCVs is for example much harder to implement, making the commercialization of FCVs harder. By creating successful niches, the BEV has a better chance of becoming the dominant design.

After and during the last year of the discontinued wave of hydrogen FCV development found by Wesseling et al. (forthcoming: 2012), we observed an increase in BEV licenses and in BEV and FCV component supply contracts, belonging to large incumbents. Furthermore, Wesseling et al. (forthcoming: 2012) found an increase in the large 15 CAs' patent portfolio shares for BEVs after 2006 and a decrease in patent portfolio shares for FCVs after 2007. We also observe a large increase in BEV patents (for all types of organizations) and a decrease in FCV patents (for incumbent firms). Our finding is in line with the finding of Wesseling et al. (forthcoming: 2012). It seems that the large incumbents are making their comeback in the BEV industry now that the small incumbents and outsiders proved the BEV to be a viable technology. However, to catch up and exchange their fast or late follower position into a first mover position it seems that large incumbents start obtaining licenses and start buying components as the other types of organizations seem to own important knowledge on for example batteries and powertrains that the large incumbents are lacking.

In short, a potential catch up by small incumbents and outsiders does not seem to be caused by their asset position due to knowledge development, but by the shift of large incumbents to another technology (FCV). Future dominance by large incumbents seems to become harder over time because of the lead of the small incumbents and outsiders that was made possible by the large incumbents themselves. In terms of innovation strategy, the large incumbents made it possible for the small incumbents and outsiders to become first movers instead of fast or late followers and made themselves fast followers. Although, obtaining a first mover position does not seem impossible for the large incumbents, now that the small incumbents and outsiders have proved the BEV to be a viable technology. Further research is needed to confirm if large incumbents are able to make a successful comeback or that they are merely becoming imitators because of a knowledge gap.

6.4. Limitations

Based on a lack of data on new entrant licenses and a low amount of licenses in general, the data collection on licenses must be further improved. Due to the current lack of data on licenses, it was not possible to test hypothesis 2b. In order to work around this issue, not only the firms that issued a license have been analyzed, but also the firms that received a license have been analyzed. This made it possible to test the other corresponding hypotheses besides hypothesis 2b. In addition, knowledge development, acquisition and transfer strategies are partly quantitative and partly qualitative examined and explored. A future study that quantitatively studies the relationship between firm type and knowledge development, acquisition and transfer strategies is therefore desirable.

It was furthermore difficult to discover trends for the FCV industry as only 34 cited patents were found over the period 1990-2010. Although this amount is very low, by using the full EPO database, probably the most important patents were found. Including, for example, the USPTO in the search might have returned additional patents, but also less important patents. Using IPC codes in the search strings instead of keywords might be another option in this respect, as it will return all relevant patents in certain IP classes regardless of the words in the title and abstract, but also many irrelevant patents.

The patent data does show that outsiders and small incumbents might overtake the large incumbents in the future in terms of knowledge quality. Despite this observation, the large incumbents mainly seem to be the organizations that currently bring BEVs to the market. According to Teece (1986), imitators can outperform innovators if they are better positioned in terms of complementary assets. Large incumbents should not be confused with imitators, but both imitators and large incumbents with a late entry timing might have the advantage of complementary assets. It therefore seems not plausible that the outsiders and small incumbents will outperform the large incumbents in the future. Examining the relation between knowledge quality and firm position in terms of effective sales, available products and complementary assets is therefore desirable.

Finally, licensing and the supply of components are dependent on partnerships between firms. The types of partnerships could, however, not be distinguished in this respect. It is therefore important that further research is done on the relation between a firms' willingness to license and willingness to supply components and the types of partnerships a firm is in (with the firm that wants to acquire a license or buy a component).

