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Innovation Strategies for SMEs: The case of component suppliers in the automotive industry

A Master's Thesis submitted for the degree of
"Master of Business Administration"

supervised by
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Affidavit

I, **MATTHIAS SCHMID**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Innovation Strategies for SME: The case of component supplier in the automotive industry", 55 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 30.07.2017

Signature

Abstract

Statements like “Your petrol-fueled car will become a thing of the past” is not really new, except it comes from the CEO of one the biggest vehicle manufacturer in the world, Mary Barra, CEO of General Motors. The technological change in the automotive industry is omnipresent in today’s media and the citation above points up that it is “the topic” as well as at huge OEMs. But what are the effects on the automotive supplier industry and especially those small and medium-sized enterprises, who are responsible for many different parts in a vehicle, what is their opinion about the technological change, do they have a specific strategy for and if not, what could be potential strategies. These are the main questions which are addressed in this thesis.

This thesis is especially addressed to small and medium-sized components supplier in the automotive industry. Why is that? First, particularly small and medium-sized enterprises do not have the financial power and stamina to react on changes in their business environment. Second, component manufacturer will face life-threatening changes in the future, especially those who are mainly engaged in the internal combustion engine and “traditional” powertrain environment.

To be well prepared for future disruptive changes, small and medium-sized enterprises have to develop a sense of urgency, because in the past companies failed in disruptive situations, because they simply did not see the change or were too arrogant to adapt. But a sense of urgency is not enough to compete with disruptive technological changes. Affected companies have to develop innovation strategies to be prepared when disruptive change arise.

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1 Introduction

In this chapter, an outline of the thesis and its aims are given as well as a brief description of innovation strategies is provided. A context for understanding the current development in the international automotive industry and its implication on the automotive supplier industry is described.

1.1 Exposure of the problem

For more than a century, the internal combustion engine (ICE) was the dominant design for the transportation industry. Rudolf Christian Karl Diesels and Nikolaus August Ottos inventions made it possible, that individual and public transportation of people and goods on land and sea, become affordable to mass-market. Especially in combination with massive investments in exploration and refining of oil, no other technology had a chance to battle against the supremacy of the internal combustion engine. The result was and still is, that the internal combustion engine is responsible for over 99% of all motorized vehicles, from the tiny motorbike, to smaller and bigger autos, to small and highway commercial vehicles to all kind of ships with a power range from less than one kW to over 80MW.[1]

Although the overall fuel efficiency is not really outstanding, due to the huge energy density of fossil fuels, the cruising range of combustion engine driven vehicles was never an issue. And until recently, emissions of ICEs were also not an insuperable barrier for their success. Because of this extraordinary long technological S-curve of ICEs, only a few engine manufacturers remained on the market and as a result of huge initial investments to develop and manufacture an ICE, there have not been a serious newcomer to the industry for decades now. And although original equipment manufacturer (OEM) of ICEs, like Daimler, BMW, Volkswagen, Ford, GM, Chrysler made huge developments in terms of fuel efficiency and reduction of emissions, up to -41% of CO_2 emissions since 1995[2], the development steps can be described as incremental, due to the reason that, all state of the art technologies, which are implemented into today's ICEs, are already known for decades now. Direct injection, turbo charging technologies just to name some of them. To run an ICE efficiently, all components of the powertrain have to harmonize with each other, gearbox, transfer case, differential and so on. This

[1] Wärtsilä Corporation, 2016

[2] Bayerische Motoren Werke Aktiengesellschaft, 2016

means, when we talk about ICE driven vehicles, there are many other components necessary. All these components together, we call them conventional powertrain. The added value of a conventional powertrain of an entire car sums up to 35% in average. In specific, the added value of the ICE of a compact class car, for example a Volkswagen Polo, sums up to 18%. These 18% added value are equally split up between OEM (51%) and supplier industry (41%) in this specific case. These developments resulted in a very concentrated and interlocked supplier industry for ICE, where supplier have been specialized and focused in specific parts or modules of the conventional powertrain and put all or at least most of their innovation efforts to develop these components and modules further. This innovation strategy worked out very well in the past, when almost every motorized vehicle was driven by a conventional powertrain and the overall worldwide vehicle market grew every year.

