CHALMERS

Technology sourcing and exploitation in the knowledge economy:
The case of the Hybrid Electric Vehicles industry

Master of Science Thesis in the Master Degree Programme,

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ABSTRACT

This is a master thesis at the Masters Program: Business Design, specifically School of Intellectual Capital Management, Chalmers University of Technology. The purpose of the thesis is to investigate if the knowledge economy will create new challenges of how firms compete for technology. I have chosen to look at the automotive industry in general and the Hybrid Electric Vehicles (HEV) industry in particular to find how technology is source and exploited in the HEV industry as well as the effects the inclusion of HEV technologies has had on the network of technology providing actors in the HEV industry. By performing a number of interviews, making a literature study of the existing HEV technology areas and conducting several patent database searches within the HEV landscape the research questions are answered. By looking at different actor groups of contextually equivalent actors the actor groups were compared in terms of their technology position in the value chain. These groups are OEMs, system providers, component providers, technology providers and consultancy service providers and they are compared in the technology areas Powertrain Management Unit – Control system, Powertrain - Electric Machine, Power source – Lithium Ion, Power source – Battery management unit.

The HEV industry has two primary sourcing strategies called specialization and integration and the strategy pursued differs between primarily Japanese who follow an integration strategy and European actors who follow a specialization strategy. Furthermore it is found in this thesis that one step in the traditional automotive value chain is skipped and OEMs and component suppliers collaborate to include new technologies in the industry. Since the introduction of the first HEV new actors have been introduced alongside the HEV technologies and there has been a shift in responsibilities among the actor groups where some actors are given a higher responsibility for technology upstream technology development. These actor groups are in particular Technology Providers and Component Providers. From the patent data analysis we can see that this has changed the structure of the network of technology actors slightly.

When considering the value network from the three perspectives of centrality, centralization and inter-block relations I find that Toyota through the introduction of the first HEV technologies became a highly central firm in the HEV value network and that OEMs in general have a high centrality. This also provides a high centralization of the value network but where as previously stated the European HEV industry has a lower centralization compared to the Japanese HEV industry. The introduction of new technologies in the HEV industry have brought a structure loosening trend to the European HEV industry where external demands and internal limitations of firms to some extent force them to decentralize the network structure and push technology development upstream in the value chain.

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FOREWORD

The knowledge economy and the exponential change in societies producing the commoditization of knowledge are ever intriguing. Starting of this thesis I wanted to find out what aspects of an industry that changes as it moves towards becoming more knowledge centered. As it turned out it was hard to concretize something abstract by nature. Building on an interest spurred in the master course Advanced ICM theory and an interest for the automotive industry I sat out to investigate if the introduction of the hybrid electric vehicle could mean that also the automotive industry is entering this economy of knowledge and if so how would the infrastructure of that industry change. This proved to be an interesting and challenging task.

I have now reached the summer and closing in on the end of my thesis I am thinking of what I've learned this autumn and from whom. Throughout this spring I have spent many hours investigating the hybrid electric vehicles industry and by that got an insight to both managerial principles and technical innovations but experiences are gained through interaction with others. Starting of I would therefore like to thank Anders Sundelin who has supervised and mentored me throughout the spring. He has also provided me with tools and principles from CIP Professional Services that have been used in this thesis. Thank you for your patience and support. Furthermore I would like to thank all interviewees for helpful and interesting interviews and a willingness to share your experiences. To everyone at CIP Professional Services, thank you for making this spring both fun and interesting. My last thank you goes to the ever cheerful Eva Henricsson for being a sounding board and support during this spring.

1 INTRODUCTION TO THE THESIS

"The change brought about by the networked information environment is deep. It is structural. It goes to the very foundations of how liberal markets and liberal democracies have co-evolved for almost two centuries".[1]

The knowledge economy differs from the industrial economy in the way the fundamental scarce resources in economic production of the economy are assessed. In this new economy the traditional resources such as land, labor and capital are superseded by knowledge as such[2]. What can be seen in this economy is that access and production of knowledge becomes prerequisites for value creation[3]. As an analogy it is said that the role of knowledge in the knowledge economy is of similar importance as capital in the industrial economy.[4] What also can be seen is that the neoclassical view of the firms is no longer valid since the firm cannot be assumed to be unable to affect its environment and market conditions. Innovation and the creation of markets is dependent on the firm, the system in which the firm operates and the firm's ability to affect this system[5]. Hence, innovation is no longer exogenous and can be sourced through the collective ideas and knowledge within a system.

But what are an economy and a market? Economic theory describes an economy as markets where products, services and monetary flows are analyzed in terms of their impact on said market. The theories are based on the assumption that humans are rational and profit maximizing and models are created over how rational humans will act to consume, produce or trade goods or services under the pressure of scare resources. This choice made by humans is connected to an opportunity cost[6]. Hence, a market is driven by human choice. A less abstract definition of a market is that it is

> "*a means by which the exchange of goods and services takes place as a result of buyers and sellers being in contact with one another, either directly or through mediating agents or institutions*"[7].

Although expressed in a number of different ways[8] a market is usually defined as a means for an exchange of goods between actors that are in some way connected through mediating agents or institutions. Hence, defining a market includes describing the different means for exchange of goods, the actors which make the exchange, how these actors are connected and the agents and/or institutions which mediate the connection between different actors. The concept of division of labor, as introduced by Adam Smith, is that the means for productivity is specialization. In order for this specialization to function there needs to be an exchange. If the cost of this exchange (the transaction cost) is lowered the specialization will increase. According to the theories of Ronald Coase, the cost of exchange depends on the institutions of a country: its legal system, political system, social system, educational system, its culture etc[9].

Kotler et al (2009) takes a marketing management perspective on markets and specify the exchange as a transaction of any product or service class. This highlights the issue if knowledge that is not codified or tacit can be said to be a product or service class. Petrusson (2004) categorizes knowledge that is codified, valuable and transferrable as intellectual capital. While some assets e.g. innovations or technologies can be codified as Intellectual Property Rights some might not be possible to be represented as property or capital as a product or

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[1] Benkler, 2006
[2] Liu, 2007
[3] Drucker, 1994
[4] Liu, 2007
[5] Kim & Mauborgne, 1999
[6] Wessels, 2006
[7] www.britannica.com (2011-02-11)
[8] Kotler, 2009
[9] Coase, 1990

service class could be. It can therefore be interesting to find effects of specialization and cost of exchange (benefits of exchange) regarding innovation and technology in the knowledge economy.

Each economy e.g. regional economy, national economy and global economy and consequently also the knowledge economy consist of complex interactions interlinked through transactions[10]. This is by Kotler et al (2009) referred to as the network economy. The network economy is defined as a dynamic, technology and knowledge dominant environment where organizations and institutions have evolved into networks such as[11]:

- **Internal networks** that reduce hierarchy and open up firms towards the environment
- **Vertical networks** that maximize the output of serially dependent functions by collaborations
- **Inter-market networks** that leverage through horizontal synergies in an industry
- **Opportunity networks** are networks centering on consumer needs and market opportunity to try to solve this market imbalance.

The networked economy shares some of the characteristics of the definition of the knowledge economy given in this thesis but in the knowledge economy a dimension of exchange of knowledge within the network is further emphasized besides the exchange of information. Kotler et al argue that when companies become more networked and through this business markets and the actors within these markets become more networked the level of complexity increases for the player in the market. This has several effects, out of which Kotler et al mention four:

1. Outsourcing and relationships that allow companies to operate blur the concept of the value chain.
2. As buyers and sellers collaborate in joint development efforts the concept of customer relationship is blurred.
3. The line between organizational functions are blurred since departments are interlinked through technology
4. The concept of product, experience and service is blurred as the economy moves from and industrial base to knowledge-based business.

There exist a basic set of collective resources for the knowledge economy which represent a supportive framework for the knowledge economy. This includes infrastructures, R&D potential, educational and training environment, pool of relationships and rules & norms providing trust and reliability i.e. institutions[12]. Furthermore the logic for strategic management can be said to have changed where primary strategic focus in the knowledge economy must be to expand existing markets or create new markets over outperforming competition in obsolete markets[13]. Blaxill and Eckhardt (2009) also argue that the concept of open or collaborative innovation in essence is about jointly growing the collective market[14]. Therefore it seems to exist a need to investigate under which conditions a firm can strategically interact with its environment and create wealth.

The knowledge economy has brought new types of actors and increased complexity of roles and relationships among actors[15]. One such actor and role that has undergone a change in responsibility and role is that of the service provider, especially regarding innovation and regional competitiveness. This is due to the fact that knowledge services systematically contribute to the distribution and implementation of knowledge[16]. Furthermore, knowledge services are also the starting point for the dispersion of the knowledge economy and

[10] Kotler, 2009
[11] Kotler, 2009
[12] Fuchs & Shapira, 2005
[13] Kim & Mauborgne, 1999
[14] Blaxill & Eckhardt, 2009
[15] Link & Siegel, 2007
[16] Fuchs & Shapira, 2005

knowledge markets as is exemplified in the quote below from Benkler (2006). "By codification, knowledge picks up more and more of the properties of a commodity. Market transactions are facilitated by codification: codified knowledge can be more precisely described and specified in terms of content and intellectual properties, and this can reduce uncertainties and information asymmetries in any transaction involving knowledge."[17]

In creating wealth, knowledge is becoming more and more important and is gradually replacing traditional assets as the key asset for wealth creation[18]. When intellectual properties are transacted and packaged so that they by the receivers are perceived as transactable the property can be interpreted as intellectual capital. It is not so much the transaction as such as the acceptance of the asset being transactable by the economic infrastructure that is the determining factor. The asset shall have reached a level of acceptance and perceived value that enables it to be used as collateral, basis for a technology license or other financial extraction means[19]. The value of intellectual capital or tradable intangibles (IPRs) is contextual and can have more than one revenue stream, in more than one context at the same time[20]. Since intellectual capital is a twofold issue of packaging the asset on the sending end and acceptance of the same asset on the receiving end both sides must be investigated to understand the creation of valuable assets in the knowledge economy. If assets are not accepted as a financial instrument they become dead capital[21]. There seem to exist a need for further studies that set out to investigate the infrastructures surrounding the receiving and creation of intellectual capital. This includes how infrastructural factors have evolved when knowledge is turned into intellectual capital and how knowledge is used to leverage ones position among a network of interdependent actors competing for the knowledge and technological upper hand.

Primary technological advancement has erased the physical and material barriers to production of information and knowledge which has produced a society in its foundation based on human creativity where economics of knowledge and information are the core infrastructure of the networked information economy or the knowledge economy. This structure for the new economy differs from the foundations of the structures of the industrial economy and the prevailing consensus around economic production of the past century or two[22]. One of the most radical observations as a result of this new economy is the emergence of effective, large-scale cooperative production efforts of knowledge, information and culture. The typical example of the co-creation era and also the success of the same are coming from open-source software and the Information & Communication Technology industries e.g. Linux[23] and Wikipedia[24]. Lately we there has been a growth of similar efforts also in other areas where it is no longer just software platforms that are co-created[25], e.g. the Human Genome Project[26].

The potential of co-creation seems to grow as more industries gradually evolve into using a similar set of assets or try to serve similar markets. Industry convergence is generally described as a blurring of industry boundaries[27]. Technological innovations are in many cases the drivers of industry convergence. Industries can be said to be technologically convergent when their products and processes rely on a similar set of technological assets[28]. In one general definition there exist two types of technological convergence, in

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[17] Fuchs & Shapira, 2005
[18] Kim & Mauborgne, 1999
[19] Petrusson, 2004
[20] Sullivan, 2004
[21] De Soto, 2000
[22] Benkler, 2006
[23] http://www.linuxfoundation.org/
[24] http://en.wikipedia.org/wiki/Wikipedia:About
[25] Benkler, 2006
[26] http://www.ornl.gov/sci/techresources/Human_Genome/project/hgp.shtml
[27] Stieglitz, 2002
[28] Stieglitz, 2002

downstream and upstream markets. In upstream convergence of markets products of diverging traits to a larger extent rely on the same set of technological assets. One classical example of this upstream convergence of markets is the convergence of telecommunications, computing and entertainment into a multimedia industry[29]. In downstream convergence of markets existing technological assets form diverging markets are used jointly or pooled in order to create new products and services[30]. One example is the Smartphone/PDA industry where telecommunications firms, computer firms, entertainment firms and the calculator industry competed to develop the first PDAs[31] and continue to compete for new generations of hand held devices. What effect does this industry convergence have on the creation and exploitation of technology and the actors creating this technology?

As an example we can see that more than 50% of the inventions stemming from Bell Laboratories are used outside the telephone industry[32]. There are also numerous examples from e.g. the consumer electronics industry where knowledge and products are co- created from numerous actors. This include the iPhone/iTunes interface where users, music providers, Apple and its suppliers all partake in the (co-)creation of not just the phone but the whole system of applications, media and hardware. This need for collaborative creation of knowledge can be further exemplified by the graph below showing a vast increase in R&D partnerships over a wide range of industries.

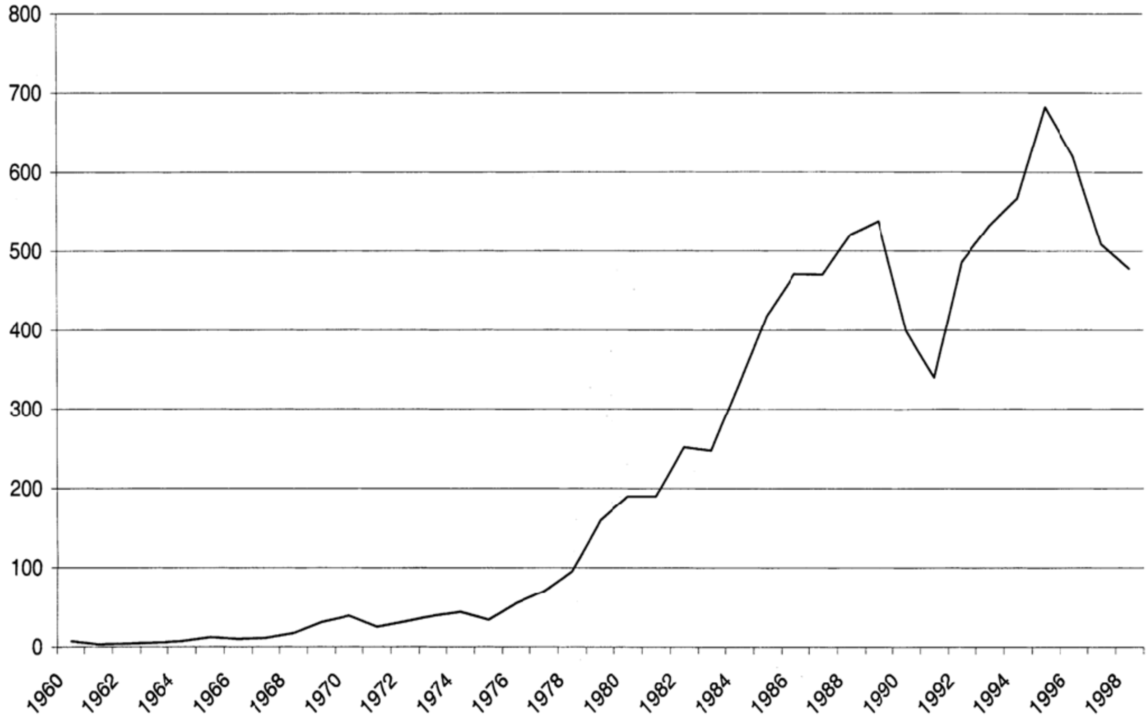

Figure 1 – The growth of newly established R&D partnerships 1960-1998. Source: Hagedoorn, 2002

A traditional industry very much a part of and driver of the industrial economy is the automotive industry. Automotive Original Equipment Manufacturers (OEMs) have traditionally invested heavily in R&D in order to be at the forefront of product and production technologies. Due to an increasing cost and innovation pressure this whole industry needs to find new sources to cope with the dilemma of cutting costs and increasing

[29] Stieglitz, 2002
[30] Stieglitz, 2002
[31] Stieglitz, 2002
[32] www.economist.se

innovativeness simultaneously[33]. So far the tendency has been to look outside the boundary of the firms but the industry has lacked external paths to market outside the current business up until today[34].

The trends leading up to the argument that we are entering a knowledge economy are both compelling and interesting but some industries seems to be more affected and adjunct with this new economy than others. I.e. one can see these new forms of collaborative innovation and open usage of knowledge in the software industries and consumer goods[35] but will it be able to enter old industries such as the automotive industries? If this transformation is underway, how will it affect the industry and the network of actors in the industry? What roles, relationships and characteristics will a mature industry characterized by industrial and production assets need to undergo this change?

A highly attenuated topic of research and management literature is the notion of open innovation which also argues for an open and collaborative approach towards innovation where knowledge (R&D) is sourced from outside the boundaries of the firm and is exploited externally[36]. How appropriate this external sourcing of knowledge is depends on the extent to which a firm conforms to macro level trends such as globalization, technology fusion, technology intensity, introduction of new business models and knowledge leveraging; characteristics set up by Henry Chesborough[37]. From the chart below we can see that the automotive industry seems to conform to the trends but more importantly the trends seems to become even more relevant for the automotive industry moving forward.

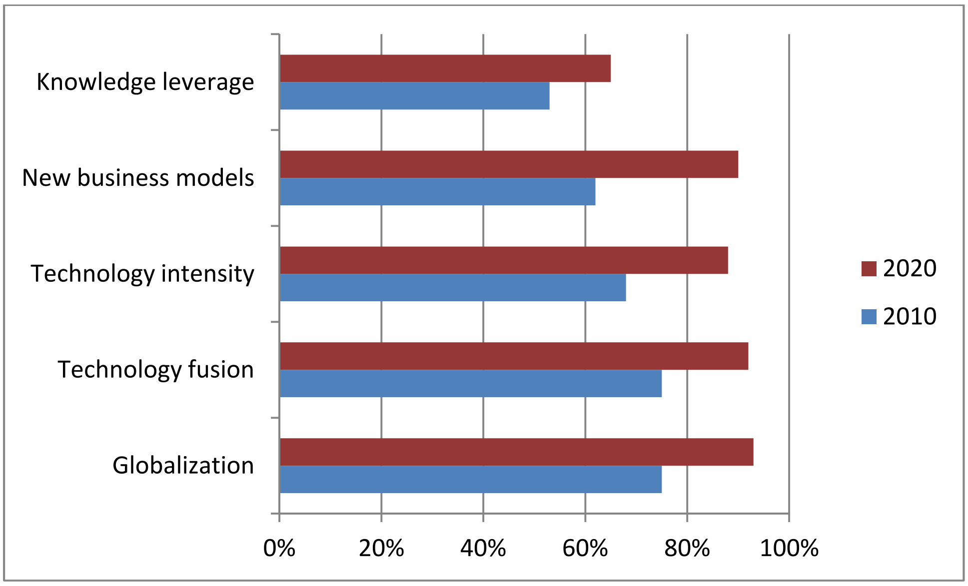

Figure 2 – Relevance of five trends and developments for the automotive industry today and in ten years. Source: Ili & Albers & Miller, 2010

In a recent study the automotive industry was investigated on the basis of 6 criteria's for open innovation set up by Chesbrough (2006). In this research it was found that with high significance the automotive leans towards the closed innovation paradigm[38].

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[33] Ili & Albers & Miller, 2010
[34] Ili & Albers & Miller, 2010
[35] Ili & Albers & Miller, 2010
[36] Chesborough, 2006
[37] Gassmann, 2006
[38] Ili & Albers & Miller, 2010

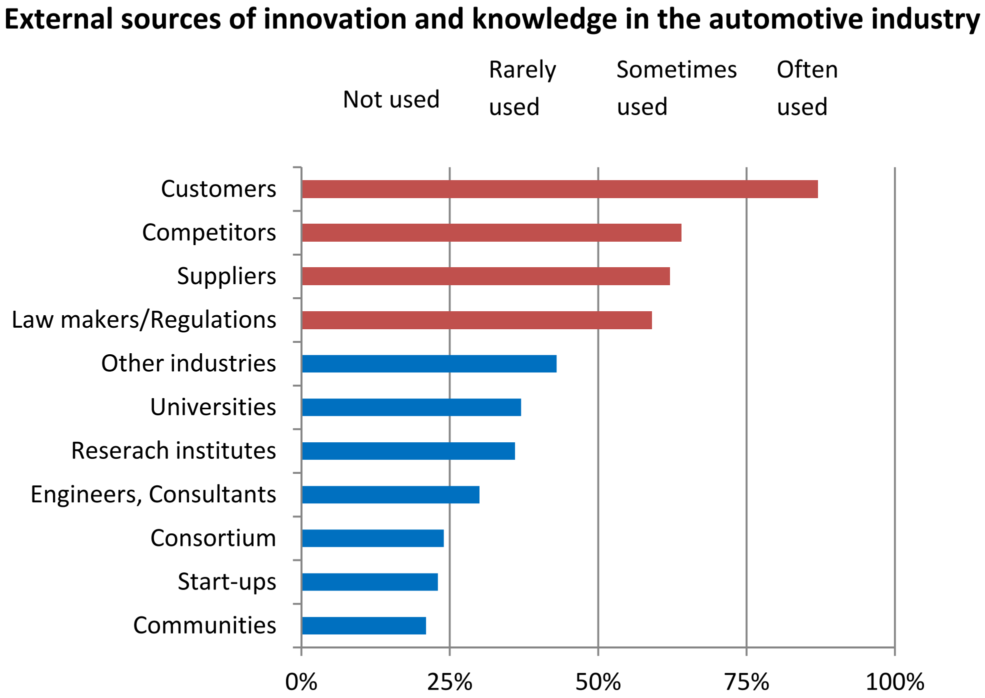

Figure 3 - External sources of innovation ranked based on their preference in the automotive industry. Source: Ili & Albers & Miller, 2010

The automotive industry to a large extent use in-house R&D as the primary source for knowledge. Apart from this they also to some extent use the actors most closely connected to them in their value network. As shown by the graph above (Figure 3) many sources of external innovation are rarely used but Customers, Competitors, Suppliers and Governmental actors are fairly common sources for innovation. This means that the automotive industry may be overlooking potentially valuable external sources of innovation[39]. It could therefore be interesting to investigate which external sources that are used, by whom and under which circumstances.