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Appendix 1: License Agreements

Firm	Firm type	Licensed to	Firm type	Description	Publication date	Component	URL
A123	Outsider Supplier	IHI Corporation	Large incumbent Supplier	A123 Systems to license Li-ion battery system technology to IHI Corporation; IHI makes $25M equity investment in A123	November 7, 2011	battery	http://www.greencarcongress.com/2011/11/a123-20111107.html
Argonne National Laboratory	PRO	GM, LG Chem, Envia Systems	Large incumbent CA, Outsider Supplier, New Entrant Supplier	Cathode technology licensed by Argonne that allows for longer-lasting charges at higher voltages and a longer battery life	February 23, 2011	battery	http://www.cars21.com/content/articles/51520110223.php
Argonne National Laboratory	PRO	BASF	Large incumbent Supplier	BASF is one of only two licensed suppliers of the Argonne National Laboratory's (ANL) patented Nickel-Cobalt-Manganese (NCM) cathode materials, which employ a unique combination of lithium and manganese-rich mixed metal oxides.	November 16, 2010	battery	http://www.electric-vehiclenews.com/2010/11/basf-builds-production-facility-for.html?m=0
Detroit Electric	New entrant CA	Proton	Large incumbent CA	Detroit Electric will license two vehicle platforms while Proton will assemble the EVs under the Detroit Electric brand	August 5, 2010	vehicle platform	http://www.cars21.com/content/articles/3620090330.php
Electrovaya	Small incumbent Supplier	Miljobil	Large incumbent CA	Electrovaya Receives Initial License Payment for Electric Car and Battery Production in Norway	October 2, 2008	car	http://evworld.com/news.cfm?newsid=19337
Fiat	Large incumbent CA	Chrysler	Large incumbent CA	Chrysler has a license from Fiat to build the fuel- and battery-powered versions of the 500, which means the U.S. automaker gets all the profits--or losses--from North American sales of the cars.	April 1, 2011	car	http://www.autoweek.com/article/20110401/GREEN/110409992

Hydro-Québec's Institut de recherche d'Hydro-Québec (IREQ)	PRO	Focus Metals Inc	Outsider Other	Focus Metals and Hydro-Québec IREQ sign graphite purification technology agreement and anode production agreement for Li-ion batteries	May 13, 2012	battery	http://www.greencarcongress.com/2012/05/focus-20120513.html
Intelligent Energy	Outsider Supplier	Suzuki Motor Corporation	Large incumbent CA	Intelligent Energy and Suzuki Motor Corporation Establish Joint Venture Company to Develop and Manufacture Fuel Cell Systems (gives Suzuki access to fuel cell technology)	February 7, 2012	fuel cell	http://www.fuelcelltoday.com/news-events/news-archive/2012/february/intelligent-energy-and-suzuki-motor-corporation-establish-joint-venture-company-to-develop-and-manufacture-fuel-cell-systems
ITOCHU	Outsider Other	Ener1	New Entrant Supplier	Ener1 Signs License Agreement with ITOCHU for Li-Ion Technology	September 11, 2007	battery	http://www.greencarcongress.com/2007/09/ener1-signs-lic.html
LiFePO4+C Licensing AG (Hydro-Québec (Montréal); Université de Montréal; and Centre National de la Recherche Scientifique (CNRS, Paris)) an affiliate of Clariant AG	PRO	BASF	Large incumbent Supplier	BASF, through its global Battery Materials business unit, today announced that it has signed a long-term licensing agreement to acquire global rights for the production and sale of Lithium Iron Phosphate (LFP) battery materials technology from LiFePO4+C Licensing AG, Muttenz, Switzerland, an affiliate of Clariant AG.	March 16, 2012	battery	http://beta.cars21.com/news/view/2766 http://www.greencarcongress.com/batteries/

Ovonic Battery Company	Outsider Supplier	EVB Technology	Incumbent Supplier	EVB is a battery manufacturer with licenses from Ovonic	February 10, 2011	battery	http://www.cars21.com/content/articles/50520110210.php
Tesla	New entrant CA	Mercedes and others	Large incumbent CA	Licensing Tesla's power train	June 25, 2009	powertrain	http://beta.cars21.com/news/view/1613
Tokyo Electric Power Company	Outsider Infrastructure	AKER WADE	Small Incumbent Infrastructure	License for manufacturing and marketin of Level III DC fast chargers for Evs	April 8, 2010	charging	http://www.cars21.com/content/articles/28020100408.php
University of Illinois at Urbana-Champaign	PRO	Xerion Advanced Battery Corp	RO	University of Illinois licenses StructurePore cathode technology to Xerion for commercialization of the ultra-rapid charging technology	July 25, 2011	battery	http://beta.cars21.com/news/view/3450
University of Texas	PRO	Hydro-Quebec	Outsider Infrastructure	The University of Texas at Austin has announced an agreement with Canada-based Hydro-Quebec for lithium-ion material technology invented and patented by Dr. John Goodenough, a world-renowned scientist at the university	July 20, 2011	battery	http://beta.cars21.com/news/view/3463
US Department of Energy's Pacific Northwest National Laboratory (PNNL)	PRO	Zap	Small incumbent CA	The US Department of Energy's Pacific Northwest National Laboratory (PNNL) has licensed its Smart Charger Controller to the California-based electric car maker Zap.	April 27, 2010	charging	http://beta.cars21.com/news/view/2395
ZAP	Small incumbent CA	Zhejiang Jonway Automobile Co. Ltd.	Small incumbent CA	ZAP will perform research and development of the core technology in Santa Rosa, California and license the technology for this partnership.	January 23, 2010	car	http://green.autoblog.com/2010/01/23/does-zap-have-an-electric-suv-up-its-sleeve/