The current situation in the automotive industry is characterized by a variety of economic and technological change processes, which have a lasting influence on the structures within this industry. A central driver is the increasing relevance of electric drive trains. In contrast to conventional powertrain drives, an electric powertrain require electric drive components such as electric engines, traction batteries and power electronics, called battery electric vehicle (BEV) or in case of a fuel cell electric vehicle (FCEV) a smaller battery compared to a BEV but in addition a fuel cell stack, which converts chemical stored energy into electric energy. Whereas the proportion of the added value of the electric powertrain will be in the same range to conventional powertrains, the components have very little in common compared to conventional powertrain components from a technology point of view. In this context, new, so far non-industry players will also enter the established value-added system of the automotive industry. At the same time, there are also high growth potentials for the traditional automotive suppliers. As long as, they can consistently scrutinize, expand and successfully position their product portfolio in the market for electrical drive components.

Against the backdrop of these change processes in the automotive industry, especially the supplier industry will undergo a profound structural change. Due to the changes caused by electric mobility, small and medium-sized companies (SMEs) are particularly vulnerable, if they do not prepare themselves for future market developments in time. In the case of companies whose product portfolio has a high concentration on combustion engine drive components, the greatest need for action exists, in order to ensure the future viability of the company and the related jobs. At the same time, the growth market for electric mobility offers great opportunities automotive suppliers, in order to be able to benefit from the positive market development in the long term with a corresponding (innovation) strategy.

1.2 Objective of the thesis

Changes in the automotive industry are one almost everybody’s lips, whether it is business model wise or technology wise. Whether car sharing in whatever form, or whether hybrid electric vehicle (HEV), where conventional powertrains are combined with electric powertrain, BEV or FCEV will be the dominant design of the future powertrain. But do announced transformations come true? The ICE along with the conventional powertrain was already declared dead for many times in the past. And if the transformation comes true, yes there is no doubt that the importance of the conventional powertrain will be less in the future. With this decline of importance of the ICE powertrain, less research, less developments and finally less market share with lower volume and revenues come along. Therefore, the objectives of the thesis are the following:

- Illustrate the dramatic changes and create awareness

The phrase: “Disruptive trends that will transform the auto industry”[3], has been used inflationary today. But is it really that dramatic? And if yes, will it be a gentle transformation or once the tipping point is passed it pops up/out like a ketchup tube.[4] One aim of the thesis is to illustrate different scenarios and create out of that an awareness to innovate. It is not an aim to provide a certain year with a certain market share of hybrids BEVs and FCEVs, which is not predictable today, because of too many dependencies, like battery and fuel cell developments and regulations on fuel efficiency and emissions, just to name two of them.

- Point out that especially for specialized SMEs urgent need to innovate is required

When it comes to dramatic changes in the automotive industry, anyone is aware that this will affect OEMs like Volkswagen, Toyota, GM etc. and some major supplier, like Bosch, Denso, Magna etc., but there are many SMEs involved in the automotive industry as well. Either as a direct supplier (tier1) to the OEM or trough one of the major supplier mentioned

[3] McKinsey & Company Corporation, 2016
[4] Gerster, 2016

existence. But there is a huge difference how big enterprises and SMEs have to manage these changes in the industry. OEMs for example are affected by changes in the business model, from development and manufacturing of cars to a provider of mobility services, but as well as from a technology point of view, when it comes to paradigm change in the powertrain, away from ICE, where all OEMs are heavily engaged to electrified powertrains, where core competencies are not yet formed respectively other big enterprises have them. But once these lack of core competences are identified, these big enterprises can invest heavily into these fields. As for example Volkswagen, when they realized that the traction battery will be the main added value to the future powertrain, Volkswagen started to built up a competence-centre for batteries and is thinking of establish a battery cell manufacturing in Germany.[5]

Both facts would have been sounded ridiculous in the past. But Volkswagen as well as many other OEMs have the financial power and endurance to do so. In contrast to OEMs, SMEs are not able to invest heavily into a total new technology even if they want to. It is simply the size of the company, which makes the difference, because if Volkswagen invest some % of their revenues into a new venture, absolute amount of money is still notable.

- Disclose innovation strategies for affected SMEs

As already mentioned SMEs will need other approaches for this transition, than big enterprises. This will affect their innovation strategies as well. A major aim of this thesis is to uncover innovation strategies, which are best suitable for SMEs. These innovation strategies will be demonstrated on a prototype company. A family owned SME, which is heavily invested into ICE powertrains. By means of this example company, conclusions can be drawn on all SMEs, which are in the international ICE powertrain supplier industry.