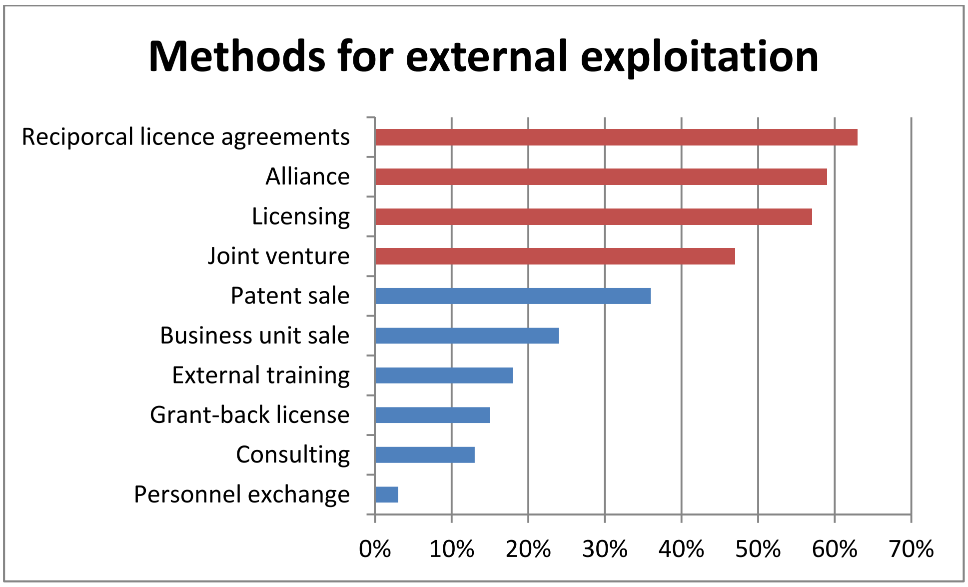

Figure 4 – Methods for external exploitation of own IP in the automotive industry, Source: Ili & Albers & Miller, 2010

[39] Ili & Albers & Miller, 2010

The most commonly used methods for exploitation of IP (knowledge) are licencing, alliances and reciprocal agreements. These are manly put in place as a measure to avoide conflict (reduce cost) rather than as means for profit maximization. So far there exists no norms or mindsets for active expliotations over the full automotive industry[40]. This thesis will investigate to what extent the industry will change in its view on technology sourcing and exploitation when entering into an era where knowledge access and knowledge production becomes more important. Potentially this change will be brought to traditional manufacturing industries such as the automotive industries as has happened in other areas of information and communication technologies, biotechnology etc. This industry wide change could be brought by the green era with fossil fuel reductions and the chase for reduced emissions with the use of new technology. The green era has already started alongside a electrification trend in the automotive industry. As stated earlier, technological innovation drives industry convergence and could it be so that these trends will bring new players to the industry, create new relationships, new knowledge and an increase in the usage of IPRs? I set out to analyze the transition to the knowledge economy in the automotive industry by looking at the growing hybrid and electrical vehicles market. Since the introduction of the first Toyota Prius in 1997[41] many of the large actors in the automotive industry have followed and introduced hybrid electric vehicles[42]. It does not only seem as though it is the car manufaturers (or OEMs) that are introduceing the new electrified technologies, new actors appear on the market and the whole value chain of actors seems to be affected in one way or another. In the knowledge economy where access to knowledge becomes crucial, will and have the dynamics between the actors in this industry changed?

[40] Ili & Albers & Miller, 2010
[41] http://www.hybridcars.com/history/history-of-hybrid-vehicles.html
[42] http://www.hybridcars.com/cars.html

1.1 RESEARCH QUESTIONS

The introduction introduced a number of interesting areas of research which have been boiled down to two thesis research questions. The introduction highlighted challenges and characteristics of the knowledge economy where new knowledge and innovation brings industries to converge which in turn brings new players, products, relationships and challenges to an industry. The industry studied in particular is the automotive industry and the “electrification” trend of the same where modern cars use hybrid electric drive trains to reduce emissions and fuel consumption. The thesis will investigate the industry development over time focusing on indicators of the knowledge economy with a high focus on where, how and by whom technology and knowledge is created in the Hybrid Electric Vehicles industry. The aim is to look at the dynamics of an industry in transition and to see if there is a shift in how technology is sourced. From this conclusions will be draw on what trends that are apparent in this transition to the knowledge economy and how the industry infrastructure changes in this transition. The research questions are presented below:

1. How is new technology sourced and exploited in the Hybrid Electrical Vehicles industry?
2. What effects has the introduction of new technology had on the network of actors creating the technology in the HEV industry: how has the network changed?

In my opinion there are a number of ways in which these questions can be answered so I will elaborate on what sub-questions were generated by the presented research questions. Hopefully this will also bring some clarity into the way in which I have approached in answering the questions which in turn lead to the chosen research methodology. Starting with the first question it focuses on new technology in the hybrid electric vehicles industry. This industry segment is chosen since it is closely coupled to recent introductions of technologies within the electrification of the automotive industry. To find sourcing and exploiting strategies my study will include mapping the technology areas of the HEV industry as well as mapping the different actor groups participating in the creation of these technology areas. By studying the relational types between these actor groups the exploitation strategies existent in the industry can be found. Also, by investigating how technology ownership and R&D activities to create new technology differ between different actor groups I will be able to conclude if the network of technology creators has changed since the introduction of the HEV technologies.

2 RESEARCH METHODOLOGY

The purpose of this section is to describe the process in which the research questions were answered and to motivate why the conclusions are valid as well as providing a set of limitations of the thesis.

This thesis aims at empirically testing the transition of an industry to become more knowledge centered when new technological innovations are introduced. When performing empirical research three commonly used approaches are deductive, inductive and abductive research. The three methods differ in how theory is applied and related to the empirically collected data. Deductive research takes the starting point in existing theory to produce a hypothesis and proves or rejects that theory with the support of empirical findings. Inductive research on the contrary uses empirical findings to produce a theory or improve existing theory. Abductive research combines the two concepts and starts with writing a theory on the basis of empirical findings and then uses new empirical data to test and improve the theory[43].

The research was initiated by an investigation of existing literature and theoretical concepts relating to the research questions. Literature in the form of books and articles has been used to produce the theoretical framework. This theoretical framework was then used as a basis for the empirical research and the conclusions drawn from the collected data. Hence, this thesis can be said to have deductive research approach.

The empirical research strategy used in this thesis is a case study. A case study typically studies an individual unit such as a child, a class, a school or a community[44]. The HEV industry studied in this thesis can be said to represent a community, sharing common characteristics. Furthermore, the purpose of a case study observation is to gain a deep understanding and analyze the life cycle of a unit and its many shifts and turns[45]. A case study is said to be applicable when you want to find phenomena close to peoples experience and practice and at the same time be able to draw generalized conclusions on a wider scale. This thesis uses the case of the HEV industry to be able to draw conclusions on the automotive industry at large. Furthermore, the suitability for small scale research also makes the case study a practical choice from a resource perspective[46].

[43] Patel and Davidson, 1991
[44] Biggham, 2008
[45] Biggham, 2008
[46] Blaxter, Hughes and Tight, 2006

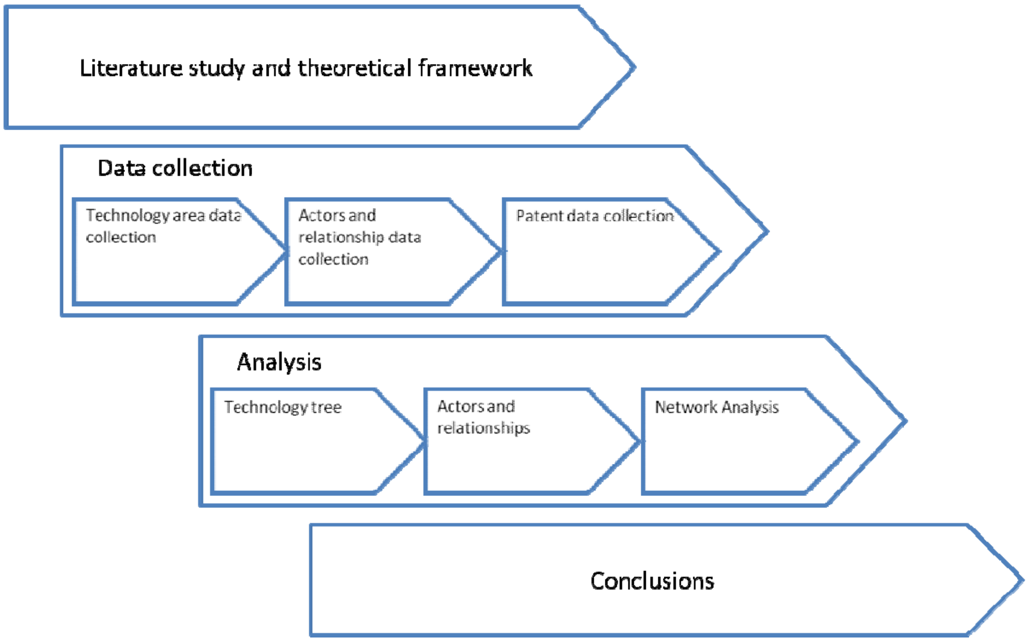

Figure 5 – Schematically described method used in this thesis

As is shown in Figure 5 the starting point in the thesis was to conduct a literature study and create a theoretical framework used to guide the analysis. After the theoretical framework was chosen a data collection phase started. This phase can be said to be divided into three parts as described in the figure. The first part was to map the knowledge base by presenting the technology areas in the HEV industry depicted by a technology tree. This was followed by an identification of the value chain of processes and actors in the industry. To be able to build a value network I investigated what actor types, roles and relationships that exist and group them in order to be able to analyze and compare the different groups in the analysis. To finalize and answer the questions of the effect of new technology have had on the network of actors creating the technology in the HEV industry I looked at changes in IPR position between different actor groups holding different positions in the value chain.

2.1.1 DATA COLLECTION

Quantitative and qualitative methodologies are two different approaches to systematic collection, organization and interpretation of data[47]. In this setting qualitative approaches can be said to hypothesis generating while quantitative approaches can be said to be hypothesis validating[48]. A qualitative approach is used to investigate the meaning of social phenomena as they are experienced by individuals themselves in a natural context[49]. Hence, the knowledge is acquired by interpreting the dataset. Au contraire, in quantitative research knowledge is acquired strictly based on positive affirmation[50].

An interview can be either quantitative or qualitative. A qualitative interview is used to unfold a characteristic or phenomenon. The interview can be either structured or unstructured[51] and depending on the research method they will differ in suitability. A structured interview will be performed in a questionnaire leaving less

[47] Malterud, 2001
[48] Ödman, 2007
[49] Malterud, 2001
[50] Ödman, 2007
[51] Phillips and Stawarski, 2008

room for flexibility outside the questions in the questionnaire whereas an unstructured interview leaves more room for reasoning from the interviewee[52].

The nature of the research in this thesis makes it suitable to use both quantitative and qualitative research methods. Initially this thesis sets out to find a set of characteristics in the HEV industry which were not set from the beginning. Therefore the qualitative approach was used through semi-structured interviews. These interviews rendered in a number of characteristics such as actors, roles and relationships. In order to find changes and trends in the characteristics generated in the interviews a more quantitative approach was used. Through patent database searches this thesis set out to find changes in their position in the value network. Since the thesis sets out to find developments in an industry at large this approach was chosen due the higher validity when studying the whole population by using patent searches.

The interview questionnaire (Appendix C – Interview Questionnarie) and the interviews was created with respect to that the interviewee ideally should be able to elaborate as much as possible on the different questions and depending on the expertise of the interviewee questions were given different emphasis during the interviews. The patent searches were performed in the patent database tool Thomson Innovation[53]. The searches were performed with respect to that a specific population of patents would represent the HEV industry. The population chosen to represent the HEV industry was ~16 500 patents found when performing a search for “hybrid” NEAR2 (“vehicle” OR “car”). All subsequent searches were done within this dataset.

The searches within the dataset will make the result skewed since it is tainted by the search phrase but it has been triangulated from a professional patent search report[54]. The patent dataset will also be skewed towards architectural patents meaning that there is a risk that the firms doing architectural R&D could be overrepresented in my searches. In effect this means that OEMs might be overrepresented in the results. Although a rigorous literature study and presentation of the technology areas of the HEV industry is made in the results chapter, this thesis chooses to focus in on a few specific technology areas to try to see trends in technology development and knowledge creation between different actor roles and position in the value chain.

For practical and resource reasons only a sample from the total population could be investigated in the interviews. There are many sampling techniques available, including, random sampling, stratified sampling, cluster sampling, systematic sampling quota sampling and convenience sampling. This thesis has chosen a convenience sampling of the interviewees due to the highly disperse and large population of actors in the HEV industry. Convenience sampling is as the name suggest non-random[55] and was implemented due to the accessibility of interviewees. Therefore the results from the interviews have to be treated with care and the reliability of the data from the interviews has been triangulated[56] by comparing it to a third source providing secondary data. The types of sources were data from industry reports, annual reports, business databases and web searches. The thesis therefore can argue for the possibility to generalize the findings over the full population of actors.

2.1.2 DATA ANALYSIS

[52] Phillips and Stawarski, 2008
[53] http://www.thomsoninnovation.com/
[54] Lloyd & Blows, 2009
[55] Biggham, 2008
[56] Biggham, 2008

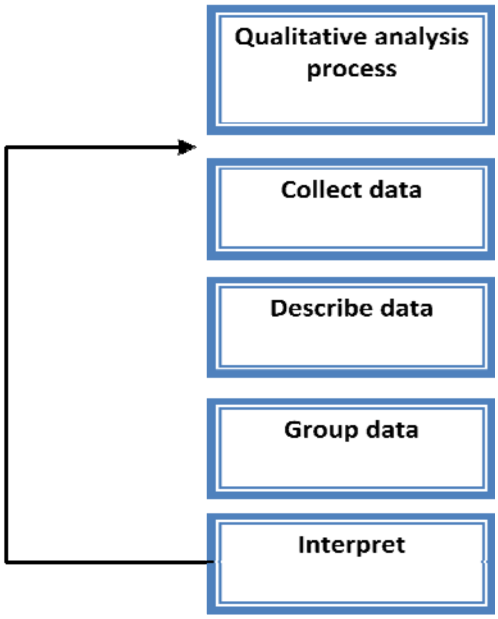

Figure 6 – Process for data analysis

The data used in this thesis comes from two primary sources of data namely interviews and patent database searches. To support this data secondary data from industry reports, annual reports, business databases and web searches has been used. To analyze the qualitative data an iterative analysis process has been used. This process is focused around the concepts of description, analysis and interpretation. Analyzing qualitative data requires an iterative process[57], why this has been applied. This process is shown in Figure 6.

The collected data was described and grouped into the themes actors, roles and relationships and analyzed separately. This was then interpreted at a whole to produce a broad understanding for the network of actors, relationships and technologies building up the HEV industry infrastructure. After this the findings from the data analysis were put into the analytical framework to find an academic context for the findings.

The actors were grouped into OEM, component and system supplier, consultancy or technology provider. This grouping was based on the interviews and also supported by industry reports. There exist a number of ways in which this large industry could be grouped but given the purpose of the thesis this level of scope in terms of comparable value chain/value network actors was considered suitable. A higher number of groups were expected to generate less clear-cut differences between the groups why this grouping was chosen.

2.1.2.1 PATENT DATA ANALYSIS

The actor groups were then analyzed in terms of their activity and IP ownership in general but also specifically within four technology areas. This analysis was based on the theoretical framework and was used as basis of comparison between the groups and to find changes over time within each actor group. The test plan is presented below in Figure 7.

To understand the technology and knowledge creation positions between different actor groups this thesis has investigated the IP position in different technology areas. These areas has been chosen since they were considered as key technology areas in the HEV industry and have the possibility to represent the positions of different actor roles. The areas chosen were powertrain management unit, the electric machine in the powertrain, the battery management unit and the battery. The powertrain technology areas are included since

[57] Biggham, 2008

they were mentioned in the interviews as key areas and areas where OEMs wants to keep a powerful technology position. Electric machine and battery were chosen since they are stated as important areas in the interviews but also as areas where OEMs have a less powerful technology position. Due to the large size of the investigated patent dataset only the top 20 assignees were used as a basis for comparison between the different actor roles. In Appendix D – Patent Analysis the tables with the top assignees in each technology area can be found and also which role each assignee has been given and the number of patents published by each actor during the two periods 2000-2005 and 2006-2010. The method for grouping the actors was done through internet searches on corporate websites combined with third party automotive industry organization' websites.

	Powertrain Management Unit – Control system	Powertrain - Electric Machine	Power source – Lithium Ion	Power source – Battery management unit
OEM				
System				
Component				
Technology				
Consultancy				

Figure 7 - IP data test plan

2.1.3 VALIDITY DISCUSSION

This thesis is claimed to be valid due to several reasons. First since the data collection is two-fold, both qualitative in the form of interviews and quantitative in the form of patent data I argue that my model for data collection provides a more complete empirical data than a choice of only one method for data collection would have given. The use of semi-structured interviews is considered to be a tested and trusted way of providing in-depth information about a subject[58], in this case an industry segments actors, roles etc. The length of the interviews and knowledgeable interviewees with both professional and academic experience from the HEV industry provide a solid understanding for the issues of the study that are qualitative by nature; such as relationships, roles and actors. The quantitative part of the data collection makes the analysis possible to generalize since a high number of interviews would be needed to be able to provide industry wide insights. Instead the quantitative use of a patent dataset covering all hybrid patents provides a dataset with the possibility to draw conclusions on a wider part of the population. Furthermore, the case study is supported by a literature review which provides both the possibility to triangulate the results. It is also a commonly used and tested research strategy. Therefore the thesis can be said to rest on a solid and by academia trusted research foundation. Hence, the data collection methodology is claimed to be valid.

The method for analyzing the data by grouping them into the distinct groups are analyzed under different themes is a commonly used method for analysis which is accepted by scholars. Furthermore, the analysis is supported by using and building on research and analytical techniques presented under Theoretical framework. Hence, I claim that the data analysis provides grounds for claiming that the conclusions are valid.

[58] Biggham, 2008

2.1.4 LIMITATIONS

In order to set a suitable scope in relation to the time at hand and thereby be able to put more efforts into specific parts of the thesis the research area has been limited to not include all aspects of the automotive industry and the HEV industry segment. First of all, this thesis focuses on the business-to-business aspects of the industry and uses a technology development and deployment perspective solely and leaves market performance, sales etc to a large extent untouched. The underlying reason is that looking into this would be a step away from reaching the answers to the research questions which focus on technologies and actors without considering sales and financial performance to a large extent. Therefore, markets aspects have been limited to provide room for a deeper and more insightful analysis in the other areas covered by the thesis. The thesis also limit the area of research to a fewer number of technology areas due to the same reason as earlier, ability to focus on the research areas deemed to have highest importance. Nonetheless, the chosen technology areas were chosen in conjunction with and confirmed by researchers active in the area of hybrid electric vehicles. Therefore the chosen level of detail in the technology areas is considered to be sufficient.

A limitation was also made in terms of areas where patent data is used. Since the thesis focuses on the relational aspect of technology and tries to measure the impact of technology a deep-dive into the network of technology actors in the HEV industry was made by analyzing the patent landscape. The starting point was to investigate which actors and actor roles that hold the most powerful and widely used technologies. Once again, to provide a subset of comparable variables providing valuable information the actor groups and the technology areas needed to be limited to the once with highest importance. A few areas of interest was chosen based on information from the interviews and the literature study and the basis for choosing the areas was if the technology area was “new” to the industry and the relative importance of that technology area. This was an iterative process with some elements of trial an error and the use of supporting information gained in the interviews to find a scope where the quantitative data was focused enough to provide results showing differences or similarities between the chosen groups of actors and technologies.

The research questions are to a large extent focusing on industry wide issues why different actors, relationships and roles are not singled out and examined but rather grouped and compared on a more aggregate level. To stay focused on the research questions at hand and to be able to find similarities or differences between larger groups this choice was made, but the author do recognize that looking in to specific relationships is an interesting field of research which could be interesting areas for future research.

An assumption that is made throughout the thesis is that patent information can be used as an indicator for knowledge and technology creation. This is a far too simple version of the world but when patent data it is used as a measure of comparison between groups containing several actors, patent data can be used as a proxy for technology creation e.g. in cases such as the one applied in this thesis but several factors affect the quality of the patent information and its usefulness[59]. Furthermore, Carpenter and Narin (1981) argue that important innovations are more likely to be highly cited[60].

The thesis uses non probabilistic sampling of the interview in a case study which could form a problem of skewed or misguiding data. However, the data was not used for generalization but rather as a foundation for the quantitative research. As argued by Malterud (2001), a qualitative approach is used to investigate the meaning of social phenomena as they are experienced by individuals themselves in a natural context[61]. This experience was later supported by more quantitative measures. The non-probability problem is therefore reduced and accounted for giving the thesis grounds for generalizability.

[59] Basberg, 1987
[60] Carpenter and Narin, 1981
[61] Malterud, 2001

3 THEORETICAL FRAMEWORK

This section will provide an overview of the theoretical concepts used as foundation for the analysis and conclusions of this thesis. Taking a starting point in the introduction this thesis will investigate concepts of technology sourcing and technology exploitation using and aggregated view considering a whole chain or network of actors. The focus is to look at theories of how firms in different levels of the value chain interact in terms of knowledge and technology, the significance of integrated or disintegrated technology functions, the structure of how they interact in a value network and how this evolves over time.

3.1 THE VALUE CHAIN

To analyze the transactions of intellectual capital in an industry characterized by knowledge transaction we need to place both actors and transactions into context. Since, as previously stated, knowledge become capital first when it is perceived as transactable the context for transaction is as important as the object transacted. As stated above, outsourcing and relationships that allow companies to operate blur the concept of the value chain. Therefore there exists a need to understand the concept of the value chain to be able to understand the change it will undergo in a transition to the knowledge economy and thereby understand the context in which intellectual capital is transacted.

The concept of value chain analysis was introduced by Michael Porter[62] as a strategic management tool to analyze industries. The term value chain can be defined as a linked chain of activities (the value chain) that creates value[63] or more specifically the sequential and productive actions that generate and support the end usage[64] of a product or service. The value chain concept has over the course of strategic management consisted of creating strategies for controlling the value chain and has been a useful tool for analyzing first and foremost manufacturing industries[65]. As industries and economies are evolving to become less focused of physical products the material value chains as it was introduced becomes insufficient for analyzing and understanding industries and value creation[66].

The value chain is built around the end product and the logic and consecutive order in which it is performed. The value chain encompasses all the activities from raw material to end product and that every company holds a position within the value chain. Upstream actors provide input for the closest downstream activity and actor in the chain who in turn pass it forward until it reaches the customer[67]. In strategic management the value chain has been used to analyze the competitive landscape and find gaps where a firm could take action to close the gaps. This can be considered very valuable when considering the material value chain and manufacturing firms but can prove to be less valuable when the industry is not focusing on manufacturing industries[68]. When considering a system with products and services characterized by being to some extent intangible (blurred) and the value chain itself lose its physical dimension the value chain approach becomes obsolete as a tool for uncovering value and value creation in industries[69], industries characterized by the being part of the knowledge economy.