Appendix 2: Component supply contracts

Firm	Firm type	Contract with	Firm type	Description	Publication date	Component	URL
Beiqi Foton Motor Co. of Beijing	Large incumbent CA	AC Propulsion	Small incumbent supplier	AC Propulsion signs electric vehicle drivetrain and battery pack supply contract with Beiqi Foton Motor	October 26, 2011	battery, powertrain	http://www.greencarcongress.com/2011/10/acp-beiqi-20111026.html
Changan Automobiles	Large incumbent CA	LG Chem	Outsider supplier	LG Chem to Supply Batteries to Changan Automobiles	February 5, 2010	battery	http://www.evworld.com/industry/news.cfm?newsid=22796
Chery Automobile Co.	Small incumbent CA	China BAK	Outsider supplier	China BAK Battery awarded li-ion supply contract for Chery Automobile Co.	September 15, 2010	battery	http://green.autoblog.com/2010/09/15/china-bak-battery-awarded-li-ion-supply-contract-for-chery-autom/
Daimler	Large incumbent CA	Ballard	Small incumbent supplier	Ballard Power Systems has announced that it has received a $24 million contract from Daimler to supply its FCvelocity fuel cell systems.	December 23, 2009	fuel cell	http://green.autoblog.com/2009/12/23/ballard-gets-contract-to-supply-fuel-cells-to-daimler/
Daimler	Large incumbent CA	Quantum	Small incumbent supplier	Daimler awards Quantum contract to develop advanced high capacity hydrogen storage systems for fuel cell vehicles	September 12, 2011	fuel cell	http://www.greencarcongress.com/2011/09/daimler-awards-quantum-contract-to-develop-advanced-high-capacity-hydrogen-storage-systems-for-fuel-.html
Mercedes	Large incumbent CA	Dynetek	Small incumbent supplier	CANADA: Dynetek to supply Mercedes A-class fuel cell storage systems - report	September 24, 2003	fuel cell	http://www.just-auto.com/news/dynetek-to-supply-mercedes-a-class-fuel-cell-storage-systems-report_id78685.aspx

Mercedes/Daimler	Large incumbent CA	Tesla	Small incumbent supplier	Details of the deal are expected to be announced in the coming months, but it will further Tesla's collaboration with Daimler with deliveries under the Smart Fortwo and Mercedes A-Class programmes scheduled by the end of this year.	November 4, 2011	powertrain	http://www.thegreencarwebsite.co.uk/blog/index.php/2011/11/04/mercedes-hands-electric-car-project-to-tesla-motors/
Exide Technologies	Outsider supplier	Axion Power	Outsider supplier	Axion Power Enters Worldwide Supply Agreement with Exide Technologies for PbC Batteries	April 13, 2009	battery	http://www.greencarcongress.com/2009/04/axion-exide-20090413.html
GM	Large incumbent CA	A123 Systems	Outsider supplier	General Motors has awarded a production contract to A123 Systems, a developer and manufacturer of advanced Nanophosphate® lithium ion batteries and systems, for batteries to be used in future GM electric vehicles to be sold in select global markets.	August 11, 2011	battery	http://evworld.com/news.cfm?newsid=26264
Honda	Large incumbent CA	Ballard	Small incumbent supplier	Ballard to supply Honda with 32 fuel cells over next three years	December 3, 2002	fuel cell	http://www.just-auto.com/news/ballard-to-supply-honda-with-32-fuel-cells-over-next-three-years_id82878.aspx
Hyundai	Large incumbent CA	EnerDel/Ener1	New entrant supplier	Ener1 to Supply Batteries for Hyundai Electric Buses	August 7, 2010	battery	http://evworld.com/news.cfm?newsid=23788
Mahindra & Mahindra	Large incumbent CA	Quantum	Small incumbent supplier	Mahindra & Mahindra awards Quantum contract for hydrogen ICE vehicle development	January 12, 2012	fuel cell	http://www.greencarcongress.com/2012/01/mm-20120112.html
Citroën	Large incumbent CA	Axeon	New entrant supplier	New battery for the electric Citroën C1 ev'ie	February 3, 2010	battery	http://www.greencarsite.co.uk/econews/ELECTRIC-CITROEN-C1-EV-IE.htm
PSA	Large incumbent CA	Mitsubishi	Large incumbent CA	Mitsubishi, PSA Finalize Electric Car Agreement	March 9, 2010	car	http://evworld.com/news.cfm?newsid=22982