- Highlight best practices of different industries in the past

The automotive industry has no exclusive right to drastic transition processes, but other industries have seen such change processes earlier before. Out of history we can learn how former companies had reacted in such situations and how they came out of it. Did they survived, or even got stronger or finally disappeared? Therefore. the thesis aims at

[5] Time Incorporation, 2016

finding such industries an extract best practices, which can be applied to SMEs of the automotive supplier industry.

1.3 Procedural method of the thesis

For this thesis, a conceptual analysis as the underlying method was chosen. Keeping the thesis' aims in mind, literature to automotive industry, disruptive innovations, transition processes, innovation strategy, use cases and related products were collected, analysed and compressed.

1.4 Structure of the thesis

The thesis is divided into six chapters. Chapter 1 gives a brief introduction to the underlying problem, the main objectives if the thesis and an overview about the applied method. The following chapters are described below:

Chapter 2 deals with disruptive technologies and provides a theoretical overview, how disruptive technologies occur and what is their special character. In addition to that, small and medium-sized companies are described further. A framework is discussed how companies can be categorized and their overall and specific contribution to the economy within the automotive industry is given.

In Chapter 3 is devoted to the actual state of the automotive industry and where it is heading to. Essentially, the two main topics in this chapter are the ongoing digitalization and electrification of the automotive industry. In the further course, the electrification and its possible implication on the power- and drivetrain are discussed. And finally the future drivetrain components are presented and what potential there is for actual ICE drivetrain component manufacturer.

Chapter 4 deals with the conducted empirical study. It starts with the general framework of the study, followed by the results and its interpretation.

In chapter 5 several innovation strategies are presented and how affected SME may gain profit from these strategies. It starts with identification of core competencies, followed by technological competence leveraging and collaboration strategies. At the end of the chapter some recommendations for SMEs are discussed.

Chapter 6 provides a final discussion of the topic and an executive summery about the thesis and its outcomes.

2 Disruptive Innovation and small and medium-sized enterprises

In the following chapter the general character of disruptive innovation is described on the one hand and on the other hand an overview of small and medium-sized enterprise (SME) is given and in specific SMEs in the automotive context is elaborated and its contribution to the whole industry is provided.

2.1 Disruptive innovation / technology

Today disruptive technology or innovation, these terms are used interchangeable in this work, is in everyone’s lips. Therefore, it is necessary to describe the theory behind to have a common understanding. The term disruptive technology was first proclaimed by Clayton M. Christensen and Joseph Bower in their article Disruptive Technologies, Catching the Wave in 1995.[6]

To get a deep understanding of disruptive technologies, we must discuss also about sustaining technologies, in this regard the counterpart of disruptive technologies. Sustaining technologies, which can be ranged in difficulty from incremental to radical, are new technologies which foster improved product performance. These sustaining technologies can be discontinuous or more radical in their character, while others are improving the product incrementally. All sustaining technologies have in common, that they improve the overall or specific parameters of the performance of established products. The performance or specific parameters are dimensions of performance that most of existing and future customers have valued in the past.[7]

The predominant majority of technological advances in each industry have a sustaining character. In contrast to sustaining technologies, disruptive technologies bring very different value propositions to the market, which had not been available previously. In general, disruptive technologies underperform on first sight established products in mainstream markets and that is probably the most dangerous characteristic of disruptive technologies. Because, in our performance driven world we have adapted a subconsciously thinking, that underperformance technologies can never beat over-performance technologies.

[6] Christensen & Bower, Disruptive Technologies: Catching the Wave, 1995

[7] Christensen, The Innovator’s Dilemma, 1997

But disruptive technologies have other at least one features that a few edge customers value. Products which are based on disruptive technologies are in most cases cheaper, simpler, smaller and especially more convenient to use that the products which are substituted.[8]

In The most important task of managers and innovators is to ensure that disruptive technologies that do not make sense today, are taken seriously within the organisation, without forgetting about the needs of present customers who provide revenue, profit and growth. Being arrogant as an organisation, and underestimate technologies which are not yet established in the organisation, could be worse in disruptive innovation environment.