The nature of the knowledge economy and the new business environment which appears alongside this new economy calls for a reassessment of traditional methods for analyzing competitive environments. Linear

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[62] Porter, 1985
[63] Peppard & Rylander, 2006
[64] Sturgeon, 2001
[65] Peppard & Rylander, 2006
[66] Peppard & Rylander, 2006
[67] Norman & Ramirez, 1994
[68] Peppard & Rylander, 2006
[69] Norman & Ramirez, 1994

models, including the value chain approach, does not explain the nature of alliances, competitors, complementors and other members in business networks, and the collaborative environment in many industries[70].

3.2 THE VALUE NETWORK

In order to understand how value is created, sourced and exploited in the knowledge economy we must recognize that value is created in relationships between actors. Understanding these relationships is the shorthand to understanding how value is created in the network[71] of interrelated relationships. Value creation must be viewed as a product of its context and the individual actors' ability to extract value must be analyzed on the basis of her ability to create value in the value network[72]. Understanding the competitive environment can to a large extent be reduced to understanding the underlying network of relations[73]. A value network is constantly evolving and this change is driven by the actors in the network. Therefore all aspects of the network have an impact on the analysis of the value network, including customers, competitors, allies, regulators etc[74].

When observing the chain of actions leading to the production and usage of a product aforementioned as the value chain is called value chain analysis, which in essence means analyzing and mapping vertical and sequential activities of delivery, production, maintenance to mention a few[75]. A contrasting way of observing the value-adding activities performed to generate a product or service is to observe the value creating system itself. In this system: suppliers, customers, allies and partners jointly co-produce value[76]. The network approach emphasize on the infrastructure for and extent of inter-firm relationships that connects firms to form economic groups or economic networks[77]. From one perspective the logic for competition that was once among distinct firms has now changed to become a battle between networks of interrelated actors. Leading positions and competitive advantage becomes dependent on maintaining the health of the network, hence not only the own firm but also the relationships and other actors participating in the value creating network[78].

Value networks are constructed from nodes and linkages connecting the value creating network. Firms in the network are independent, otherwise they would be considered to be in a lose state of vertical integration. The nodes in the value network are autonomous and independent actors that function under a common set of rules in a common infrastructure[79]. Inter-firm relationships play an important role in strategic performance and in industry evolution[80]. Madhavan et al. (1998) argue that inter-firm networks evolve as responses to events in said industry causing the industry structures to become reinforced or loosened. One can also argue that these events can be identified in advance and that managers are able to act on based on these assumptions on structure reinforcing or loosening events by improving the individual position in the firm[81]. The theories of transaction cost provide a framework for understanding why transformations occur in an industry. This is based on two options for a firm to organize its activities, internal hierarchical structures that integrate activities or in market relationships with external firms[82]. The information era and the knowledge economy have brought a

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[70] Peppard & Rylander, 2006
[71] Blankenburg Holm & Eriksson & Johansson, 1999
[72] Blankenburg Holm & Eriksson & Johansson, 1999
[73] Rylander & Peppard, 2006
[74] Rylander & Peppard, 2006
[75] Sturgeon, 2001
[76] Rylander & Peppard, 2006
[77] Sturgeon, 2001.
[78] Rylander & Peppard, 2006
[79] Rylander & Peppard, 2006
[80] Madhavan et al., 1998
[81] Madhavan et al., 1998
[82] Willianson, 1985

significant cost structure change reducing both inter and intra firm transaction costs[83]. Traditional positive effects of integrated firms due to transaction cost reductions are therefore lowered. Evidence of this lowering can be seen across several industries[84].

3.3 KNOWLEDGE SOURCING

Internally controllable activities are hierarchically or contractually controlled and relates closely to the strategy of the firm. The resources are used to provide customers with value while still having a competitive advantage over competition through the in-house control over the assets. Further resources can be obtained by means of exchange with the environment[85]. The absorptive capacity of a firm is described as the ability to identify and assimilate knowledge from external sources and the ability to commercially exploit this knowledge[86]. To be able to understand the foundation of firm boundaries and how this relates the ability to exploit knowledge I will investigate the concepts of integration and disintegration and relate them to the knowledge that can be claimed by an individual actor.

Vertical integration is often analyzed from a market foreclosure perspective to see to which extent joint ownership of upstream or downstream functions hinder goods from market exposure by creating internal markets and taking away the means for actors on the market to meet (connect). Typically this will produce a higher concentration of actors which in turn is expected to raise prices[87]. Nevertheless, under some specific market characteristics, vertical integration can have the opposite effect and put a downward pressure on prices[88].

In an example from the semiconductor industry including several companies the internal knowledge flow and human capital dependent information flows within the firm is used as an example of why and when vertical integration support innovation[89]. Information and knowledge sharing within the firm boundaries will become streamlined and the implementation of new technologies will be facilitated when complex and interdependent stages in the development process are vertically integrated[90]. Furthermore, when innovations are systemic and firms hold critical capabilities in-house, sourcing from outside the firm can make it loose its edge and leadership in the longer term. The firm should therefore source less critical knowledge from outside the firm but source critical parts of the value chain in-house[91]. Later management literature although put higher focus on the sourcing of knowledge outside the firm and less focus on owning critical parts of the value chain when technology is said to be disruptive rather than incremental[92].

The relation between vertical integration and performance remains both inconclusive and unpredictable[93] and studies has historically focused on economic and financial performance[94]. Li & Tang (2010) focus on the importance of sourcing knowledge from outside the boundaries of the firm to sustain the innovative capability of a firm. It is recognized that vertical integration is likely to affect the returns on R&D which is stated to determine the absorptive capacity[95] of a firm. The absorptive capacity will in turn influence the external

[83] Rylander & Peppard, 2006
[84] Rylander & Peppard, 2006
[85] Håkansson & Snehota, 2006
[86] Cohen and Levinthal, 1990
[87] Bunn, 2010
[88] Bunn, 2010
[89] Monteverde, 1995
[90] Monteverde, 1995
[91] Chesbrough & Teece, 1996
[92] Chesbrough, 2006
[93] Li & Tang, 2010
[94] Li & Tang, 2010
[95] Cohen & Levinthal, 1990

knowledge sourcing[96]. In the same study by Li & Tang (2010) it is found that vertical integration at an early and limited stage can have positive effects on innovative performance but that the effects will turn negative as the level of vertical integration increase. Hence, external knowledge sourcing is to some extent dependent on the level of vertical integration, at least in its effectiveness[97].

It seems evident that vertical integration has a twofold effect on innovation and the knowledge base of a firm since it improves the internal information and knowledge transfer[98]. At the same time vertical integration is shown to have the impact that it can render a firm with a less flexible organization that reduce the innovativeness and competitiveness of the firm. This is explained as stemming from the new entrants ability to transfer capabilities from one sector to another.[99]

Vertical integration might not give conclusive answers to technology output in terms of commercial products or offerings but R&D contracts and licenses could be seen as representing the upstream knowledge (base) that a firm needs to have access to in order to be competitive in downstream activities[100]. The pace of technological change and the risk inherent in R&D investments put firms in a position where they have to rely on external linkages for knowledge sourcing. Knowledge and information from outside the boundaries of the firm has become more important as R&D becomes multidisciplinary and innovation is to a larger extent derived from a network of actors interacting on different levels[101,102]. The effect of this external sourcing of knowledge is found to have largest effect when the firm possesses an internal R&D infrastructure[103]. The need for an internal infrastructure and external linkages suggest that both internal and external factors affect a firms potential for external knowledge sourcing. When an industry is facing a change in technological base, technology sourcing (internal and external R&D) is detrimental to generating capabilities for technology output[104]. Upstream actors entering with radical innovations and downstream actors with a large set of complementary business assets enter a symbiotic relationship where scientific research and downstream assets are utilized through alliances such as joint ventures and license agreements. It is suggested that new entrants focus on upstream activities whereas incumbents focus on downstream activities[105].

Technology sourcing, or the wider notion of knowledge sourcing used in this paper, refers to a firm's ability to generate new technological capabilities from a multidimensional subset of sources. These sources can be both internal; in-house R&D and external technology sources (linkages or alliances) such as; R&D contracts, licenses, joint ventures, minority equity investments and acquisitions[106]. The success in this external technology sourcing partnerships is depending on the technology being pursued, the degree of technical change in the industry and uncertainty in the external environment[107].

The external availability of knowledge affects the ability and incentives for a firm to innovate[108]. One could therefore argue that the knowledge pool of an industry will determine the incentives for the actors in the industry to innovate. This should mean that an industry characterized by knowledge-based business is dependent on the available knowledge pool. Further supporting arguments is that the frequency and density of

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[96] Li & Tang, 2010
[97] Li & Tang, 2010
[98] Li & Tang, 2010
[99] Li & Tang, 2010
[100] Nicholls-Nixon & Woo, 2003
[101] Veugelers, 1997
[102] Nicholls-Nixon & Woo, 2003
[103] Veugelers, 1997
[104] Nicholls-Nixon & Woo, 2003
[105] Hill & Rothaermel, 2003
[106] Nicholls-Nixon & Woo, 2003
[107] Nicholls-Nixon & Woo, 2003
[108] Caloghirou et al., 2004

interactions together with knowledge openness are detrimental for the generation, utilization and distribution of knowledge[109].

3.4 VERTICAL SCOPE

When analysis locus is lifted from firm level to industry level, vertical specialization must be view in the context of the value chain. When taking this perspective vertical specialization becomes a function of the diversity of productive capabilities in the value chain. This in turn will affect the vertical scope of the industry. Vertical scope is the accumulation of knowledge bases in an industry. When this heterogeneity of capabilities appear in an industry this generates a process which promote vertical disintegration. The disintegration will change the industry capability pool and actor composition in the industry and drive the capability development and vertical scope of the industry[110]. Thus, going from being an integrated industry to a disintegrated industry will change the nature of the industry and the structure of the capabilities needed to compete[111]. Hence, integration and disintegration to some extent is a selection process where the fittest will survive and earn market share, market growth and profits[112].

When the vertical scope of an industry is changed it has the potential of altering the pool of actors and the set of relevant knowledge bases. When actors become more specialized and the industry is divided into pieces some activities performed will closely resemble or be closely linked to activities performed by actors in other industry sectors. Learning from this we can see that specialization can be linked to opportunities for new entrants[113] and that the specialization could further lead to a networked firm and industry. The boundaries of the industry should therefore be viewed as set by the knowledge accumulation processes of all firms in an industry[114].

Industries will also in some cases have incentives to vertically integrate when new knowledge or actors have entered the industry. The integrated firm will in these cases be in a better control position. In the case of telecommunications the ability to develop and deploy new technologies is argued to relate to the control an actor exercise over the value chain[115]. It is in this case the most vertically integrated firm that holds the best position to develop interdependent technological architectures[116]. In general this type of benefits could be found in manufacturing industries where single actors have the ability to provide “the total solution”[117].

3.5 THE VALUE NETWORK FROM AN INFRASTRUCTURE PERSPECTIVE

If the industry vertical scope will change in a transition from an industrial economy to a knowledge economy and we are to understand this transition we need a framework that can guide the analysis. The value network and consequent relationships in the value network of an industry could provide the insights this thesis is searching for. Relationships with external actors provide access to key resources. The structure of these relationships describes and controls the access to raw material, information, key technologies, markets etc. Hence, the network structures provide the infrastructure for competitive action[118].

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[109] Caloghirou et al., 2004
[110] Jacobides & Winter, 2005
[111] Jacobides & Winter, 2005
[112] Malerba et al., 2008
[113] Jacobides & Winter, 2005
[114] Jacobides &Winter, 2005
[115] Raynor & Christiansen, 2002
[116] Raynor & Christiansen, 2002
[117] Jacobides & Winter, 2005
[118] Madhavan et al., 1998

The principles of the value network forms the structural order actors in the value network must conform to in order to extract value[119]. Drawing parallels to the notion of vertical scope and evolution of the knowledge base in an industry one could argue that the entrance of new firms with new knowledge bases is an entrepreneurial activity. This entrepreneurial activity can to some extent than be seen as a way to be disloyal to the set structures of the industry and it is the entrepreneur and entrepreneurial firm that has the capability to either or both be disloyal to the structure in the value network or absorb and accept the disloyalty from new entrants, i.e. new nodes in the value network.

The network infrastructure manages and controls the access to key resources of a specific firm. As a consequence it is the infrastructure that enhances or constrains the ability each firm in the networks ability to shape the industry roadmap. An actor that is disconnected to the network will lack timely information about and knowledge input to mandate decisions with industry wide implications[120]. One cannot build an efficient network without the ability to attract the right partners or allies. Alliance activity is also shown to have a positive effect on innovative performance. A large change in this infrastructure, a structural change, would be characterized by a significant change in the pattern of relationships in the network between the subset of actors[121].

Stemming from the theories of networks this thesis chooses to deconstruct the value network infrastructure into three distinct parts, centrality, centralization and interblock relations. Network centrality at a conceptual level represents the significance of an individual firm. The significance in turn is a measure of the number of relations with other firms in the network. Hence, a central firm has a high number of network relations and connections[122].

The accumulated firm centralities together represent the centralization of a network. Centrality can be said to represent the significance of a firm and centralization represent the network level concentration of central firms. This network level measure indicates whether a given firm in the midst of the network is likely to be more central than other firms in the network. A centralized network is characterized in that it hold a few very central firms and that the main bulk of actors are peripheral. The centralization measure provides indications of the distribution of centrality in the network. In order to assess structural change in a network the centralization before and after an event can be used[123].

Centrality and centralization help establish an understanding for the relational patterns between individual actors. By analyzing groups of firms we are able to analyze general patterns and relational types between different groups of firms, defined as interblock relations. To support this analysis, groups of firms can be divided into blocks based on three criteria; structural equivalence; general equivalence and contextual equivalence. Structural equivalence and general equivalence are built from analyzing the relational patterns in the network to construct groups that are discrete enough to analyze. Contextual equivalence uses similarity between the attributes of a number of firms to group them into blocks[124]. This thesis sets out to analyze the development in the relations between different actors and actor groups in an industry (value network). Contextual equivalence provides a tool for keeping the interblocks constant and analyzing the change in relations and relational types over time. The blocks of actors in this thesis are chosen on their attributes as a technology provider in the value network and are used as basis for the analysis. This approach provides a

[119] Petrusson, 2004
[120] Madhavan et al., 1998
[121] Madhavan et al., 1998
[122] Madhavan et al., 1998
[123] Madhavan et al., 1998
[124] Barley, 1986

meaningful and constant difference between groups or blocks of actors while observing the relational differences and changes over time[125].

In a short comparison with the initial discussion on the blurring of marketing concepts we can see that this concrete choice of infrastructure building blocks, that can be said to be somewhat more constant in both the intra and inter actor relations in the value network, we get a tool for analyzing an industry from a knowledge economy perspective. This is done through recognizing actor roles as tightly linked to technology and to group these actors with similar technology roles into interblock groups that are contextually similar.

3.6 THE ENTREPRENEURIAL CHANGE OF THE VALUE NETWORK INFRASTRUCTURE

Restructuring in an industry occurs when actors face exogenous chock[126]. Early adopters as opposed to late adopters of technology are more likely to increase their centrality in the network[127]. Madhavan et. Al (1998) proposes that it is key industry events that provide this exogenous chock that ignites a restructuring of a value network of e.g. technology actors. The events change the industry wide basis for competition and could include the introduction of new technology, new competitors or competitive, regulatory changes, shifts in consumer preferences or other efforts defined as entrepreneurial activities in this thesis[128]. Entrepreneurial activities center on the creation of structures, including the value network structures, by the entrepreneur[129], the exploitation of these structures[130,131] and how these structures relate to environment[132]. In other words, the structures and the environment form the source of opportunities and the process for discovering, evaluating and exploiting opportunities[133].

Some industry events provide opportunities or challenges for an actor to improve or change her position in the network[134]. Hence, there exists a need for firm level entrepreneurship to be able to discover, evaluate and exploit this opportunity or challenge. The opportunities or challenges in the events could stem from fundamental regulatory changes or the introduction of a disruptive innovation[135] that reshape the basis for competition. This will in turn have substantial impact on the value network of relations in the industry and put pressure on actors to access new resources from a new set of actors. To access the new set of resources actors will join forces with new actors/partners setting up new relationships. Consequently, some industry events have the potential to fundamentally alter the network structure[136].

If or when a structure changing event has occurred the question becomes what effect it will have on the network. Two tools available are to categorize the change as structure reinforcing or structure loosening. A structure reinforcing event would render in a network where already powerful firms become more powerful and less powerful firms are reduced in power. This would translate into a higher centralization of the value network strengthening the existing distribution of power. If on the contrary the event has a structure loosening effect on the network structure, the previously powerful firms are reduced in power and centrality as opposed to the less powerful actors the increase in power and centrality, reducing the centralization of the network. The

[125] Madhavan et al., 1998
[126] Barley, 1986
[127] Burkhardt & Brass, 1990
[128] Madhavan et al., 1998
[129] Petrusson, 2004
[130] Gartner, 2001
[131] Shane, 2000
[132] Gartner, 2001
[133] Shane, 2000
[134] Madhavan et al., 1998
[135] Christiansen, 1997
[136] Madhavan et al., 1998

direction of change in the network is dependent on if the network power is reinforced or loosened by centralizing or decentralizing the power in the network[137].

To be able to predict the direction of change one can analyze the event or occurrence that is expected to drive the structural change and through this analysis predict the structural change. Structure reinforcing events reify the present structure in the network by fortifying industry trajectories in general and in our case technology trajectories. This fortification will naturally benefit previously set key actors and key technologies and are therefore also likely to have been initiated by industry key actors. However, structure loosening events function much in the opposite way. They initiate changes in previously set structures and relationships since they are likely to be disruptive to the norm structure of the industry. This type of event would benefit peripheral actors and provide an opportunity for them to improve their position in the network. Hence, this event is less likely to be initiated by actors with high network centrality[138]. Thus, predicting an event and analyzing its implication can provide information that enables an actor to initiate the managerial activities needed to improve its position in the network.

3.7 THEORETICAL FRAMEWORK DISCUSSION

In the Introduction To the thesis the knowledge economy is described as an economy where knowledge plays the key role for the success of firms. Furthermore, indicators of large-scale cooperative production of knowledge and the convergence of industries are mentioned as effects of the transition to the knowledge economy. The theoretical framework provided above aims at finding a way of guiding the analysis of a network and industry in transition. My conclusions from the theoretical framework is that the change in the structure, symbolized by the change in the value network, is driven by technology and actors reshaping the vertical scope of an industry by integration or specialization in terms of technology.

The value chain and value network provides a framework for analyzing the production of knowledge, although these tools might not provide a complete picture. This is related to the strategy of integration or specialization of a firm and the ability to source knowledge form both inside and outside the firm. The theories presented in this chapter suggest that an industry knowledge base is built up by the network of actors in that industry and that the development and evolution of the vertical scope is technology and actor driven by entrepreneurial efforts. This entrepreneurial effort could then potentially also change the structure of the network, a structure built up by actors and relationships, in this thesis grouped into groups of actor types and how the groups relate to other groups. The final part of the theoretical framework provides a framework and vocabulary for investigating the effects on the value network.

The introductory chapter provides some insights of an industry in transition, where manufacturing capabilities of the industrial economy are gradually mixed with demands for knowledge sourcing and production capabilities of the knowledge economy. Leaning on the presented theory I will set out to find the effects on an infrastructural level of the HEV industry. The starting point will be to map the knowledge base by presenting a technology tree of the HEV industry. This will be followed by identifying the value chain of processes and actors in the industry. To be able to build a value network I will investigate what actor types, roles and relationships that exist and group them into "contextually equivalent[139]" groups. To finalize and answer the questions of the effect of new technologies will have on the industry infrastructure I will look at changes in IPR position between different actor groups holding different positions in the value chain.

[137] Madhavan et al., 1998
[138] Madhavan et al., 1998
[139] Barley, 1986

4 FINDING THE KNOWLEDGE BASE – A TECHNOLOGY TREE

In this chapter the hybrid electric vehicle and knowledge base of the HEV industry will be presented using a technology tree and a short description of key technology areas of the HEV. This will form a foundation for the analysis of the technology position held by different actors groups and also provide a framework for analyzing what phase of integration or disintegration the industry is in depending on technology area. This chapter will also contribute to finding which technology areas that are new to the automotive industry.

4.1 TECHNOLOGY DEVELOPMENT IN ELECTRIC HYBRID VEHICLES

In an internal combustion engine sudden accelerations or increases in load causes rapid increases of fuel consumption and emissions due to an increased injection of fuel when the engine tries to accelerate as a response to the change in load. When breaking an internal combustion engine has limited possibilities for recovering some of the energy spent when acceleration and most energy will be lost[140]. Hence, there exists a problem of energy utilization.

In a hybrid electric vehicle (HEV) alteration or combination of the power source used for traction between a traditional internal combustion engine (ICE), based on fuel, and an electric power source can even out the load peaks in the combustion engine. By using the electric motor or a combination of the electric motor and the ICE load peaks with high fuel consumption and emissions can be reduced. The battery also enables regeneration of braking energy. The main drawback with the HEV is the increased costs due to the increase in complexity level that it incurs to the drive train and energy supply[141].

The electric ICE hybrid engine is in general built up from two main parts, the ICE and the electrical machine. The electrical engine evens out the load on the ICE to produce higher efficiency and lower emissions. HEVs can often be differentiated by how the different parts of the hybrid engine are organized and by what percentage of power is provided by each part. The two main categories of HEVs are series hybrids and parallel hybrids[142].

Technologies improving fuel consumption performance and emissions performance are measured how they can improve the performance in relation to the International, United States, European or Japan driving cycles (for cars). This means that improvements are measured in a way that creates design restraints since if the cycle is not improved the technology in many cases is discarded. Another example is EURO NCAP for safety. If safety initiatives are not affecting the EURO NCAP score they are not considered as having as high potential and therefore have less probability of reaching the market. This will have implications since the driving cycles are different depending on the vehicle type and the driving cycle therefore has to be kept in mind when considering the technologies deployed and if technologies are transferrable between light weight and heavy duty HEVs[143].

4.1.1 THE HYBRID ENGINE

A conventional ICE uses diesel, gasoline or other fossil fuels as energy source and in the beginning the car industry the electric vehicle was on par with the inefficient ICE engine. Due to the restraints put on the electric vehicle in the form of battery technology and its effect on driving distance the ICE has been the dominant design[144].

[140] Jonasson, 2005
[141] Jonasson, 2005
[142] Omonowo & Omoigui, 2009
[143] Interview with Jonathan Rice, 2011-03-24
[144] Omonowo & Omoigui, 2009

A hybrid engine could refer to the fuel used as primary energy source in an ICE (fuel hybridization) or to the combination of propulsive power from an electric source where the energy is stored in batteries, often referred to as: drive train hybridization[145]. Below is a schematic representation of the technology areas of HEV vehicles.