Renault	Large incumbent CA	LG Chem	Outsider supplier	LG Chem charms over Renault, agrees to largest lithium-ion deal to date	October 6, 2010	battery	http://www.cars21.com/article.flash.php?Id=1346 http://green.autoblog.com/2010/10/04/lg-chem-charms-over-renault-agrees-to-largest-lithium-ion-deal/
Shanghai Fuel Cell Co., Ltd.	New entrant CA	Ballard	Small incumbent supplier	Ballard Power Signs Supply Agreement with Shanghai Fuel Cell Vehicle Powertrain	July 5, 2006	fuel cell	http://www.asiapacific.ca/fr/news/ballard-power-signs-supply-agreement-shanghai-fuel-cell-vehi
Tata	Large incumbent CA	Energy Innovation Group Ltd.	Outsider supplier	Tata Selects EIG Lithium Batteries for Electric Car	October 27, 2009	battery	http://evworld.com/news.cfm?newsid=22067
Tesla	Small incumbent CA	Panasonic	Large incumbent supplier	Tesla and Panasonic enter into new supply agreement	October 11, 2011	battery	http://www.torquenews.com/1070/tesla-and-panasonic-enter-new-supply-agreement
Think	Small incumbent CA	EnerDel/Ener1	New entrant supplier	BREAKING: Ener1 and Th!nk sign the largest contract for lithium-ion batteries in automotive history	October 15, 2007	battery	http://green.autoblog.com/2007/10/15/breaking-ener1-and-th-nk-sign-the-largest-contract-for-lithium/
Toyota	Large incumbent CA	Tesla	Small incumbent CA	Officially Official: Tesla inks $60M Toyota deal to supply components for RAV4 EV	October 14, 2010	powertrain	http://www.autoblog.com/2010/10/14/officially-official-tesla-inks-60m-toyota-deal-to-supply-compo/
Valence	Small incumbent supplier	PVI	Small incumbent supplier	Valence signs extended supply agreement for Li-ion batteries with PVI	May 30, 2012	battery	http://www.greencarcongress.com/2012/05/valence-20120530.html
Van Hool NV	Small incumbent CA	Ballard	Small incumbent supplier	Ballard fuel cell power modules to power 5 HyNor hydrogen buses in Norway	February 21, 2011	fuel cell	http://green.autoblog.com/2011/02/21/ballard-fuel-cell-power-modules-to-power-5-hynor-hydrogen-buses/
VIA Motors	New	A123	Outsider	A123 to Supply Lithium Ion Batteries to VIA	January 8, 2012	battery	http://www.evworld.com/ne

	entrant CA	Systems	supplier	Motors			ws.cfm?rssid=27169
Volvo	Large incumbent CA	EnerDel/Ener1	New entrant supplier	Volvo Debuts C30 Battery Electric Car Today	September 17, 2009	battery	http://www.evworld.com/news.cfm?newsid=21770
Volvo	Large incumbent CA	Getrag	Large incumbent supplier	GERMANY: Getrag secures Volvo electric drive unit contract	November 11, 2010	electric drive unit	http://www.just-auto.com/news/getrag-secures-volvo-electric-drive-unit-contract_id107080.aspx