Figure 1 the impact on the one hand of sustaining technologies and on the other hand of disruptive technologies is illustrated. The two dotted arrows are the borderlines of the performance demand of actual and potential customers. The distribution is Gauss like, so a few demand low and few demand high performance, the overwhelming majority demands performance in the middle of the two borderlines. On the axis of abscissae time and on the axis of ordinate the product performance is plotted. Now we discuss the overhead continuous arrow, which represent actual technology A. It starts at the low end of the demanded performance and due to continuous sustainable innovations, the technology improves in performance and becomes attractive for most of potential customers. At some point in time, the technology improves further and exceed the performance demand even of the high end demanded market.

At this time technology A makes itself attackable for disruptive innovations, which is represented by the continuous arrow starting below the performance demand of customers (technology B). For some time, the performance of technology B is not sufficient even for the low end of the market, but due to sustainable innovations the technology improves and at a certain point in time the performance is sufficient for user who demand low performance.

I this particular case, the supposed to be low end technology outperforms the superior technology, just because the gradient of the performance demand of the market is lower than the gradient of performance increase of technology A due to sustainable innovations. And at some point in time technology B meets the performance demand of the market

[8] Christensen, The Innovator's Dilemma, 1997

and offers other benefits in addition, like mentioned before: cheaper, simpler, smaller and especially more convenient to use etc.

For instance, 10 years ago, no automotive company was threatened by electric vehicles, and none of the OEMs considered a dramatic change is sales in that area. The automobile industry did well, internal combustion engines have never been more reliable than before and never before internal combustion vehicles with such high performance and build quality have been available at such low prices. Aside from political orders, there was no reason why established OEMs should tune in to electric vehicles.[9]

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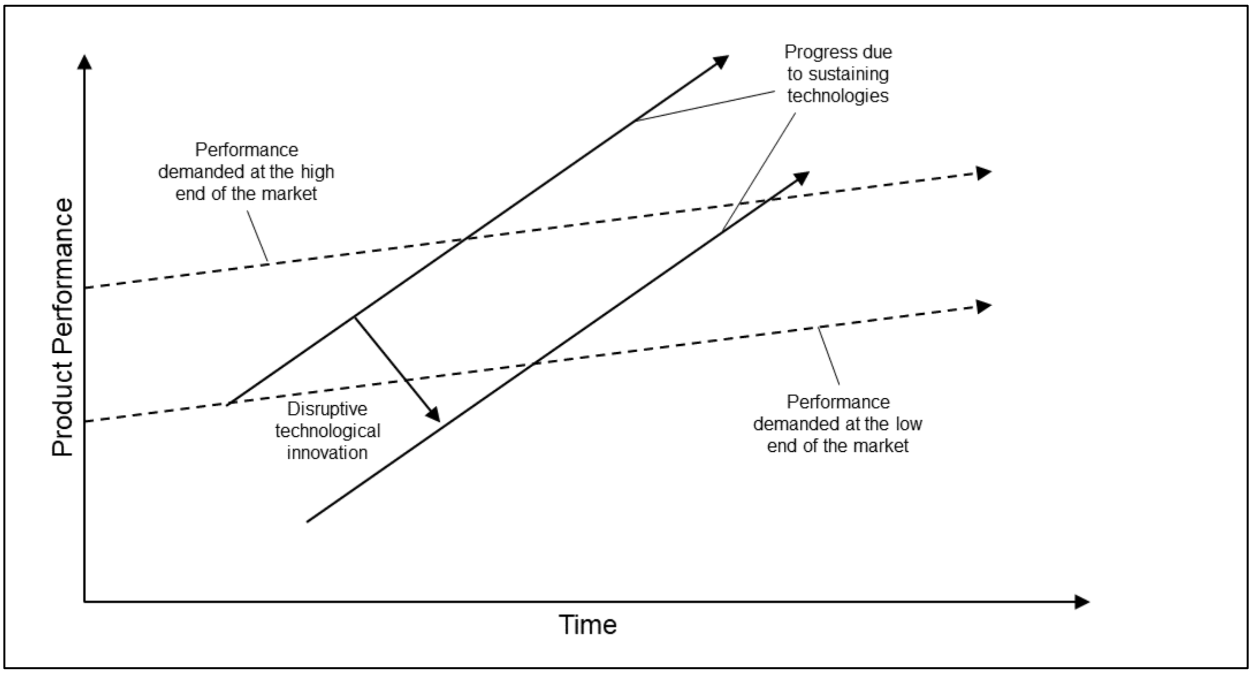