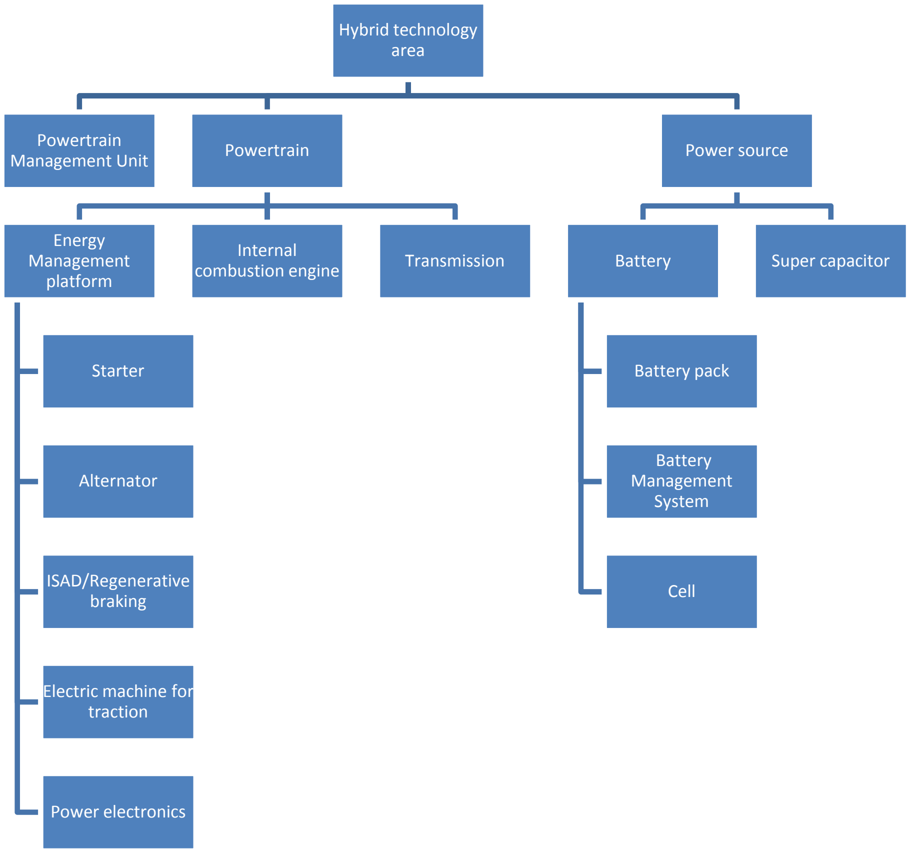

Figure 8 - The key technology fields in hybrid electrical vehicles (Source: Omonowo & Omoigui, 2009)

4.1.2 HYBRID ENGINE TOPOLOGY

There are many way of combining the above mentioned key technologies of the combustion engine. This thesis will focus on hybridization of engines by introducing at least on electrical engine. The two mentioned main variants of a HEV series and parallel can be supplemented in a number of different ways, each providing distinct pros and cons dependent on chosen vehicle solution and working condition[146]. Since most topologies are variants of series and parallel HEV and topologies is not the main focus of this thesis this section will be limited to a short description of parallel and series systems.

4.1.2.1 SERIES HYBRIDES

In series HEV systems the ICE is not connected to the drive train but it is rather power source and generator which provides energy for the electric engine(s) which power the drive train. In some cars one electrical engine is situated at every wheel. This enables good control of the power delivered to each wheel and therefore enables features such as traction control, all wheel drive etc. The advantageous features of the serial HEV is that it eliminates the need for a mechanical link between the ICE and the wheel and thereby increases the flexibility of the system. The drawbacks of the system are that the series system requires separate motor and generator portions. This can be combined in parallel systems. The separate engine and generator portions will

[145] Omonowo & Omoigui, 2009
[146] Jonasson, 2005

reduce the combined efficiency of the generator and the motor to a point below conventional transmission and by that also offset potential efficiency gains. Series hybrid systems are most efficient in driving cycles with high frequency of start-stop cycles such as for delivery vehicles, urban buses or city driving[147].

Since the series HEV incorporates a mechanical connection between the wheels and the ICE there are less restrictions on the load point but it also brings efficiency reductions due to the need for more energy conversions than in a parallel system. In a series system the thermal energy created in the ICE is converted to mechanical energy which powers a generator which in turn converts the mechanical energy into electricity. The generator charges a battery which supplies the power electronics and the electric machine. In its simplest version the series HEV is an electrical vehicle with a range extender[148].

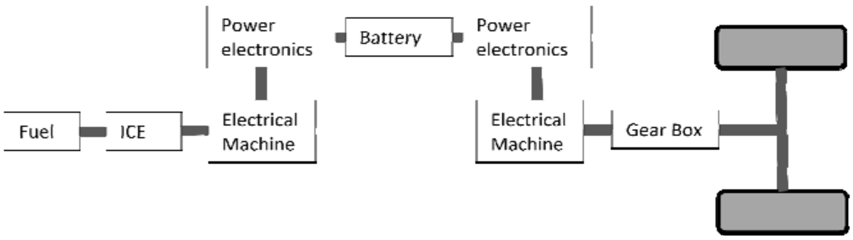

Figure 9 - Series hybrid topology

4.1.2.2 PARALLEL HYBRIDS

In parallel hybrid systems both the internal combustion system and the electrical system is connected to the transmission. Parallel systems can are sometimes further classified into subclasses based on the relative contribution of the different components of the system. E.g. the ICE provides the main bulk of the energy supply with only short support from the electrical engine or vice versa where the battery and electrical engine provides most of the energy supply[149].

Most designs of parallel electric hybrid are designed so that the electric motor and the generator are combined into one unit and placed between the internal combustion engine and the transmission. This motor/generator unit is also in many cases used as replacement of conventional starter motor and alternator. The parallel system also used a large battery pack providing higher voltage than 12V[150].

In a parallel system the ICE is mechanically connected to the transmission through the gearbox. The low number of energy conversions compared to the series system has can potentially increase the efficiency of the system. In the parallel system the combination of speed and torque in the ICE can be combined so that the speed is chosen by the ICE and gearbox and the torque by the electrical machine. The four most common choices of operation is solely electrical machine, solely ICE, a combination of ICE and electric machine where the ICE is used to charge the battery and a combination where both the ICE and the electric machine is used to provide power for traction. When both the ICE and the electric engine are used a peak level of power for traction is reached[151].

[147] Omonowo & Omoigui, 2009
[148] Jonasson, 2005
[149] Omonowo & Omoigui, 2009
[150] Omonowo & Omoigui, 2009
[151] Jonasson, 2005

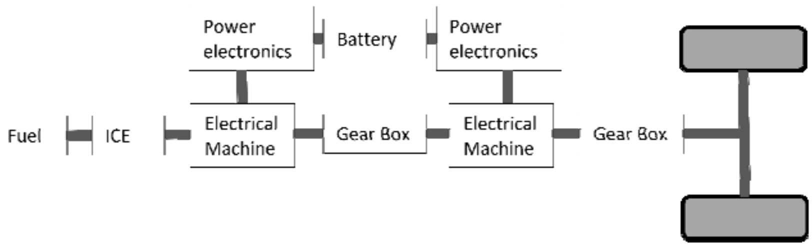

Figure 10 – Parallel hybrid topology

4.1.2.3 DEGREE OF HYBRIDIZATION

The diverging types of hybridization efforts from either drive train hybridization or fuel hybridization have led to a situation where hybrids are often classified based on their degree of hybridization.

Full hybrid electric vehicles: A fully hybrid vehicle is one that has the ability to run solely on the engine, batteries or both. Hence, the ICE need not be running at all times for the vehicle to function. To balance the forces from both the batteries and the ICE a differential linkage between the ICE and the electrical motor is usually used. The differential linkage is connected to the head end of the transmission[152].

Mild hybrid electric vehicles: The assist hybrid uses the ICE as primary power source but has an electrical motor as supplemental provision of torque and boost to the power train. The system usually contains a large engine which works in start-stop and when extra throttle is needed[153]. Most current HEVs are mild hybrids.

Micro hybrid electric vehicles: A mild hybrid use a conventional ICE system but incorporating a larger starter motor which allows the ICE to be turned off when the car is coasting, braking or stopped and then restart quickly and cleanly. The electrical motor is used for regenerative braking to recapture energy and to bring the engine to operating speed without injecting fuel[154].

4.1.3 POWER SOURCE

Out of the large R&D budgets the last decades devoted to technologies reducing fossil fuel dependency batteries have been viewed as one of the most or the most critical components. This has lead to a situation where recent battery improvements bring a promising future for HEVs and EVs. Contributory to this has been governmental research programs such as DOE in the EU, USABC in United States and CRIEPI/LIBES in Japan where the introduction in of the non-aqueous lithium technology is the most notable[155].

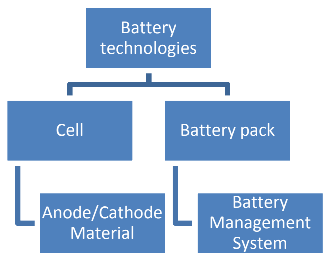

Figure 11 - Battery technology field breakdown

The batteries are used as source and storage of electrical energy and to drive the electric motor which provides the alternative propulsive force to the ICE by converting electrical energy to mechanical energy. There are many types of battery technologies available for HEVs[156].

The lithium ion battery was first developed in 1990 as a result of over 40 years of research efforts. Lithium ion batteries have the main advantages of power density, longer life time and potential economies of scale in

[152] Omonowo & Omoigui, 2009
[153] Omonowo & Omoigui, 2009
[154] Omonowo & Omoigui, 2009
[155] Husain, 2010
[156] Omonowo & Omoigui, 2009

production. Many different versions of lithium ion batteries have been discussed over the course of the Li battery development and the carbon type negative anode and the metal ion positive electrode can be produced from a number of different materials[157].

4.1.3.1 BATTERY MANAGEMENT SYSTEM

The battery management system (BMS) governs the battery for it to function within its limits in a safe way and with optimal performance over the life-time of the battery. The level of complexity of a BMS can vary widely but in general is must match the chemical requirements of the battery, the requirements of the vehicle and the vehicles operation requirements. Hence, the BMS will to a large extent be dependent on other design requirements of the vehicle. The BMS ensures that different operating limits are observed and not exceeded. This provides longer battery life and higher performance. The information provided by the BMS in terms of current state and performance provide means for better utilization of the battery. A BMS usually includes some or all of the following functions: monitoring, measuring, calculating, communicating, controlling and balancing the electrochemical cells used in the battery pack. These functions are used primarily to protect the battery and secondly to provide optimal performance depending on operational conditions[158].

The implementation of a BMS could range from a simple temperature monitor implemented as a fuse to large systems and subsystems of electronic components that can perform all of the previously mentioned functions. This is highly dependent on the type of vehicle and in a larger hybrid electric vehicle could require a widely distributed BMS with several components and subsystems. Furthermore, a BMS designed for electric vehicles for traction differs significantly from battery management systems in other industries such as consumer electronics[159].

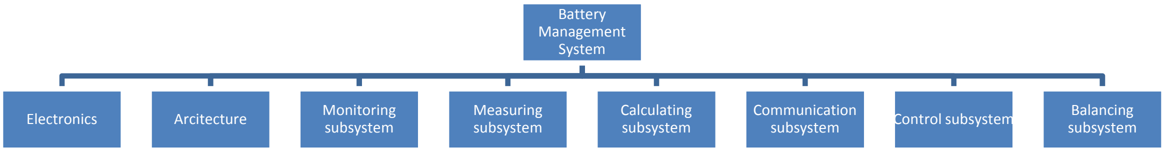

Figure 12 – Technology tree for a Battery Management System

4.1.4 ELECTRICAL MACHINES FOR HYBRIDE ELECTRICAL VEHICLES

The alternators and motors used in hybrid electric vehicles follow the same principles as in other applications but the electric motor in some cases need to be adapted to be used in a hybrid system, which is the case in parallel hybrid engines. A major advantage from electric motors in hybrid electric drive trains is that torque generation is fast and accurate[160]. Electric machines used for traction, i.e. an electric motor, use current, magnetic field and physical geometries to create a torque that creates an acceleration of the vehicle. The magnetic flux in an electrical machine follows two fundamental principles: 1) The voltage requirement is proportional to the speed of the electrical machine multiplied by the magnetic flux; 2) The torque is proportional to the current supplied to the machine. This has two important implications; the torque is high at low speeds and will reduce as the speed goes up due to the voltage requirement[161].

4.1.4.1 INTEGRATED STARTER ALTERNATOR DAMPER

[157] Husain, 2010
[158] Husain, 2010
[159] Husain, 2010
[160] Omonowo & Omoigui, 2009
[161] Jonasson, 2005

An integrated starter alternator damper (ISAD) combines the starter, generator and damper (that minimizes engine vibrations) into one energy management platform unit and a single electric device. The ISAD has the function of capturing the energy in the engine when the engine decelerates, sometimes called regenerative braking[162]. Regenerative braking is used by applying retarding torque from reversing the magnetic field in the electric motor. This generates electricity which is used to charge the batteries[163]. The ISAD is an integrated part of the power train of the HEV between the ICE and the transmission and can potentially substitute traditional starters and generators (alternators) in HEVs. The ISAD starts the engine by applying energy directly to the crankshaft, thus producing a rotation electromechanically. The benefits of the ISAD is that it reduces fuel consumption, increases power production, enhanced engine start ability and reduces power train oscillations[164].

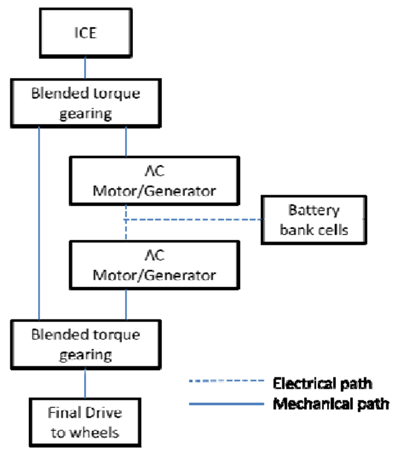

Figure 13 - Regenerative braking in parallel hybrid buses

4.2 TECHNOLOGY CHAPTER DISCUSSION

The interview study and literature study show that HEV technology areas are schematically similar over the different automotive segments. Nonetheless, several interviewees point out some areas that are significantly different between heavy and light weights vehicles and some technology areas of high(er) importance when developing all types of HEV vehicles.

Starting off with the differences, the norms in terms of technology evaluation differ significantly between heavy and light weight vehicles. Passenger cars are evaluated on emissions and performance in respect to different driving cycles[165],[166]. Therefore, technology choices are made depending on their effect on the driving cycle rather actual or technologically best choices[167]. Heavy commercial vehicles does not have a standardized driving cycle in the same way as passenger cars but the real driving cycles of heavier vehicles can be said to differ significantly compared to passenger cars and also within the different application areas and types of heavier commercial transportation. The drivers of heavier commercial vehicles behave and act different and have different preferences and driving patterns than a passenger car driver[168]. Therefore, one can assume that technologies strictly dependent on driving behavior will be less transferrable between different automotive segments and by that also the technology development and sourcing strategies deployed.

Since all OEMs are in need of smart control and need to configure the system on an architectural level to support and create the OEM specific brand identity the highest technology development is within control strategies and software development for HEV vehicles. These are the technologies that create the interface towards the customer. Suppliers are focusing on developing the components which in many cases are off-the-shelve products and OEMs focus on the system control and implementation of the products and technologies. Off-the-shelve products are used since the development costs for a vehicle has grown over the years and estimated costs for developing a car is $1 bn and added to that can be approximately $0,5 bn for developing

[162] Gartner, 2010
[163] Bennett, 2009
[164] Gartner, 2010
[165] Interview with Hans Pohl, 2011-03-29
[166] Interview with Jonathan Rice, 2011-03-24
[167] Interview with Jonathan Rice, 2011-03-24
[168] Interview with Hans Pohl, 2011-03-29

the hybrid system[169]. Furthermore, many automotive manufacturers do not have the infrastructure to enter a new technology area. This requires knowledge, employees and resources[170],[171].

The highest potential for further improvement still in terms of technology can be found within energy recovery and regenerative breaking and control and management software[172]. The demands on the components are very different since the load in a truck is much higher (on average) in a truck than in a car. In the heavy commercial industry there will also be differences in how the benefits of an HEV are evaluated. A truck must make business sense. Heavy commercial vehicles customers are more focused on real usage than driving cycle and will ask about savings, usage costs etc. This descends from the fact that the heavy commercial vehicles customers are more powerful and rational buyers. The customers will also be more concerned about lifecycle costs. For instance, what happens when the battery is worn out? What extra cost will this add over the lifetime of the vehicle? Hence, cost savings will be very important and a strong argument that the OEMs will need towards heavy commercial vehicles buyers which in turn will affect the choice of technology pursued and how this is sourced[173].

In general when it comes to HEV development cars are ahead in technology development. Knowledge and technology is expected to spill over from the light weight industry to the heavy duty industry since many of the technical principles are shared between the two industry segments[174]. Buses, Long-distance trucks and delivery trucks are more predictable in their usage. This makes HEV technologies very interesting for urban usage for buses and trucks but less likely to be implemented in long-distance trucks since HEV have less efficiency improvements to bring to these vehicles and due to the cost and weight added by the HEV system[175]. Nonetheless, HEV are not yet widely adopted in heavy commercial vehicles why the thesis hereinafter will put higher focus on the passenger car HEV.

The highest relevancy technologies for HEV would be energy management systems, switching technologies, smart gear box and alternators. But it is the integration of power train and the build-up of the hybrid architecture that has the highest relevancy for HEV since many of the components in the system can be purchased off-the-shelve. The integration especially includes the choice, management and control strategies of the architecture and design of the system. The controller and control system has high relevancy for HEV development since it can provide efficiency out of the system and make the product easy to use and seamless for the customer creating the customer experience. This knowledge about the consumer experience and usage is usually kept in-house by the OEMs[176].

169 Interview with Andrew Dawkes, 2011-03-24
170 Interview with Andrew Dawkes, 2011-03-24
171 Interview with Jonathan Rice, 2011-03-24
172 Interview with Andrew Dawkes, 2011-03-24
173 Interview with Hans Pohl, 2011-03-29
174 Interview with Jonathan Rice, 2011-03-24
175 Interveiw with Jonathan Rice, 2011-03-24
176 Interview with Jonathan Rice, 2011-03-24

5 THE AUTOMOTIVE INDUSTRY

This chapter will investigate the HEV automotive industry in terms of actors, roles and relationships to be able to group actors in terms of their role as technology provider. Once we have the groups of actors, their roles and how they relate to other groups we can investigate the difference between the groups and how the groups have evolved over time in terms of their position in the value network and the roles in the industry. This analysis will be performed by looking at patent data in the end of this chapter.

Lean production has revolutionized the automotive industry and Lean enterprises are seen as groups of individuals, functions and legal entities that create, sell and service a family of products. They collaborate technically and share market information business units that are connected and compete through vertical and horizontal connections and with other companies within a single project. The lean enterprise structure for exploiting globally emerging automotive products and markets has evolved to aim at uniting skills and reapplying them in collaborative relationships where leadership is allocated to the actor best positioned in the network and to integrate the internal product design process with external markets, actors and trends. Examples show that large automotive actors e.g. BMW, Fiat and Volkswagen divest activities and focus their resources to become so called system integrators in a network of specialized actors devoted to a specific part of automotive manufacturing. The vertical disintegration of activities could involve separate suppliers and affiliated actors and that large portions of the R&D and design activities are divested to system suppliers[177].

Since the heavy commercial industry is still in its emerging phase of developing hybrid electric vehicles a situation analysis of the actors, roles and relationships in HEV development in the automotive industry in general will be made. This will form the basis for a trend analysis and conclusions about expected developments in the heavy commercial automotive industry regarding HEV development. This approach is chosen since the two industries and its players are very similar, the technologies to some extent are interchangeable between the industries and since many of the actors are present in cars, light weight commercial vehicle and heavy commercial vehicle development[178].

5.1 THE AUTOMOTIVE VALUE CHAIN

The automotive business value chain is defined as consisting of auto manufacturing and auto component manufacturing[179]. To this can be added raw material producers such as fuel, steel, coating and plastics actors and aftermarket actors providing services, reparations and retailing[180]. I will focus in on the two parts of the value chain most relevant for this thesis, auto manufacturing and auto component manufacturing.

Auto manufacturing is defined as containing the production of passenger cars, light weight commercial vehicles, heavy trucks, buses and coaches. Auto component manufacturing can be divided into several sub-categories and includes the manufacturing of all components used in auto manufacturing[181].

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177 Hodkinson, 2001
178 IMAP 2010
179 IMAP 2010
180 http://www.automotive-online.com/auto-industry.html
181 IMAP 2010

Figure 14 - The Automotive industry value chain (source: IMAP 2010)

5.2 THE AUTOMOTIVE ACTORS

Traditionally the automotive industry has been dominated by three large US-based passenger car manufacturers[182] General Motors, Ford Motors and Chrysler which together represented 50-percent of the US market and 20-percent of the world market in 2007[183]. When the financial crisis hit the automotive industry all three were pressured by the recession which increased an already abundant shift in dominance where Toyota surpassed all three into becoming the largest auto manufacturer and surpassed GM with a production of close to 9 million cars in 2008[184]. As a result of Ford, GM and Chrysler's setbacks other companies such as Nissan and Toyota have gained market shares[185].

[182] For production statistics see http://oica.net/category/production-statistics/
[183] IMAP 2010
[184] IMAP 2010
[185] IMAP 2010

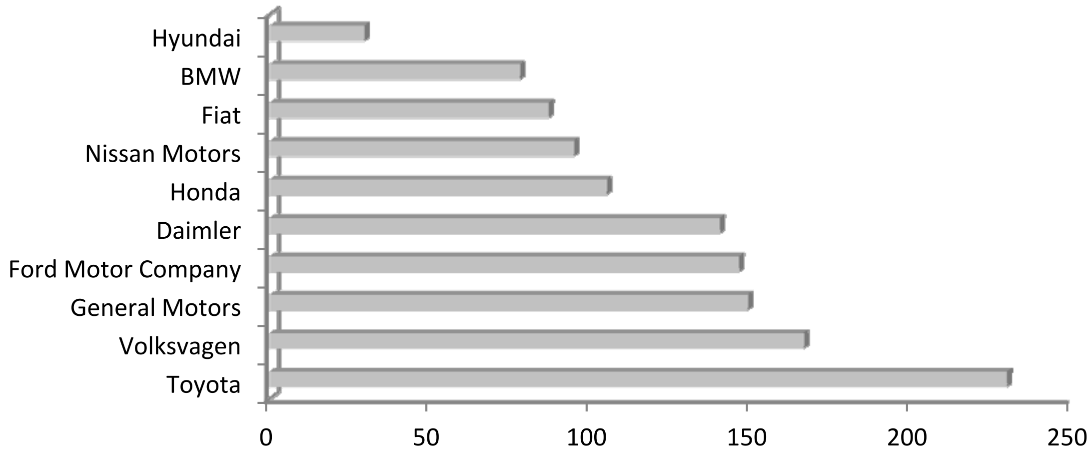

Figure 15 – Ten Largest Auto Manufacturers by revenue (2008) (source: IMAP, 2010)

Compared to the auto manufacturing market the auto component manufacturing market is less consolidated and is not in the same way concentrated to a few players that hold a large market share. The actors are also in general smaller than their auto manufacturing counterparties. The four top actors in auto components manufacturing and equipment (Affina, Valeo, Delphi and Federal Morgul) together represented less than 2-percent of the industry turnover. Although, the tire and rubber market is highly concentrated to the four largest players Bridgestone, Michelin, Goodyear and Continental represent more than 60-percent of the global market revenues in tires. The majority of production facilities for auto component manufacturing are centered to Asian nations such as Japan, China, India and Thailand due to the favorable sourcing alternatives of raw material and growing domestic markets[186]. A more thorough description of the Auto Manufacturers and Auto Component manufacturers can be found in Appendix A – Twenty largest auto component manufacturers and Appendix B – Ten largest auto Manufacturers (OEM).

[186] IMAP 2010

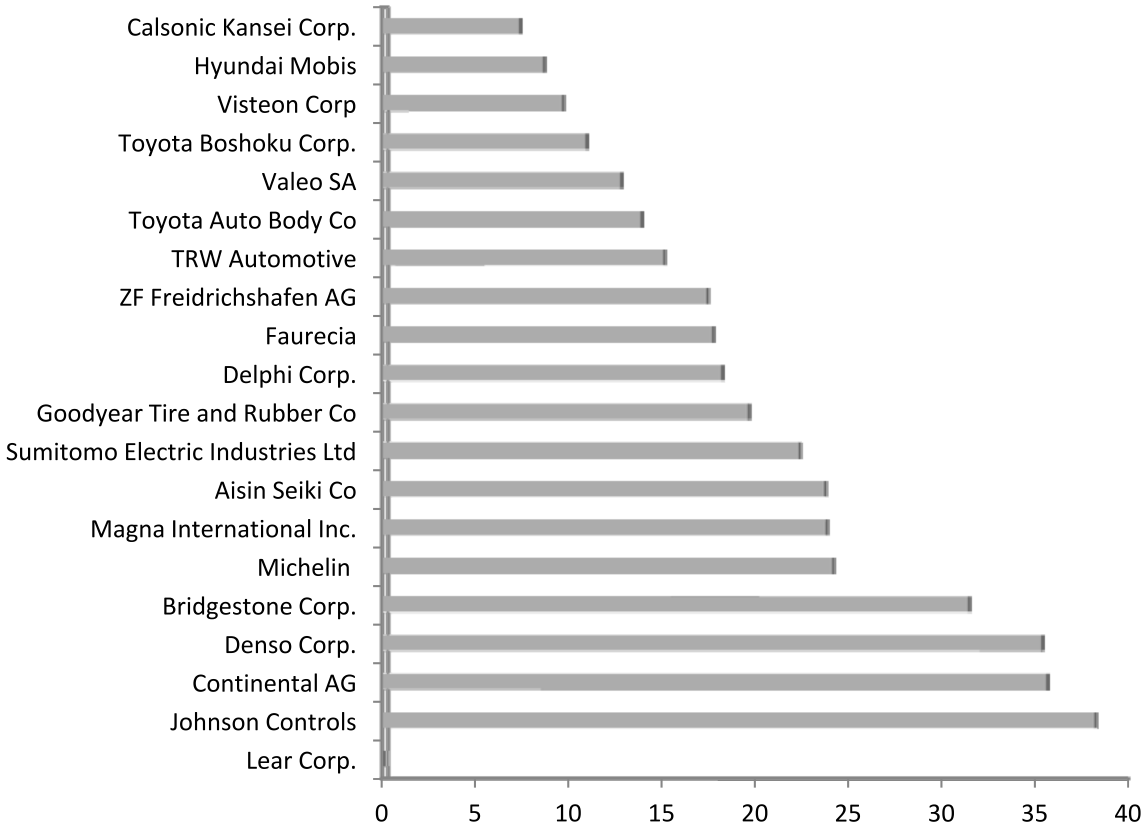

Figure 16 - Twenty Largest component manufacturers in the automotive industry (source: IMAP, 2010)

5.2.1 BATTERY ACTORS

The most widely used battery systems today is the Nickel Metal Hydride (NiMH) battery system sold by PEVE, which is a joint venture between Toyota Motors and Panasonic. The first NiMH battery pack for HEVs was introduced by Toyota in 1997 as a part of the introduction of their HEV Prius. Other leading manufacturers of battery systems are Sanyo and Johnson Controls-Saft[187].

Li battery technologies have been used in consumer goods such as power tools and electronics for several years and have a proven W/kg by far exceeding that of competing technologies. The high energy/weight ratio could previously only be found in ultra capacitors. The application of Li batteries in HEVs have been a goal for the industry for several years which not the least is evident in the large R&D budgets that have been devoted for this. Daimler Benz recently introduced their S400 HEV which is one of the first HEVs with Li batteries on the commercial market. The battery uses a cylindrical cell manufactured by Johnson Control-Saft and a battery pack assembled by Continental (in Germany). Yet another example of a Li battery that uses a prismatic design is the EH6 Li ion cell manufactured by GS-Yuasa. There are several Li ion developments under way as a part of different HEV programs. Li batteries differ from their NiMH counterparty in that there are several families of Li batteries depending on what type of electrochemistry is applied[188].

I will briefly go through the competing technologies and which actors are supporting each technology. One category of Li batteries are the so called Nickel based Li batteries. The LiNiCoAlO (also called NCA) has the best cycling and calendar life in the industry and is developed and implemented by Johnson Controls-Saft and

[187] Husain, 2010
[188] Husain, 2010

Toyota. Nickel/manganese/cobolt oxides (also called NMC) have similar merits of properties and advantages but with considerably less industrial application time. NMC is selected as the primary choice by GS-Yuasa and Hitachi Vehicle Energy in Japan[189].

LiMnO batteries have a somewhat lower energy density than Ni-based batteries but also have less safety risks than the NMC material design choice. The power capability is very high but the lifetime is somewhat shorter in this material design. By choosing different implementations the lifetime can be prolonged as is done by NEC in their choice of this technology. A technology that has become actualized lately is the LiFePO which has the potential for lower cost and lower safety risk. At the same time the energy density is lower than in comparable materials. The companies implementing this material are A123Systems and Valance Technology[190].

5.3 HEV ACTOR ROLES AND RELATIONSHIPS

There are high expectations on the future growth of the HEV for passenger cars moving forward. Global demand is expected by some sources to be as large as 4 million units by 2015 but the likeliness of this can be discussed and the percentage of total passenger cars sales in 2008 was only 2,5% or 1,3 million units out of a total of 52,6 million units[191]. Fossil fuel prices and new emission regulations are expected to drive demand for HEVs in the future. The limited volumes in comparison to traditional cars and the lack of technology standards in the industry regarding HEV technology has according to IMAP Automotive and Components Global Report 2010 led to that the manufacturing of motors and other HEV components are done in-house. This is expected to change as the produced volume of HEVs increase and prices decline, leading to a much larger outsourcing of HEVs component production[192].

5.3.1 HEV ROLES

The roles in the lightweight HEV industry to a large extent follow the tier structure implemented basically throughout the automotive industry. One interviewee mention that due to the increase in development costs to develop one car or car model the OEMs are pushing more and more design work towards suppliers[193]. To exemplify the interviewee used the example of gearboxes and below follows the exemplification given about HEV roles in this interview[194]. The gearbox is purchased from a tier one supplier and most competitors in the same size and segment use the same gearbox. The two suppliers mentioned in this example are ZF and Hitco, which supply components to a large number of suppliers in the same segment. The OEMs only apply software and integration technologies to create the brand specific look and feel of the gearbox in this case. OEMs creates the specifications for a total car and specifies for the system supplier what technologies and components (functions) that should be included in a specific system of the car. The system supplier is responsible for developing a system of components that are suitable for (in many cases several different models). The system supplier in turn collaborates and holds the contacts with the component providers. Hence, one could say that traditionally the OEMs technology control position towards the component suppliers is exercised through the system suppliers. Furthermore, many of the system providers serve several OEMs and hold the contact towards the component suppliers in all these relationships. I have, based on the interviews, chosen to categorize this into three distinct roles: OEM, system provider and component provider[195]. Furthermore, some of the success of the larger light weight HEV manufacturers can be derived from both superior product and production technology and the ability to produce vehicles at a low cost. Therefore are

[189] Husain, 2010
[190] Husain, 2010
[191] http://oica.net/wp-content/uploads/cars3.pdf
[192] IMAP, 2010
[193] Interview with Andrew Dawkes, 2011-03-24
[194] Interview with Andrew Dawkes, 2011-03-24
[195] Interview with Andrew Dawkes & Jonathan Rice, 2011-03-24

also production technologies and the ability to build volume to achieve economies of scale critical issues for the OEMs. It should though be noted that in general the series are smaller and the costs higher in heavy commercial vehicles than in light weight vehicles and passenger cars. Overall the OEMs can be said to be the most powerful actors in the industry[196].

The other identified roles also exist in the automotive industry in general but are not as connected to the tier structure of the industry. These two roles have been labeled technology provider and consultancy service providers. They appear to be not totally mutually exclusive and share the same characteristic in that the knowledge or technology transferred does not have to be totally connected to a product or component. Consultancy services have a large diffusion in the industry and strict technology providers have existed for a long time but the number has increase lately. This increase is considered to be due to a change in the total industry rather than due to the raise of the HEV industry and that it is the timing of the HEV rather than the characteristics of the HEV industry that has brought many new strict technology providers. The increase of technology providers is largest among private actors while universities and public technology providers have existed in the automotive industry for a longer period of time[197].

To summarize five roles are identified in the HEV industry where actors are considered to be contextually equivalent within the group/inter-block. These groups are OEMs, system providers, component providers, technology providers and consultancy service providers. The roles are not mutually exclusive and a single actor can undertake more than one role, this applies especially to the role of technology providers and consultancy service providers.

5.3.2 HEV RELATIONAL TYPES

Depending on the size of the actor, the technology focus and the industry segment the relational types are diverging to some extent. Focusing in on relationships involving technology development and technology sourcing the larger actors present two main horizontal relationship alternatives and two main vertical relationship alternatives. A horizontal relationship is where an actor has a relationship with an actor on the same level in the value chain. A vertical relationship is a relationship between actors on different levels in the value chain.

The horizontal relationships that exist from a technology perspective spans from very collaborative to very restricted in the level of collaboration that is present. One interviewee uses two examples to show how this unfolds[198]. The first mentioned examples are when one OEM develops a system or platform such as an engine and then license it out to other OEMs who make adaption to the technology and implement the technology on their products. The HEV segment does not differ significantly from the automotive industry at large in this aspect of relationships[199]. Examples of this type of relationships in HEVs can be seen between Toyota Motor Company and several different other OEMs where Toyota license out their Hybrid Synergy Drive[200,201]. The second example is that several manufacturers jointly work to develop a technology that is shared among the actors but the product implementation is actor specific. The development costs for the platform are also shared among the actors. An example from the HEV industry is the Global Hybrid Cooperation where several

[196] Interview with Hans Pohl, 2011-03-29
[197] Interview with Andrew Dawkes, 2011-03-24
[198] Interview with Andrew Dawkes, 2011-03-24
[199] Interview with Andrew Dawkes, 2011-03-24
[200] Lloyd & Blows, 2009
[201] http://www.toyota.co.jp/en/news/10/03/0329_2.pdf

automotive OEM jointly have started and finances a research organization[202]. Hence, the spectra of collaboration are wide and situation specific.

There are a large number of relationships of the vertical kind from a technology development perspective which have a number of diverging characteristics. I have chosen to divide them into two main types, supplier relationship and research collaboration. The research collaboration is generally characterized by being upstream research and in that it is less applied to a specific product or application. This is commonly done in collaboration with universities or institutes or as a result of government initiatives[203]. This approach was referred to as fishing for new technology by one interviewee since the outcome is uncertain but could potentially generate great technology. In a supplier relationship the research is in comparison much more applied and the OEM creates a specification for the system needed to the system provider. Depending on the volume and purchase power of the OEM it is then up to the system provider to develop the product jointly with the OEM but, as mentioned earlier, the architectural design on a higher level is done by the OEM and the design on lower (modular) level is done by the system provider[204]. In particular, the European automotive industry is skewed towards working with system providers in HEV development but there has been an undersupply of suppliers able to provide HEV technologies on a system provider level. This could also be related to the choice from the OEMs to do some technology development in-house in order to widen their technology base and strengthen their HEV capabilities[205]. The undersupply of system providers in the HEV industry could also be related to the lower volumes and the lack of technology standards regarding HEV technology mentioned earlier[206]. Therefore one of the traditional steps of systems providers in the value chain is underutilized. Over time a consolidation of actors and the rise of HEV system providers are expected to lead to a development where the HEV value chain is similar to the general value chain of the automotive industry[207].

The relationships take different structural forms which create different infrastructures for transferring knowledge and technology between the organizations. According to most interviewees there is not a particular trend in the setup of the relational infrastructure[208],[209],[210] and many different forms are used e.g. joint ventures like PEVE between Toyota and Panasonic, research collaborations as Global Hybrid Cooperative and numerous other examples. The differences in setup also mean that the infrastructure for transfer and sharing of technology is different.

New types of collaborations also appear where one example is between electric utility companies and electric and hybrid electric vehicle OEMs[211]. This is a totally new type of actor in the industry which can be expected to bring new knowledge to the industry and to be included in collaborations previously unexplored.

5.3.3 HOW IS TECHNOLOGY SHARED, TRANSFEREED AND CONTROLLED IN THE HEV INDUSTRY

Technology is contractually shared in developments and collaborations. Usually the supplier develops the product base and the OEM sets the restraints on an architectural level of the total vehicle. Patents are commonly used for protecting technology and usually the inventing company receives the patent rights rather than assigning it to the company ordering the product or service e.g. the OEM. The supplier can in many cases

[202] Husain, 2010
[203] Interview with Jonathan Rice, 2011-03-24
[204] Interview with Jonathan Rice, 2011-03-24
[205] Interview with Hans Pohl, 2011-03-29
[206] IMAP, 2010
[207] Interview with Hans Pohl, 2011-03-29
[208] Interview with Jonathan Rice, 2011-03-24
[209] Interview with Andrew Dawkes, 2011-03-31
[210] Interview with Hans Pohl, 2011-03-29
[211] Interview with Hans Pohl, 2011-03-29

patent the underlying technology and that the OEM patent implementations of the same technology in a specific vehicle[212]. The focus on IPRs in the automotive industry has increased in general[213].

Even if the OEMs control and set the technology roadmap it can be tough for them to negotiate background and foreground rights to the technology. OEMs rely on suppliers with good technology and suppliers which often supply several of the OEMs in the segment[214]. Based on the difference in roles between OEMs and suppliers their interests also become diverging on some points and production and implementation costs have to be valued alongside technological quality. OEMs are interested in pressing prices and look for synergies so that systems and platforms can be shared by several brands and several models. This builds huge volumes that give the OEM large advantages in negotiations. At the same time this becomes a technological lock-in for the OEM. Commonly, contractual relations have built in demands for technological improvements. The OEMs give the supplier a set profit margin and has demands on cost reductions each year. This means that the OEMs control the implementation of the technology and have a market based control over the technology while a supplier control the technical expertise and sometimes also the IPRs connected to the technology. The inventor will patent a new technology and then license to the supplier. If it is the OEM who is the inventor the technology will be licensed through the product sold by the system supplier, hence the system supplier is the one who licenses out the technology further and thereby also control the market access of the technology[215]. Hence, OEMs in many cases source architectural innovations in-house and source modular innovation trough system providers.

Consultants are a source for information and best practice in the automotive industry in general[216] and in the HEV segment in particular[217]. Many companies use the same consultants and can therefore be reluctant to relying on them too much with fear of losing competitive edge through technology leakage[218]. At the same time consultants are a great source of knowledge and one mentioned problem is that many companies lack an efficient knowledge transaction strategy which means that knowledge is lost and is in the risk of being lost in hybrid development projects[219].

Although an increasing trend in patenting[220], most products are controlled through production technology and market/customer access and market power stemming from economies of scale rather than from the control over technology but it is not one or the other. To summarize the general types of transactional norms used in the industry knowledge is transacted in products bought off-the-shelves, where the knowledge is absorbed by the company through working with the product and doing tests and implementations. The second example includes development activities where suppliers have engineering staff participating in the development work at the facilities of the client and by that transferring knowledge. Lastly, consultants are used as carriers transferring knowledge between firms and between the consultancy firm and the purchaser of the consultancy service[221].

[212] Interview with Anderew Dawkes, 2011-03-24
[213] Interview with Anderew Dawkes, 2011-03-24
[214] Interview with Jonathan Rice, 2011-03-24
[215] Interview with Andrew Dawkes, 2011-03-24
[216] Interview with Jonathan Rice, 2011-03-24
[217] Interview with Hans Pohl, 2011-03-29
[218] Interview with Jonathan Rice, 2011-03-24
[219] Interview with Hans Pohl, 2011-03-29
[220] Interview with Andrew Dawkes, 2011-03-24
[221] Interview with Hans Pohl, 2011-03-29

5.4 HEV R&D SOURCING STRATEGIES

When analyzing the HEV industry from a technology development perspective one can see that there are different technology sourcing strategies but there are also common elements shared by many actors regarding a few technology areas in the HEV industry.

When considering technology sourcing strategies we first have to analyze whether the technology is key or detrimental to the product as such, the HEV system. What we find here is that the strategy applied is tightly linked to the role of the HEV actor. For the OEMs energy source technologies are unlikely to be sourced in-house but are rather accessed through partnerships or joint-ventures. The same strategy is often applied to the electric motor. These technologies are considered as crucial for the system to work but are also a standard component, with clear tolerances that easily can be integrated into the system[222].

The control and managements system as opposed to energy source or electric motors is generally not a technology development that will be outsourced since it provides the vehicle with its efficiency and longer lifetime. This also has to be created and developed in relation to the implementation and application of the product which makes it harder to outsource this technology development[223]. This also means that the OEM needs to have some level of knowledge about the technology that is in-sourced to be able to use it. Hence, some knowledge must reside inside the company but product development and research might be done in e.g. China (when it comes to batteries)[224]. It appears to be so that one must consider key technologies, key competencies and access to both of them when evaluating the technology position of a firm and its technology sourcing strategy.

In general, large parts of the technology development is outsourced in the automotive industry[225]. Two primary sourcing strategies have been identified in the automotive industry referred to as integration or specialization[226]. Toyota follows an integration strategy with the argument that there is a need to understand the details of important technologies to not lose control or become too dependent on suppliers[227]. They even go as far as saying that developing hybrid systems is about integration. The focus on internal knowledge sourcing is also reflected in their knowledge and R&D sourcing strategy. Toyota is growing to become an industry leader not only in automotive technologies but also in power electronics, electric motors and batteries and battery systems[228]. The strategy is to develop the HEV technologies in-house and then outsource the production[229]. The level of integration is differing over the range of technologies since e.g. the battery position has been gained through a joint venture with Panasonic called PEVE[230].

European OEMs have had much lower levels of investments in hybrid powertrains and the importance of gaining capabilities in this area are not emphasized to the same extent. The European manufacturers have on the other hand pursued the specialization strategy where putting higher dependency on individual component manufacturers e.g. Bosch, ZF Valeo and Siemens VDO to develop integrated solutions is enabling OEMs to produce full hybrid electric vehicles[231],[232].

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[222] Interview with Andrew Dawkes, 2011-03-24
[223] Interview with Jonathan Rice, 2011-03-24
[224] Interview with Andrew Dawkes, 2011-03-24
[225] Interview with Hans Pohl, 2011-03-29
[226] Berggren, Magnusson & Sushandoyo, 2009
[227] Interview with Hans Pohl, 2011-03-29
[228] Berggren, Magnusson & Sushandoyo, 2009
[229] Interview with Hans Pohl, 2011-03-29
[230] Husain, 2010
[231] Berggren, Magnusson & Sushandoyo, 2009
[232] Interview with Hans Pohl, 2011-03-29

5.4.1 OEM POWERTRAIN - TECHNOLOGY SOURCING AND INNOVATION STRATEGIES

Nearly all larger lightweight automotive OEMs are developing or supplying hybrid technologies[233]. Toyota as the prime innovator has a very favorable technology position and represents one out of the two main approaches. From a technology and innovation perspective Toyota will have the chance to gain economies of scale through 1) expanding the hybrid technology to more product ranges 2) sharing technology and development cost with affiliates such as Daihatsu and Fuji Heavy[234] 3) licensing its technology to competitors e.g. its synergy drive to Ford, Nissan[235] and Mazda[236]. Toyota keeps control over manufacturing and technologies through in-house production, R&D and through its main partners e.g. Denso[237]. Toyotas main competitor technology wise pursuing a somewhat similar strategy is Honda[238].

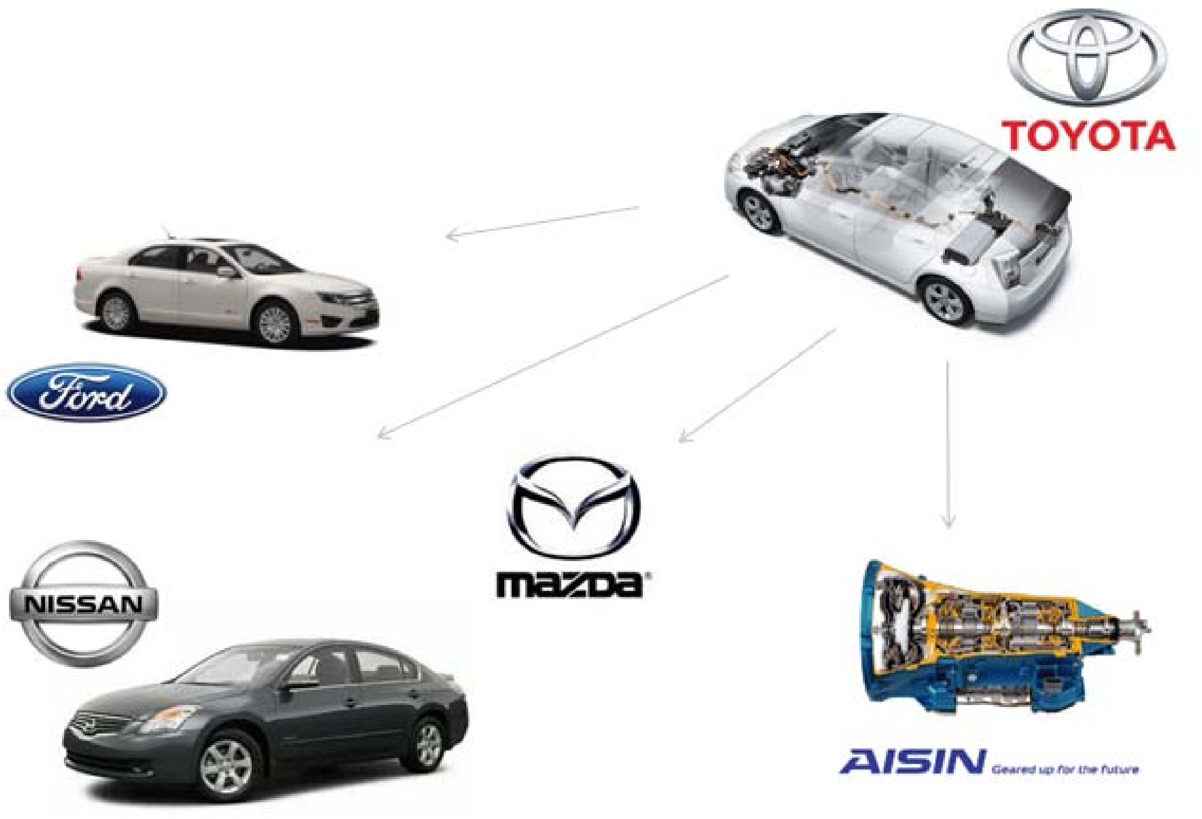


Figure 17 – Schematic picture over Toyota technology licensing activities towards different actors

PSA Peugeot-Citroen plans to offer a car with a diesel hybrid powertrain. PSA Peugot-Citroen jointly developed the electric motor, power electronics, the alternator/generator and control and management systems with Bosch. Sanyo provided the Ni-MH high-voltage batteries for this diesel hybrid project[239]. Previously PSA has also designed hybrid vehicles as a part of a British government grant together with Ricardo and QinetiQ and is currently leading a research consortium funded by the French government together with Valeo, Bosch, Saft and

[233] www.bosch.com
[234] Chanaron & Teske, 2007
[235] Lloyd & Blows, 2009
[236] http://www.toyota.co.jp/en/news/10/03/0329_2.pdf
[237] Chanaron & Teske, 2007
[238] Chanaron & Teske, 2007
[239] http://www.just-auto.com/news/psa-to-debut-worlds-first-diesel-hybrid-production-car_id105579.aspx

Michelin. Nissan have chosen a different strategy and licenses the Toyota synergy drive technology included in its Nissan Altima but has also stated that they will introduce an in-house developed hybrid technology[240].

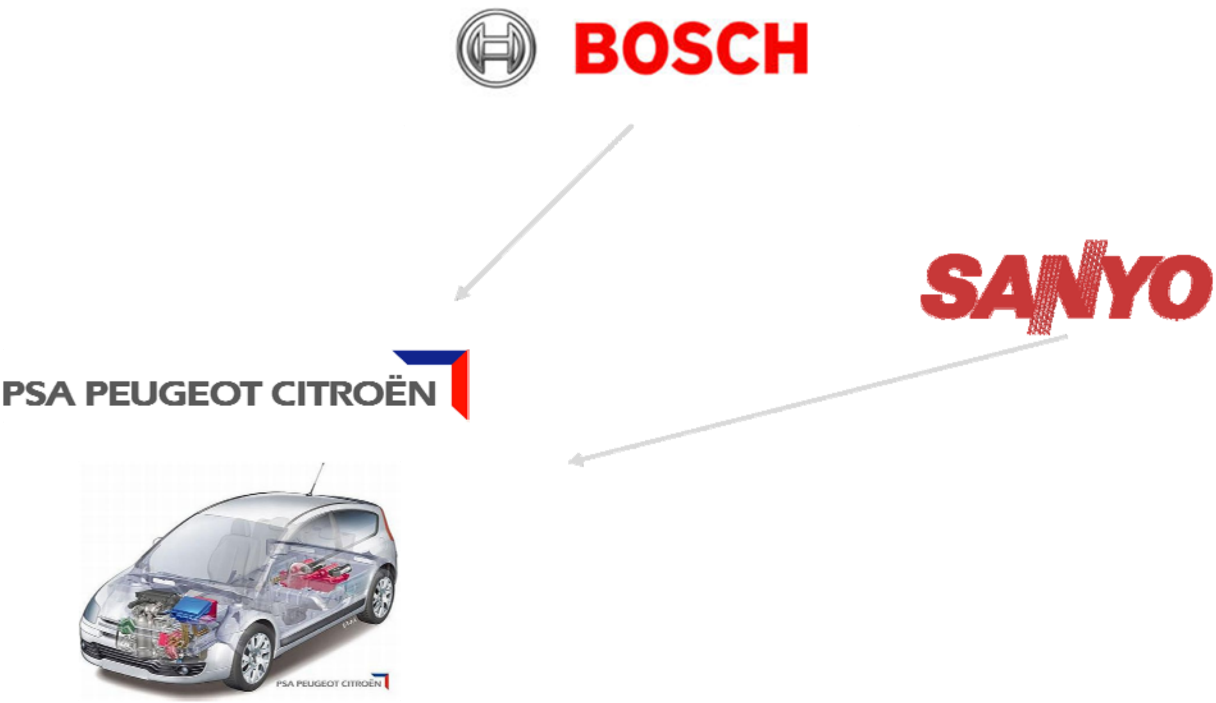


Figure 18 - Schematic picture over PSA's technology development partners for their diesel HEV

BMW, General Motors and DaimlerChrysler are jointly developing hybrid technologies in the Global Hybrid Cooperation. The primary technology produced in the cooperation is a two-mode active transmission[241]. The VAG group comprising Volkswagen and Audi has together with Porsche initiated a collaboration to develop hybrid versions for their SUVs[242]. The different manufacturers have implemented versions of the hybrid system in their Audi Q7, Porsche Cayenne and VW Touareg[243].

5.4.2 COMPONENT AND SYSTEM SUPPLIER TECHNOLOGY SOURCING AND INNOVATION STRATEGIES

Below follows a short description of the leading powertrain actors. I have chosen to distinguish between component providers that works to a large extent with one company i.e. Toyota, component suppliers that are large component suppliers to the auto industry as a whole, and hybrid technology specific suppliers.

Denso is considered to be a main partner to Toyota and supplies technologies for hybrid vehicle systems and is the largest automotive parts manufacturer in the world. This includes control technologies for engine and electric motor, traction inverters, battery monitoring systems etc[244]. Aisin is the third largest (2010) automotive parts manufacturer in the world and supplies drive train and transmission technologies to Toyota, which account for close to 70% of Aisin's sales[245]. Hitachi supplies electric engines for Toyotas synergy drive and was the first company that is non-affiliated to Toyota to become a supplier of hybrid technology and components.

240 Chanaron & Teske, 2007
241 Husain, 2010
242 Chanaron & Teske, 2007
243 Husain, 2010
244 www.globaldenso.com
245 AISIN annual report 2010

The previously mentioned Panasonic EV Energy, PEVE, is to 60% owned by Toyota and is a joint venture with Panasonic that provides nickel metal hydride batteries[246].

Figure 19 – Visualization of a few of the key supplier/technology relationships of the Toyota Hybrid Synergy Drive

A few of the key component suppliers of hybrid technology will be presented to provide an overview of the key actors and how they relate to the other actors within hybrid technology development. Continental and ZF Friedrichshafen jointly produce electrical components such as electric motors and braking components. ZF is also making gearboxes to be integrated with an electrical motor and Continental is cooperating with Volkswagen to develop parts of their hybrid design[247]. The largest component and system supplier to the automotive industry Bosch has created – Bosch Competence Center for Hybrid Systems – which develop a number of technologies aimed at providing efficient hybrid systems[248]. The primary suppliers of diesel hybrid technologies are Aisin, Continental, Denso, Robert Bosch, ZF[249].

[246] Chanaron & Teske, 2007
[247] Chanaron & Teske, 2007
[248] www.bosch.com
[249] Automotive News Europe, 2007

5.5 INTELLECTUAL PROPERTY RIGHTS POSITION

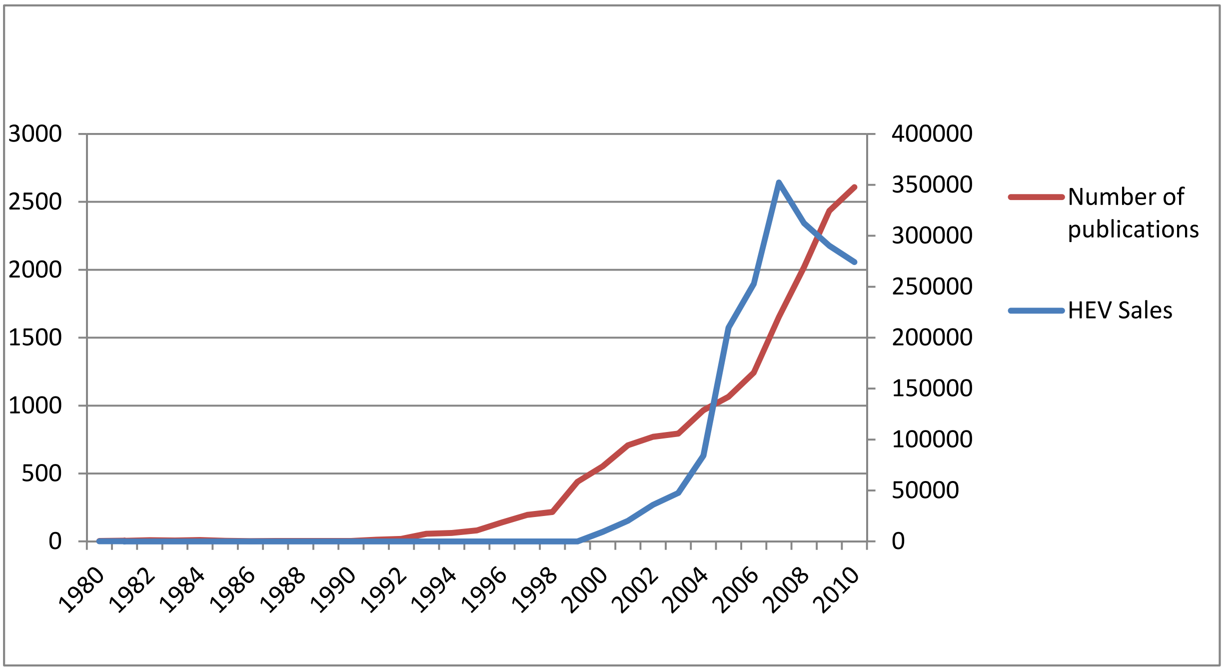


Figure 20- Number of published HEV patents (source: Thomson Innovation) and HEV sales (source: www.afdc.energy.gov/afdc/data/docs/hev_sales.xls)

As can be seen in the graph above where I have plotted HEV sales together with patent publishing, patenting has increased significantly the last decade for hybrid electrical vehicles alongside the sales of HEVs. The financial crisis hit hard on HEV sales and the drop in sales can be seen from 2007 and onwards. As stated earlier I have looked at approximately 16 500 patent families that are considered to be relevant for the HEV industry but as can be seen from the graph above the main bulk of those patents have been granted during the latter half of 2000-2010.

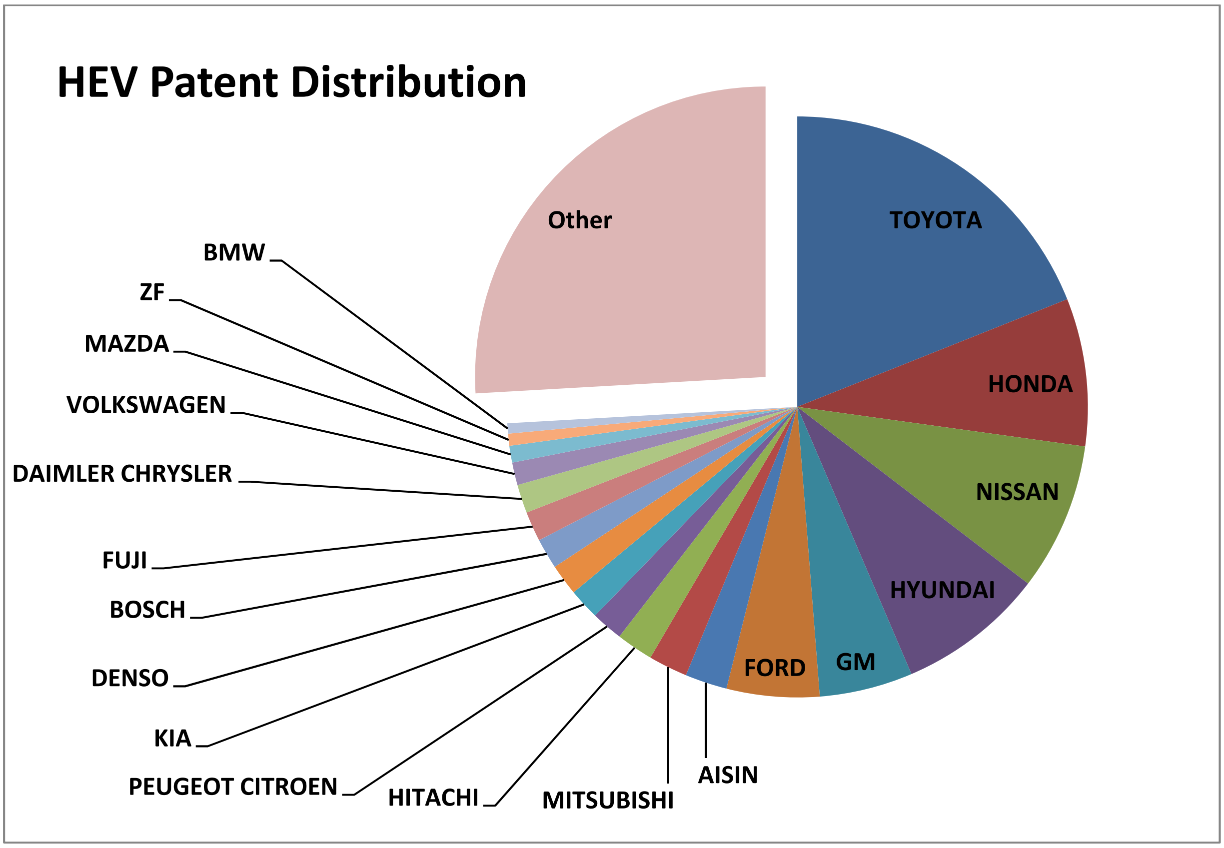


Figure 21 – Cumulative patent distribution between different actors in the HEV industry

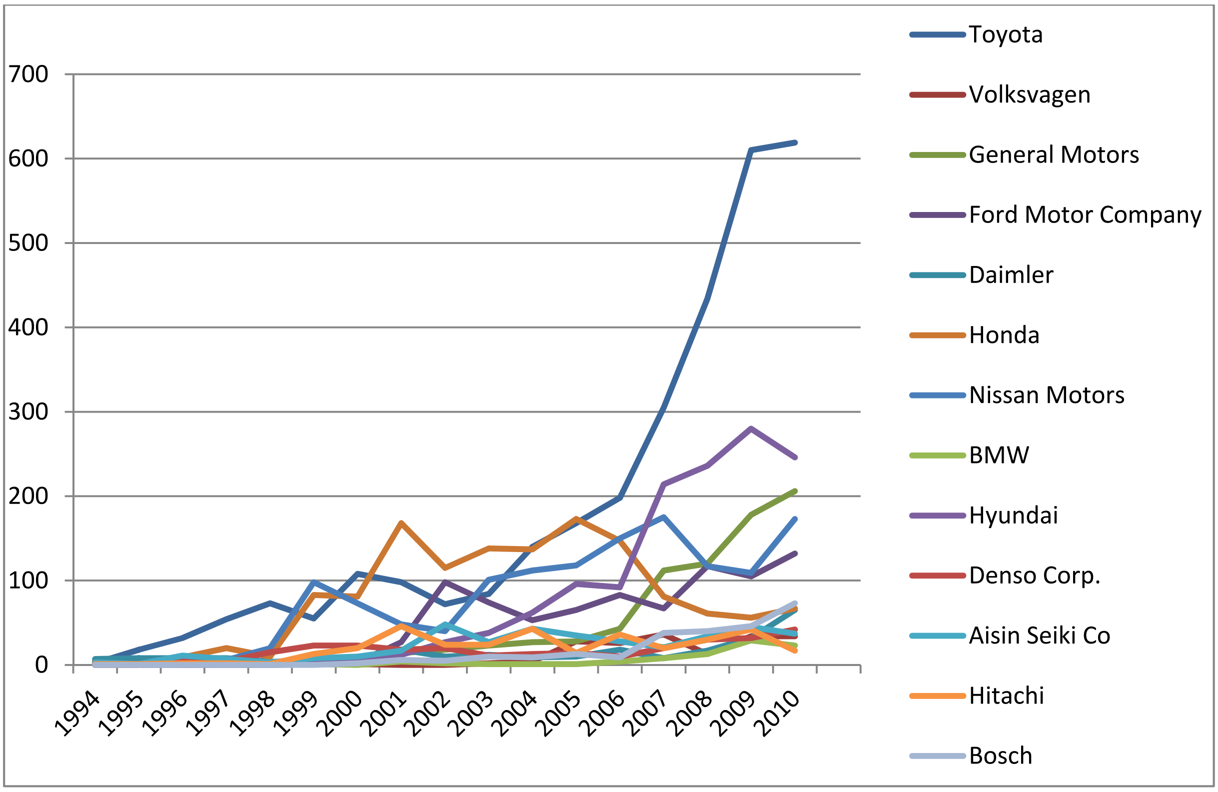


Figure 22 – Patent portfolio development over time for the top patenting OEM and Suppliers in the HEV industry

By analyzing the cumulative patenting efforts of the largest actors in the automotive industry based on revenues I was able to compare the distribution of revenues (see Figure 15 – Ten Largest Auto Manufacturers by revenue (2008) (source: IMAP, 2010)Figure 15 & Figure 16) to the distribution of patents between actors (see Figure 21). From the chart above the general power and technology distribution of the HEV, represented by patent density per actor, we can see that it is highly concentrated to a few actors. The top 19 assignees represent 74 percent of the total number of patents in HEV technologies. These top assignees are all among the largest Automotive Manufacturers or Automotive Component Manufacturers in the world. Based on this distribution we can see that the technology distribution and control seems as concentrated to the largest actors as e.g. revenues. From Figure 22 it is also evident that this patent portfolio build-up has been largest during the last half of this decade but that all actors did not initiate their patenting activities at the same time. Based on an analysis of industry revenues I found that approximately 50 - 60 percent of industry turnover can be derived from the top ten Auto Manufacturers and top 20 Auto Component Manufacturers. This leads me to believe that the HEV industry value network much like the automotive industry value network is highly centralized and that the core of the value network is made up of a number of firms with high centrality. The individual importance of the identified groups of actors in the industry can also be analyzed with the same logic and the same pattern then arises where the top ten Auto Manufacturers represent ~ 60 percent of the total number of patents in HEV technology and the top 20 Auto Component Manufacturers represent ~10 percent of the total number of patents.

By instead focusing on the relational aspect of technologies and trying to measure the impact of the technology this thesis set out to dive deeper into the value network in the HEV industry by analyzing the patent landscape. The starting point is to investigate which actors and actor roles that hold the most powerful and widely used technologies.

By investigating the 100 most cited patents in the HEV patent dataset a new logic for determining the centrality and centralization of the HEV value network from a technology perspective was found. To determine the centrality of individual firm the number of citations was used as well as the patent count of individual firms within this dataset of 100 most cited patent. Four companies have a higher concentration of patents than most other assignees and hold more than five of the top 100 cited patents. Most notable of these four companies are Toyota which hold 24 of the patents and Equos Research which hold 10 of the patents. The 100 patents are distributed over 47 assignees. Hence, a few firms still hold the high centrality described for the general HEV industry but when using citations marker for technological relationships the HEV technology value network is much less centralized. It is also evident that the concentration is much lower towards the large Auto Manufacturers and Auto Component Manufacturers and that smaller, technology providers such as research institutes and research organizations have a higher ratio of highly cited patents. What we can see from this is that the technology value network in the HEV industry is less centralized and that the centrality of smaller actors from the actor roles system, component and technology providers have a higher centrality than in the general case presented above. Especially technology providers have a higher presence constituting 15 of the 47 actors of the assignees of the top 100 cited patents from the HEV patent landscape and technology providers together hold 30% of the top 100 cited HEV patents.

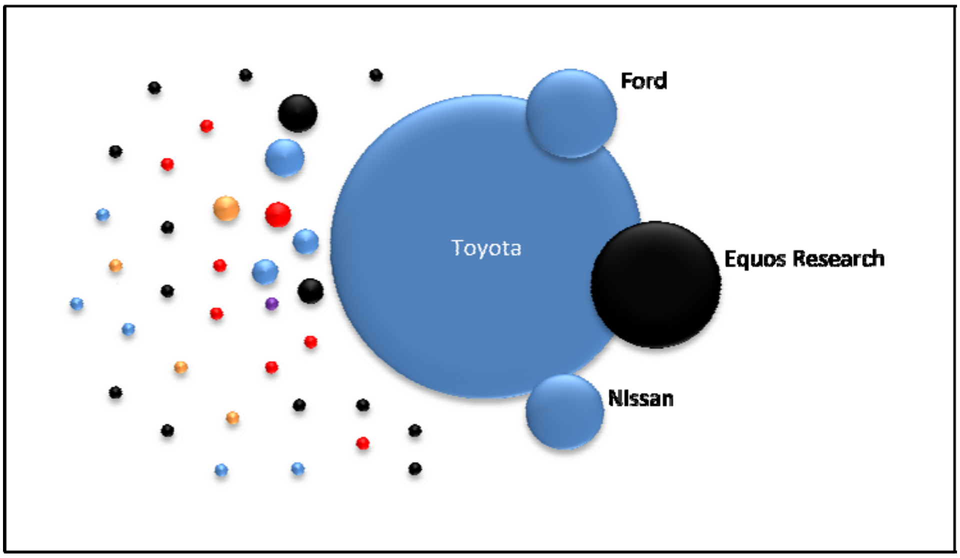


Figure 23 - Number of top 100 cited patents per actors and actor role[250]

According to patent analysis firm Griffith-Hack only one of these technology providers qualify as one of the top ten most dominant hybrid car patent holders, namely Paice Corporation. The table below presents rank of most dominant HEV patent holders based on network analysis[251].

Rank	Name	Relative dominance index	Number of patents
1	Toyota	100	3635
2	Honda	71	1435
3	Nissan	62	1644
4	Ford	60	809
5	General Motors	23	428
6	Peugeot-Citroen	22	255
7	Hitachi	21	393
8	Volksvagen	20	127
9	Paice Corporation	18	28
10	Renault	16	209

Table 1 - Most dominant HEV patent owners (Source: Lloyd & Blows, 2009)

Rank	Patent Owner
1	Paice Corporation
2	Paice Corporation
3	Eqous Research
4	Paice Corporation
5	Hybricon Inc
6	Toyota
7	Paice Corporation
8	Ford
9	Hitachi
10	Honda

Table 2 - Most dominant HEV patents by owner (Source: Lloyd & Blows, 2009)

250 For a more detailed description of the data please see Appendix D 9.4.5
251 Lloyd & Blows, 2009

By analyzing the data presented in the tables above (Table 3 - Short description of the 20 largest Auto Component Manufacturers (Source: IMAP 2010)and Table 4- Short description of the ten largest Auto Manufacturers (source: IMAP 2010)) it becomes evident that also from a technology power perspective the value network seems highly concentrated to a few players but at the same time we can see that smaller technology provider firms with, in comparison, a few number of patents have a fairly dominant technology position and hold dominant patents. The introduction of smaller "new" players with high centrality is further indication of a reduced centralization of the value network.

5.6 IPR POSITION IN TECHNOLOGY AREAS

To understand the technology and knowledge creation positions between the different actor groups presented earlier I have studied the IP position these actor groups hold in different key technology areas. The areas chosen were powertrain management unit, the electric machine in the powertrain, the battery management unit and the battery. These technology areas are highlighted in Figure 24 below. The different actor groups and technology areas are compared in terms of relative patent density and patenting activity in the technology area in the periods 2000-2005 and 2006-2010.

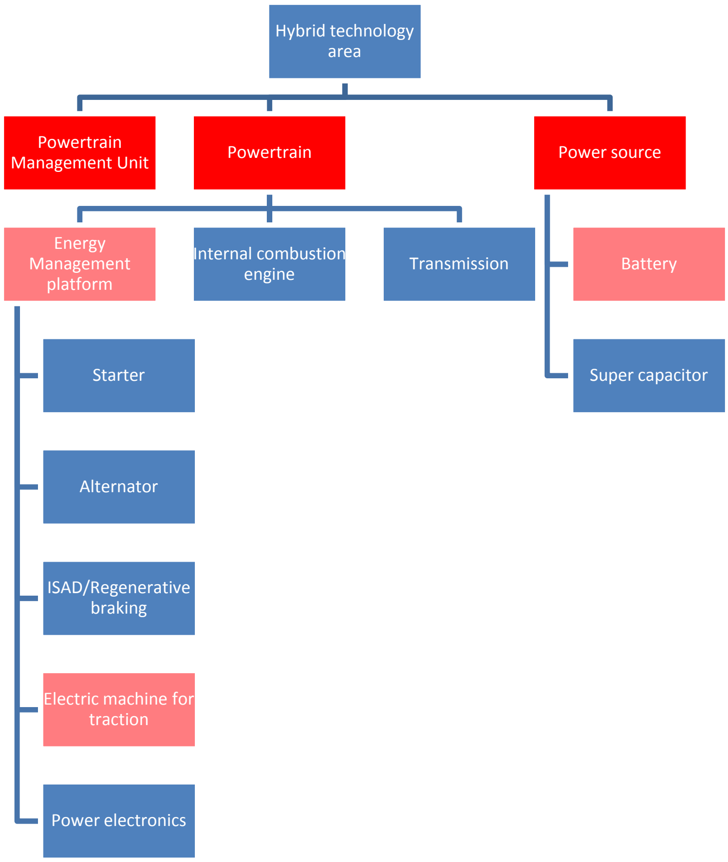


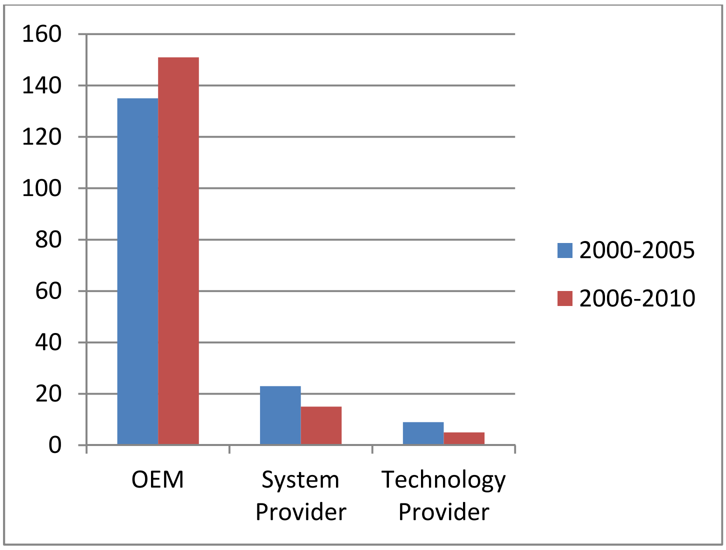
Figure 24 - Summary of key technology fields in hybrid electrical vehicles where the investigated technology areas are highlighted

5.6.1 POWERTRAIN MANAGEMENT UNIT – CONTROL SYSTEM[252]

In an HEV the control of the powertrain is equivalent to the brain of a human. This is where all parts of the system are incorporated to one system. The patent searches on the control system (see Figure 25 & Figure 26) reveal that the technology and knowledge ownership and creation is centered to the OEMs. They have a

[252] For a detailed table over the assignees and how they are grouped please see Appendix D – Patent Analysis

significantly higher patent density and their patenting activity has increased during the later parts of the investigated period. Both system providers and technology providers have a much lower density of patents and have also decreased in their patenting. This indicates that research in this technology area is focused on OEMs and that both system providers and technology providers are reducing their efforts in this area, at least on an architectural technology level. This supports the findings in the interviews where OEMs were stated to keep a higher portion of this development in-house. The component suppliers were not at all represented in this technology area which indicates the difference in level of research between an architectural level and component level and that neither system providers, component providers or technology providers seems to be focusing their efforts in this area.



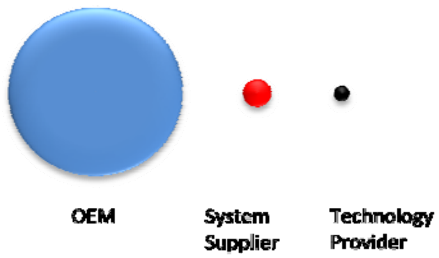


Figure 25 - Relative patent density per actor group

Figure 26 - Patenting activity comparison between 2000-2005 and 2006-2010 in control system

5.6.2 POWERTRAIN - ELECTRIC MACHINE[253]

The electric machine is basically a generator or an electric motor but it is in an HEV used for traction and energy. The patent search once again show that the patenting is highly concentrated to the OEMs and that component supplier seems to be less represented in the technology development. Again this points towards that the network is highly centralized. A factor that is unknown but could be increasing this could be that in co-development efforts between OEMs and component/system suppliers OEMs gets assigned to the IPRs. Another observation is that OEMs, System providers and Technology providers have increased their patenting activity in the period from 2006-2010 compared to the period 2000-2005. The OEM group has significantly increased their activity in this area which shows the increase in importance of this technology area at least in terms of technology ownership and IPR position for this actor group. What also can be seen in the presentation of the patenting activity is that System suppliers seem to play a not insignificant role in the creation and access to knowledge in this technology area. Pure technology providers also increased their patenting activity during the latter part of the investigated period which show that this role during this period at least sprung up as a new actor going from close to non-existent to become a small group in terms of IPR position. As discussed earlier the power of this group must probably be evaluated in terms of the strength of individual players patent portfolio since this actor group in general hold fewer patents but can potentially be very dominant patent holder as is shown in Table 4 where many of the top ten dominant patent holders in HEV are technology providers.

[253] For a detailed table over the assignees and how they are grouped please see Appendix D – Patent Analysis

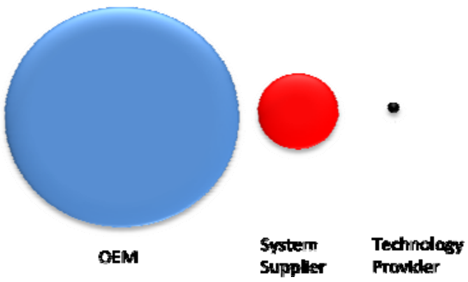


Figure 28 - Relative patent density per actor group

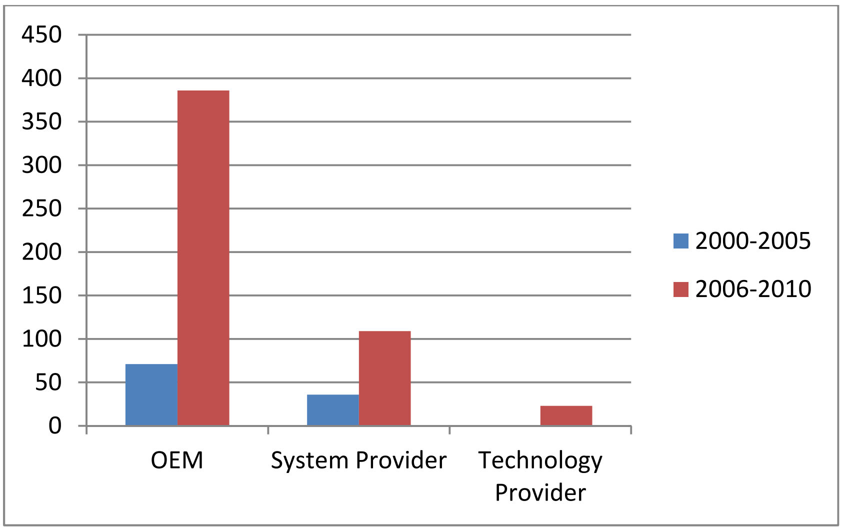


Figure 27 - Patenting activity comparison between 2000-2005 and 2006-2010 in electric machine

5.6.3 POWER SOURCE

The power source or simply battery has been mentioned previously in this thesis as a technology area where OEMs have a lower control position in terms of knowledge. This statement was reified in the patent searches where we can see that component suppliers seem to be the actor with highest centrality in terms of knowledge provision. But all actor roles have significantly increased their activity in this technology area of lithium ion batteries. The two main observations is therefore that this is a technology area which has increased significantly in importance over the investigated period and that the control position indicating which roles that contribute with technology development is pushed upstream towards component suppliers.

Lithium Ion[254]

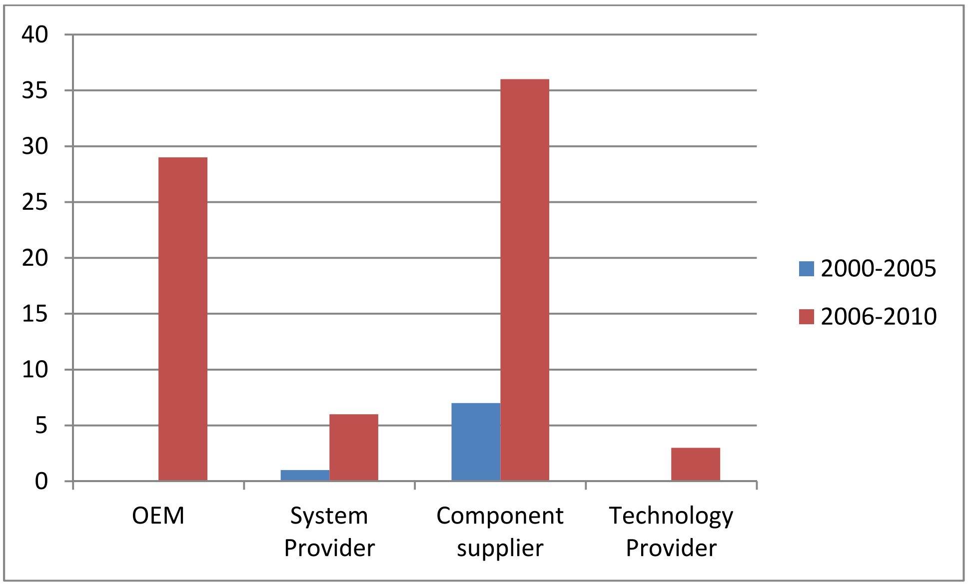


Figure 29 - Patenting activity comparison between 2000-2005 and 2006-2010 in lithium ion batteries

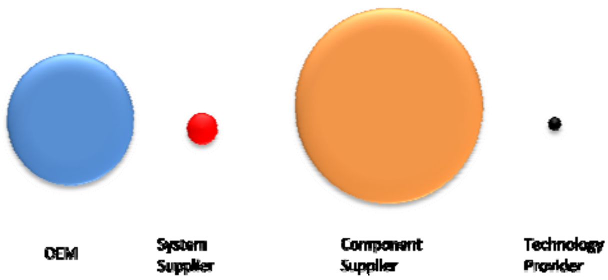


Figure 30 - Relative patent density per actor group

The patenting concentration towards component suppliers spurred an interest to also investigate to what extent this had spill-over effects on more architectural technology areas in the battery technology area. Below is a presentation of the relative patent positions between different actor roles within the battery management unit. What was found is that compared to the other presented more architectural technology areas the component suppliers seems to have a higher representation and also a higher increase in patenting than the other three actor roles. This could then be seen as further reification of the findings from the interviews where it was stated that the entrance of new technology had forced the OEMs to skip a step in the value chain in some areas and work directly with component suppliers in their technology and knowledge creation efforts.

[254] For a detailed table over the assignees and how they are grouped please see Appendix D – Patent Analysis

Battery Management Unit[255]

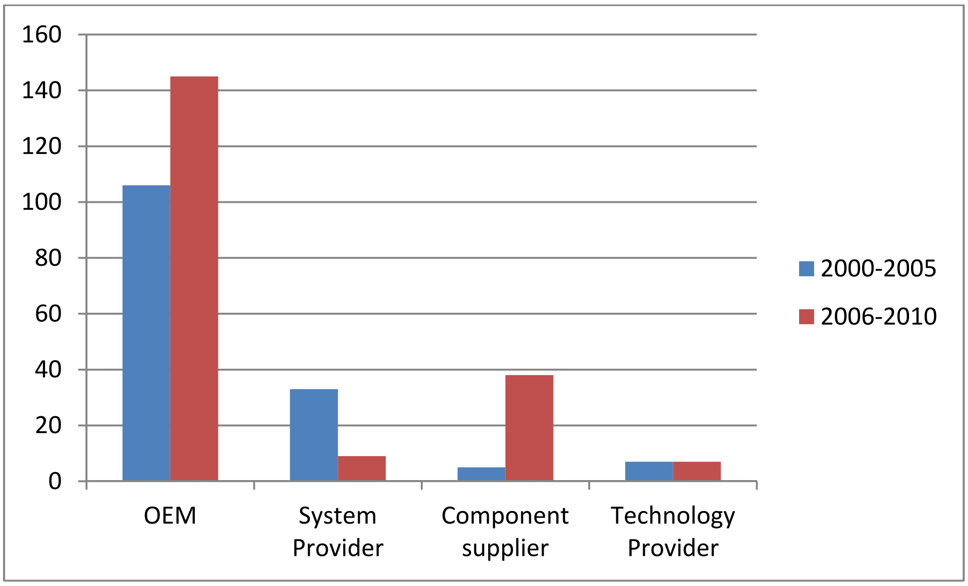


Figure 31 - Patenting activity comparison between 2000-2005 and 2006-2010 in battery management unit

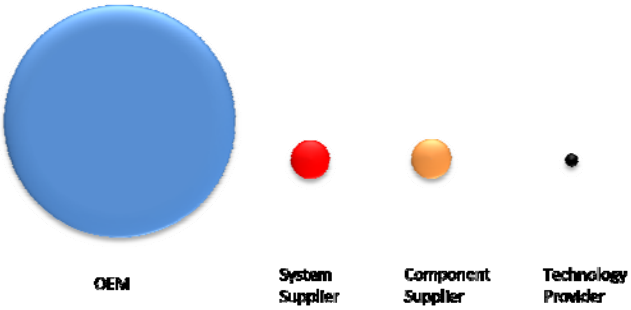


Figure 32 - Relative patent density per actor group

[255] For a detailed table over the assignees and how they are grouped please see Appendix D – Patent Analysis

6 CONCLUSION AND DISCUSSION

Figure 33 - A schematic view of technology/knowledge sharing among actor roles in the HEV value network

The introduction and evolution of the HEV, primarily the Toyota Hybrid System is a radical innovation[256]. The innovation has created a new market of on the one hand new interfaces between components and on the other hand substantial component innovation in batteries, battery control systems, transmission systems, etc. This is supported by the vast array of patents in these subfields and the importance of new competencies in e.g. power electronics, electrical engineering. In terms of technology sourcing strategies there are two distinct strategies pursued separating primarily European and Japanese actors[257]. It is found by Berggren, Magnusson & Sushandoyo (2009) that Japanese actors follow a strategy of integration while European actors follow the strategy of specialization. It is stated by Berggren et al (2009) that the most successful strategy will depend on if innovation in the HEV industry will be architectural or modular and that if innovation will be modular integrational capabilities are enough. The patent data analysis performed in this thesis shows that the technology ownership and development is to a large extent centered on the OEM group, especially in technology areas which are deemed to be of high importance in producing the look and feel of the end product. This trend is driven by Toyota Motor Company as is described in Chapter 5.4 and can be seen by their large patent portfolio (Figure 21) and the relative dominance of the Toyota HEV patent portfolio (Figure 23 & Table 3).

This thesis presents five roles of contextually equivalent actors that are identified in the HEV industry. These groups are OEMs, system providers, component providers, technology providers and consultancy service providers. The roles are not mutually exclusive and a single actor can undertake more than one role, this applies especially to the role of technology providers and consultancy service providers.

As shown in this thesis new technologies introduced in the hybrid electric vehicles such as battery technologies have been introduced by new actors, partly by innovating on an infrastructural level, where one step in the traditional automotive value chain have been skipped and OEMs and component suppliers collaborate to include new technologies in an industry. But this situation is not true for all technology areas. In Figure 30,

[256] Berggren, Magnusson & Sushandoyo, 2009
[257] Berggren, Magnusson & Sushandoyo, 2009

showing that the relative patent density of component providers in lithium ion batteries is significantly larger than in the other technology areas presented in Chapter 5.6 so it seems as if this occurrence will depend on the technology area. Throughout the thesis three reasons for collaboration between component providers and OEMs excluding/skipping system suppliers are found. The first is that there is a lack of suppliers where the system suppliers have not yet mobilized the capability to handle the technology development efforts towards the components suppliers since the new technologies are introduced by new actors. The second reason found was that the OEMs wish to gain in-house capabilities in some of the new technology areas introduced in the HEV industry and therefore does not want to outsource this part of the technology development. Instead OEMs collaborate or create joint ventures with component providers, such as the Toyota-Panasonic joint venture PEVE. The third reason is that some components such as the Lithium Ion batteries has existed for a couple of years already in products with smaller size and energy demands and that actors (component providers) active here were able to provide a leap frog in technology position for OEMs.

The HEV has not only increased the vertical scope through an inclusion of new actors but also a shift in the responsibility of the actor roles where some technology efforts are given a higher responsibility for upstream technology development. This can be seen in the responsibility of technology providers. In Figure 23 (although a static picture) it can be seen how circa 30% of the assignees of the top 100 cited HEV patents are technology providers showing their relative importance in creating and introducing new technologies. The responsibility of the component suppliers in battery development seems to have changed in much the same way. This actor group has a higher patenting activity (see Figure 30) compared to the equivalent actor roles in other technology areas pointing out that this group plays an important role in introducing and creating battery technologies. An interesting development is how OEMs enter as technology providers and, primarily through licensing, provide technologies to both upstream and downstream actors. One example found in this thesis being Toyota who licenses HEV technologies to both suppliers and competitors (see Figure 17 & Figure 19) but also the GHC R&D collaboration is an example of a shift in roles and relationships between actors. Nonetheless, it is unclear if this is an effect of the blurring of the concept of the value chain in the networked economy[258] or an evolution of the actor roles in the value network or both. To conclude, both technology providers and component providers have increased in their responsibility to create technologies previously done by OEMs or component providers.

In terms of exploitation of technology and the relationships in which this takes place the relationships take different structural forms. The study performed in this thesis did not reveal a particular trend in the setup of the relational infrastructure and many different forms are used e.g. joint ventures like PEVE between Toyota and Panasonic, research collaborations as Global Hybrid Cooperative and numerous other examples. The differences in setup also mean that the infrastructure for transfer and sharing of technology is different. Hence, I could not find specific technology exploitation trends and on actor group level it rather seemed to be situation and technology dependent. A new type of relationship that was found was where electric utility companies enter as stakeholders in the HEV industry and collaborate with primarily OEMs.

The knowledge base and vertical scope of the HEV industry was represented by a technology tree. The division of the industry into distinct technology areas enabled me to analyze the dynamics of an industry where the different branches represent different knowledge areas that are entering or leaving the industry knowledge base. Each branch will be in different modes of integration of specialization. I.e. that powertrain control system is in the HEV in an integration phase and the battery and power source technologies are in a specialization phase. This has strategic implications for actors wanting to succeed in the industry since it can provide insights to where we need to be internally strong to gain a favorable position in the value network and where we need to be good at gaining access to external knowledge to gain the sought for position in the value network. In an era of open innovation described in the introduction to this thesis it becomes a strategic implication to know in which areas innovation is sourced primarily from inside the firm and when it is sourced in collaboration with partners. This knowledge could then contribute to efforts of creating an efficient and agile R&D function.

[258] Kotler, 2009

Therefore, adding to the geographic and actor group aspects of technology sourcing it is also dependent on which technology area we study and success in technology sourcing strategy could therefore be dependent on knowledge about the sourcing strategy on different levels in the technology tree employed in an industry.

When analyzing the HEV industry from a technology development perspective one can see that there are different technology sourcing strategies but there are also common elements shared by many actors regarding a few technology areas in the HEV industry. What was found was that when considering technology sourcing strategies one first have to analyze whether the technology is key or detrimental to the product as such, the HEV system. What I find here is that the strategy applied is tightly linked to the role of the HEV actor. For the OEMs energy source technologies are unlikely to be sourced in-house but are rather accessed through partnerships or joint-ventures. The same strategy is often applied to the electric motor even though the patent data and data from the interviews were not totally coherent. The control and managements system as opposed to energy source or electric motors is generally not a technology development that will be outsourced since it provides the vehicle with some key characteristics and needs to work with many other key parts of the HEV which makes it harder to outsource this technology development. This also means that the OEM needs to have some level of knowledge about the technology that is in-sourced to be able to use it. Hence, some knowledge must reside inside the company but product development and research might be done outside of the boundaries of the firm. It appears to be so that one must consider key technologies, key competencies and access to both of them when evaluating the technology position, sourcing and exploitation strategy of a firm.

When considering the technology network from the three perspectives of centrality, centralization and inter-block relations there is no doubt that Toyota through the introduction of the first HEV technologies became a highly central firm in the HEV value network and that OEMs in general have a high centrality. This also provides a high centralization of the technology network but where as previously stated the European HEV industry has a lower centralization compared to the Japanese HEV industry. The integration strategy pursued and the high centralization might be an enabling factor of the HEV industry as such. According to Raynor & Christiansen (2002) the integrated firm will be in a better control position. This will provide an actor with the ability to develop and deploy new technologies and the most vertically integrated firm holds the best position to develop interdependent technological architectures[259]. The centralization of the industry therefore seems to be an enabling factor for introducing architectural technologies, in our case the studied HEV technologies. But on the other hand the frequency and density of interactions together with knowledge openness are detrimental for the generation, utilization and distribution of knowledge[260]. This would mean that many, highly interlinked actors, contribute to higher generation, utilization and distribution of knowledge. In the case of the HEV industry, areas where new actors have sprung up as powerful players such as within power source would contribute to both the generation and exploitation of knowledge. By finding areas of specialization/integration we can find in which areas the highest pace of innovation is likely to occur. Predicting where we need a position to be able to capitalize on future innovativeness of the industry. In conclusion the HEV industry is centralized but in a few technology areas structure loosening trends are found.

The introduction of new technologies in the HEV industry have brought a structure loosening trend to the European HEV industry where external demands and internal limitations of firms to some extent force them to decentralize the network structure and push technology development upstream in the value chain. This could allow for new firms to enter the industry allowing the vertical scope to develop and evolve through the introduction of new entrepreneurial firms. This observation could be considered to be weak but is supported by the increase in number of technology providers in the HEV industry. Although, still few in numbers and control position compared to the OEMs the trend is increasing and as can be seen in the example of Paice Corporation and the patent analysis where technology providers in many cases hold a powerful technology position even though being small in terms of patent portfolio and firm size. Therefore the structure loosening

[259] Raynor & Christiansen, 2002
[260] Caloghirou et al., 2004

trends could increase the number of firms even more since some areas of technology not seems to have reached a dominant design or technology standards.

The three concepts of structure loosening, vertical scope and actor roles seems to be interrelated and as the automotive industry move towards a transition towards becoming more knowledge centered one could expect that a change in the vertical scope brought by the introduction of new technologies will change the definitions of upstream and downstream roles in terms of technology development and then also have a structure loosening effect of the technology value network of the industry. Based on the findings in this thesis my hypothesis is that the challenges reside in the industry's ability to create transactional norms where knowledge can be transferred between firms. If the possibility to source modular innovation will not exist in the HEV industry the specialization trajectory cannot prevail and structure reinforcing effects will be the most favorable alternative. Hence, looking forward I believe it is uncertain whether a structure loosening or reinforcing trend will be dominant. The findings in this thesis suggest that the trend will differ depending the technology area in question.

The interviews point both towards increasing costs in production and R&D and that it is the integration and "consumer" experience features that are most important for automotive OEMs and especially in terms of HEVs. Although, looking forward it seems likely that segments of the automotive industry will adhere to the electrification trend and commercialize e.g. heavy duty HEVs. When entering into this new field there are a number of learning's that can be made from the light weight HEV industry evolution. In the light weight HEV industry Toyota seems to have been very successful as a first mover in technology and has through this been able to set the technology trajectory and also been able to position themselves in a position of high centrality in the technology value network. This position in the value network has provided Toyota with the chance to enter as a technology provider in the industry and successfully capitalize on this position. By using a high focus on in-house sourcing of innovation Toyota has further increased the centrality of the value network around them whereas European actors have reduced their centrality in a structure loosening manner. OEMs in heavy duty HEV industry seem to be facing two alternative roads providing diverging opportunities and risks. Furthermore, the knowledge base and vertical scope increase provide opportunities for new actors introducing new technologies and for new actors groups in the value network to change the network structure and gaining a new position in the network of actors providing technology.

6.1 FUTURE RESEARCH

For future research it would be interesting to see research done concerning individual firms putting them into the context of groups of firms that provide a framework for how to strategically act/interact with other actors to provide a successful technology sourcing. Since, commercial success often is more detrimental than technological success, at least in the short run it would also be interesting to see a study focusing the commercial gains by choosing position in the value network and technology sourcing strategy. This would then probably need an even more qualitative approach the method applied in this thesis, focusing on making a deep dive into a few specific companies in the HEV industry. Another interesting continuation of this thesis would be to look at the automotive industry at large and see how the technology creation network has evolved here and then compare this to one or several other industries. Preferably these industries could be knowledge or information centered industries such as IT, biotechnology or the alike. This could be the starting point for finding general trends of technology sourcing in the knowledge economy and industry specific trends brought by the knowledge economy. If this research is done it would be interesting to see if structure loosening trends in an open innovation era reduce companies' ability to deploy architectural innovation and if actors can change mature industries from within by introducing new markets within markets such as the HEV industry within the automotive industry. Is it so that by understanding the underlying structures in an industry that we can predict where these new markets will arise?

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8 INTERVIEWS

Jonathan Rice, Researcher at the Fluid Dynamic Dept. Chalmers University of Technology, 2011-03-24

Andrew Dawkes, Researcher at the Fluid Dynamic Dept. Chalmers University of Technology, 2011-03-24

Gunnar Bäck, CEO EL-Forest, 2011-03-29

Hans Pohl, Vinnova, 2011-03-29

9 APPENDIX

9.1 APPENDIX A – TWENTY LARGEST AUTO COMPONENT MANUFACTURERS

Auto Component Manufacturer	Country	Customers	Products
Denso Corp.	Japan	Toyota accounted for 30% of sales	Thermal systems, powertrain control systems, electric systems
Johnson Controls	USA	Ford, GM, Chrysler, Toyota, Nissan	Automotive interiors, products that optimize energy usage in batteries for automobiles and HEVs
Bridgestone Corp.	Japan	Acushnet Company, American Tire Distributors Holdings, Toyota	Tires
Continental AG	Germany	GM, Ford, AB Volvo, DaimlerChrysler, Maserati, Cayman, Audi AG, Mercedes-Benz, BMW, Volkswagen, Paccar, Porsche, Toyota, Kia, Fiat, and Suzuki	Chassis, hydraulic and electronic brake systems, sensor systems, telematics
Aisin Seiki Co	Japan	Toyota	Drivetrain components, automatic transmissions, manual transmissions, car navigation systems, brake and chassis-related products, and automobile body related products
Magna International Inc.	Canada	Aston Martin, BMW, Chery Automobile, Daimler, Ferrari, Fiat, Honda, Hyundai, Mercedes Benz	Automotive systems, assemblies, modules, and components
Michelin	France	N/A	Tires
Toyota Auto Body Co	Japan	N/A	Automobile parts
Goodyear Tire and Rubber Co	USA	N/A	Tires
Delphi Corp.	USA	Ford, Chrysler, Renault Nissan, Hyundai, and Volkswagen	Vehicle electronics, transportation components, integrated systems, modules, other electronic equipment
ZF Freidrichshafen AG	Germany	Audi, BMW, Daimler Trucks, Nissan	Driveline and chassis products
Faurecia	France	PSA Peugeot Citroen S.A, Volkswagen, Renault-Nissan, Ford, BMW, GM, Daimler, Chrysler, Hyundai, Toyota	Seats
TRW Automotive	USA	Volkswagen, GM, Ford, Chrysler	Chassis systems, engine valves, body controls, and engineered fasteners and components
Lear Corp.	USA	GM, Ford, BMW; Other customers: Daimler Chrysler, PSA, Volkswagen, Fiat, Renault Nissan, Hyundai, Mazda, Subaru, and Toyota	Seating systems
Toyota Boshoku Corp.	Japan	Aisin Seiki, Honda, Toyota	Automobile interior components such as floor carpets and seats, floor silencers, door trims, fender lines, bumpers, engine undercovers, automotive filters, and power train components
Valeo SA	France	Ford, GM, PSA Peugeot Citroen, Renault-Nissan, Volkswagen	Lighting systems, wiper systems, interior controls, electrical systems, security systems, engine management systems, compressors, climate control, engine cooling, and transmission
Hyundai Mobis	South Korea	Daimler, Mercedes Benz, Old Carco, Volkswagen	Chassis, cockpit, front-ends, safety parts, braking components, combination parts, injection parts, and wheel and deck modules
Visteon Corp	USA	N/A	Chassis, powertrain, and drive train products
Calsonic Kansei Corp.	Japan	BMW, Honda, Jaguar, Land Rover, Nissan, Toyota	Module parts, system products

Sumitomo Electric Industries Ltd	Japan	Toyota	Wire harnesses, rubber cushions, hoses for automobiles, automobile electrical parts, and others

Table 3 - Short description of the 20 largest Auto Component Manufacturers (Source: IMAP 2010)

9.2 APPENDIX B – TEN LARGEST AUTO MANUFACTURERS (OEM)

Auto Manufacturer	Product Portfolio
Toyota	Passenger cars, recreational and sports utility vehicles (SUVs), minivans, and trucks. Toyota is the market leader in hybrid cars.Toyota sells 13 hybrid vehicle models in 50 countries.
Volksvagen	Low consumption small cars to luxury class vehicles. Company has nine brands from seven European countries. In the commercial vehicles sector, the company makes pickups, buses, and heavy trucks. Leading brands include Volkswagen, Audi, Bentley, Bugatti, Lamborghini, Scania, SEAT and Skoda.
General Motors	Cars, trucks, vans, and utility vehicles under a multitude of different brands
Ford Motor Company	Cars in small, medium, large, and premium segments under a multitude of brands. They also sell trucks, buses/vans and vehicles for the medium and heavy segments
Daimler	Premium passenger cars primairlily under the brand Mercedes Benz, cars, Daimler trucks, Mercedes-Benz vans, and Daimler buses
Honda	Passenger cars, SUVs, commercial vehicles, special need vehicles, utility vehicles, and motorcycles.
Nissan Motors	Passenger cars, trucks, SUVs, light utility vehicles and mini vans. Company is in a partnership with Renault for automobile manufacturing. Renault holds a 44.3% stake in Nissan, while Nissan owns 15% of Renault shares.
Fiat	Automobiles, trucks, wheel loaders, excavators, tele-handlers, tractors.
BMW	Automobiles and motorcycles. The company owns three brands: BMW, MINI, and Rolls Royce.
Hyundai	Passenger vehicles, recreational vehicles, and commercial vehicles

Table 4- Short description of the ten largest Auto Manufacturers (source: IMAP 2010)

9.3 APPENDIX C – INTERVIEW QUESTIONNARIE

Introduction

1. Describe the thesis
    a. Study of the technology market in diesel hybrid technology development regarding key technologies, characteristics, actors, roles and relationships.
    b. Look at developments and trends over time. Based on an analysis of the car HEV industry, analyze potential future developments in heavy duty HEV industry.
2. The interviewee
    a. Which organization do you represent?
    b. What does your organization do (focus on HEV activities)?
    c. Tell me about you?
        i. What is your role in the organization?
        ii. What is your background?
    d. What is your organizations role in the HEV industry?
3. The industry
    a. Which would you say are the key technology areas in the HEV industry?

Technology development and technology tree

Technology tree

4. I have made an effort to describe the different technology areas around diesel HEVs for medium and heavy duty vehicles as a technology tree
    a. Do you believe it is possible to describe the technology areas in the form of a technology tree?
    b. Branch by branch – Do you think this is correct? Should anything be added or removed?
    c. Branch by branch – What is the development state/what is the state of the art of the technology area?
        i. Which are still emerging and which have reached a dominant design/mature state?

Development trends

5. Of the presented technology areas in HEV which would you say have the highest relevancy for diesel HEV development? Heavy duty diesel HEV?
6. Of the presented technology areas which would you say have the highest development activity?
7. Of the presented technology areas which would you say have the highest development potential?
8. Of the technology areas which would you say are HEV specific and not transferrable to or from other industries and which are transferable from other industries? Which industries?
    a. Specifically which are transferrable to or from automotive/light weight HEVs such as those provided by Toyota etc.?
    b. Which technologies must be developed in-house (are product specific) and which could be sourced from the outside when developing a (diesel heavy duty) HEV powertrain?
9. What would you say is the industry specific (e.g. light weight, heavy duty) development state of the different technology areas?
10. What have been the developments over time?

Actors and roles

The value network

1. How would you describe the value network of the HEV industry? (In general but focus in on powertrain developments and actors)
    a. What roles can an actor take on (with focus on technology developers)?
        i. How do the roles differ between OEM/1st tier/2nd tier etc.
2. Which key technology actors would you say exists on every tier-level/role in HEV powertrain development?
    a. Technology providers?
    b. OEMs?
    c. Component providers?
    d. System providers?
    e. Consultancy services?
3. What have been the developments over time?
    a. Have new roles emerged or new actors entered the market?

Roles

1. Which are the key actors in the industry?
    a. Who do you have to relate to in order to be able to act in the industry:
        i. Technology wise?
        ii. IPR wise?
        iii. Skills wise?
    b. What is the relative importance of these actors considering
        i. Market share?
        ii. Market or technology power?
        iii. Market potential?
        iv. Industry/supplier dependencies?
    c. What are the barriers to freedom of action in the industry
        i. Technology development and packaging?
        ii. Market access?
        iii. Regulatory barriers?
2. What have been the developments over time? What has changed over the last decades?

Relationships

1. What relational types exist in the industry?
    a. Competitors, collaborators, suppliers, customers?
    b. Alliance, Joint Ventures, Research collaborations, Governmental initiatives?
    c. What are the characteristics of these relationships? What is the level of collaboration in the relationships and the industry as a whole (for example arms-length relationships or open collaborations)?
    d. Are there any standards or standard setting organizations (focus on HEV)?
2. How are knowledge, technology and IPRs shared in these relationships?
    a. Which are the norms on what to bring to the table and who gets what in a collaboration?
    b. OEM power or supplier power - how is technology specifications claimed and protected?
3. What have been the developments over time? What has changed over the last decade?

Market characteristics

1. In what ways is technology transacted in the industry?
    a. Between what actors and what roles?

    b. How is it transacted? Product, consultancy, license, joint development, mix?
        i. Product specification?
    c. How is it paid for? What are the revenue streams and between whom?
2. To what extent would you estimate that the industry is open for new technology providers?
    a. How set are the structures for accessing the customers/OEMs?
    b. How is a potential technology provider evaluated?
3. How are IPRs used?
    a. To protect technology?
    b. To share technology?
    c. To transact technology?
4. What have been the developments over time? What has changed over the last decade?

9.4 APPENDIX D – PATENT ANALYSIS

9.4.1 BATTERY MANAGEMENT SYSTEM

Presented below are the top assignees within Battery Management system. The patent searches generated a total of 472 patents within this technology area.

Patent owner	Patent count	2000-2005	2006-2010	Actor type
HYUNDAI MOTOR CO LTD	87	34	54	OEM
TOYOTA MOTOR CORP	47	18	29	OEM
NISSAN MOTOR	26	23	3	OEM
FORD GLOBAL TECH LLC	21	15	6	OEM
KIA MOTORS CORP	16	1	15	OEM
GM GLOBAL TECH OPERATIONS INC	16	1	15	OEM
SAIC CHERY AUTOMOBILE CO LTD	16	0	16	OEM
PEUGEOT CITROEN AUTOMOBILES SA	14	7	7	OEM
FUJI HEAVY IND LTD	13	13	0	System supplier
HITACHI LTD	13	9	4	System supplier
SAMSUNG SDI CO LTD	11	0	11	Component supplier
EATON CORP	11	1	10	Component supplier
DENSO CORP	10	10	0	System supplier
SANYO ELECTRIC CO	8	4	4	Component supplier
COBASYS LLC	7	0	7	Component supplier
INT TRUCK INTELLECTUAL PROP CO	7	0	7	Technology Provider
DAIMLER BENZ AG	7	7	0	OEM
NIPPON SOKEN	7	7	0	Technology Provider
GEN ELECTRIC	6	1	5	System supplier
NEXCON TEC CO LTD	6	0	6	Component supplier

Actor group summary	Patent count	2000-2005	2006-2010
OEM	250	106	145
System Provider	42	33	9
Component supplier	43	5	38
Technology Provider	14	7	7

9.4.2 LITHIUM ION

Presented below are the top assignees within Lithium Ion batteries. The patent searches generated a total of 119 patents within this technology area.

Patent owner	Patent count	2000-2005	2006-2010	Actor type
TOYOTA MOTOR	18	0	18	OEM
DAIMLER CHRYSLER	11	0	11	OEM
LG CHEMICAL LTD	8	0	8	Component Supplier
SANYO ELECTRIC CO	7	0	7	Component Supplier
HITACHI	7	1	6	System Supplier
FMC CORP	6	5	1	Component Supplier
A123 SYSTEMS INC	6	0	6	Component Supplier
NIPPON Mining	6	0	6	Component Supplier
TOKAI CARBON KK	5	0	5	Component Supplier
FEV MOTORENTECH GMBH	3	0	3	Technology Provider
SAFT	3	0	3	Component Supplier
QUALLION LLC	2	2	0	Component Supplier

Actor group summary	Patent count	2000-2005	2006-2010
OEM	29	0	29
System Provider	7	1	6
Component supplier	43	7	36
Technology Provider	3	0	3

9.4.3 ELECTRIC MACHINE

Presented below are the top assignees within Electric Machines. The patent searches generated a total of 843 patents within this technology area.

Patent owner	Patent count	2000-2005	2006-2010	Actor type
PEUGEOT CITROEN	130	19	111	OEM
FORD	75	6	69	OEM
ZF	54	0	54	System Supplier
RENAULT	50	8	42	OEM
TOYOTA	48	1	45	OEM
BOSCH	46	6	37	System Supplier
HITACHI	34	23	11	System Supplier
VOLKSWAGEN	34	5	28	OEM
General Motors	33	4	26	OEM
BMW	32	3	29	OEM
DENSO	25	7	7	System Supplier
PORSCHE	22	0	22	OEM
FERRARI	17	0	17	OEM
DAIMLER CHRYSLER	17	5	10	OEM
SKODA	16	3	13	OEM
NISSAN	16	15	1	OEM
MAZDA	11	0	11	OEM
MITSUBISHI	10	3	7	OEM
Wallner Energietechnik Gmbh	9	0	9	Technology Provider
NICOLAS ROBART	8	0	8	Technology Provider
SEBASTIEN BESNARD	6	0	6	Technology Provider

Actor group summary	Patent count	2000-2005	2006-2010
OEM	463	71	386
System Provider	159	36	109
Technology Provider	23	0	23

9.4.4 POWERTRAIN MANAGEMENT UNIT

Presented below are the top assignees within Powertrain Management Unit. The patent searches generated a total of 431 patents within this technology area.

Patent owner	Patent count	2000-2005	2006-2010	Actor type
TOYOTA	73	24	40	OEM
HONDA	60	48	10	OEM
HYUNDAI	60	21	39	OEM
NISSAN	31	5	20	OEM
FORD	26	20	5	OEM
GENERAL MOTORS	21	3	18	OEM
DENSO	14	3	1	System supplier
FUJI HEAVY IND	13	9	3	System supplier
PAICE	12	7	5	Technology Provider
AQUEOUS Research	11	0	0	Technology Provider
AISIN	10	7	2	System supplier
MITSUBISHI	10	4	4	OEM
CONTINENTAL	8	0	8	System supplier
MAZDA	8	3	5	OEM
SUZUKI	7	7	0	OEM
KIA MOTORS	5	0	5	OEM
HITACHI	5	4	1	System supplier
EQUOS RESEARCH	5	2	0	Technology Provider
CHONGQING CHANGAN AUTOMOBILE	5	0	5	OEM

Actor group summary	Patent count	2000-2005	2006-2010
OEM	306	135	151
System Provider	50	23	15
Technology Provider	28	9	5

9.4.5 TOP 100 CITED PATENTS AND ASSIGNEES IN THE HEV DATASET

The table below summarizes the actors assigned to the top 100 cited patents from the HEV patent landscape dataset containing approximately 16 500 patent families. For assignees represented by individuals it has in many cases not been possible to place them in an actor group with high confidence why they are left with a question mark under actor role and are excluded from the analysis.

Company name	No of Patents	Actor role
TOYOTA	24	OEM
Equos Reseach	10	Technology Provider
Ford	7	OEM
Nissan Motor	6	OEM
AQUEOUS	3	Technology Provider
Daihatsu Motor Co.	3	OEM
Denso	2	System provider
General Motors	2	OEM
HUNT HUGH S	2	Technology Provider (Cambridge University)
Mitsubishi	2	OEM
Nippon	2	Component Supplier
ABDELMALEK FAWZY T	1	Consultancy Provider
AEL Defense	1	System provider (bought by BAE Systems)
AISIN	1	System Provider
Azure Dynamics Inc.	1	Technology Provider
B Research Inc.	1	Technology Provider
Battery Development Corporation	1	Technology Provider
Electromotive Inc.	1	Component Supplier
ELLERS CLARENCE W	1	?
Fichtel & Sachs	1	System Provider
FIELD BRUCE F | BRICHER CHARLES W	1	?
Finmeccanica SA.	1	Technology Provider
Frank Transportation Technology	1	?
FRANK; ANDREW A	1	?
Fuji Jukogyo	1	OEM
GARDNER CONRAD O	1	Technology Provider
General Electric	1	Component Supplier
GRAYER; WILLIAM | OLSON; WILLIAM R | ROSEN; HAROLD A	1	?
Honda	1	OEM
Hybricon Inc.	1	Component Supplier
Jatco Corporation	1	System Provider
Visteon	1	System Provider
KENYON KEITH E	1	Technology Provider
Lockheed Martin	1	Technology Provider

New Venture Gear (Magna Powertrain)	1	System Provider
Oshkosh Truck Corporation	1	OEM (heavy duty)
Paice Corporation	2	Technology Provider
PARISE Reserach Technologies	1	Technology Provider
Peugeot	1	OEM
Southwest Research Institute	1	Technology Provider
The Regents of the University of California	1	Technology Provider
The United States of America as represented by the Administrator of the U Environmental Protection Agency	1	Technology Provider/Gov
WALDORF L	1	?
VARELA JR ARTHUR A	1	?
Volkswagen	1	OEM
Bosch	1	System Provider