Figure 1: The Impact of Sustaining and Disruptive Technological Change[10]

2.1.1 Electric vehicle as a disruptive technology

Has the electric vehicle, in form of a battery electric vehicle or a fuel cell electric vehicle the potential to disrupt the traditional OEMs and the suppliers of internal combustion

[9] Christensen, The Innovator's Dilemma, 1997
[10] Christensen, The Innovator's Dilemma, 1997

engines? You will not find a dedicated answer to this question in this chapter, nor a prediction whether, how and in which form electric vehicles may become commercially successful. But the case is discussed within the framework presented in 2.1 Disruptive innovation / technology and at the end we can see what is possible.

We begin with the actual dominant technology for passenger vehicle, the internal combustion engine

Traction batteries were expensive and did not deliver the demanded performance in respect to energy capacity, weight and volume and key competencies like the traction battery and battery management were not classic domains of OEMs. They had to invest heavily in a segment where in the worst case the whole investment will be lost and in best case revenues would be generated which would not be noticed in the income statement and probably the resources which are invested in electric vehicles would have been missed to develop vehicles which are highly demanded in the future, like SUV[11]

2.2 Small and medium-sized enterprises

Small and medium-sized enterprises (SMEs) are a very heterogeneous group of economic entities and are part of the economic environment of very diverse economic representatives. Depending on the specific business sector SMEs operate in, the markets SMEs operate in, the products and services SMEs produce, the characteristics of SMEs vary a lot.[12]

"An enterprise is considered to be any entity engaged in an economic activity, no matter of its legal form. This includes, in particular, self-employed persons and family businesses engaged in craft or other activities, and partnerships or associations regularly engaged in an economic activity."[13] Small and medium-sized enterprises (SMEs) are defined in the European Union recommendation 2003/361. The main factors determining whether an enterprise is an SME are staff headcount and either turnover or balance sheet total, see Table 1 for the definition of the European Union.

[11] Sport utility vehicles (SUVs) are vehicles classified as a light truck, but operated as a family vehicle.
[12] North & Varvakis, 2016
[13] European Union, 2003

Across the European Union, SMEs contribute in the non-financial business sector up to 99.8% of all enterprises, 57.4% of value added and 66.8 % of total employment. In 2015, over 22 million SMEs in the non-financial business sector generated €3.9 trillion of value added and employed 90 million people.[14]

Company category	Staff headcount	Turnover	Balance sheet total
Medium-sized	< 250	≤ € 50 m	≤ € 43 m
Small	< 50	≤ € 10 m	≤ € 10 m
Micro	< 10	≤ € 2 m	≤ € 2 m

Table 1: Definition of a SME in the European Union[15]

2.2.1 Innovation at SMEs

An innovation can be understood simply as the implementation of something new - like an invention or a discovery - into a market success. Innovations are new products, processes or concepts.[16] The Austrian economist Joseph Schumpeter recognized that the interaction between innovations and their imitations is a key driving force of competition. He defined innovation as a process of implementing an invention into a market application.[17]

Small and medium-sized enterprises play a key role in creating jobs and boosting the economy finally through continuous innovation. Countries, without a vital SME economy system, will not see continuous economic growth, as already mentioned, SMEs create over 66 % of all jobs in the European Union. Among others, one of the most important purpose, which SMEs are able to contribute is their competence to realise innovations.

But the growth of SMEs is not simply achieved by government support. SMEs have to push themselves to innovation, to adopt an idea or behaviour that is new to the organization. These innovations can be embodied in the form of new tangible products, services, technologies, research findings or simply ideas. Some authors see innovation even more important for SMEs than for large corporations.[18]

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[14] Muller, Devnani, Julius, Gagliardi, & Marzocchi, 2016
[15] European Union, 2003
[16] Ahmed & Shepherd, 2010
[17] Stern & Jaberg, 2007
[18] Fritz, 1989

In order to fully integrate the innovation process over the entire company, it should be implemented on all three levels of the company: normative, strategic and operational. But especially at SMEs, these levels are not developed as in large corporations and the innovation process and innovations itself are dependent from individuals or small groups.[19]

Probably most SMEs are aware of the need of constant innovation. But particularly for SMEs innovation is challenging for them, because SMEs often suffer from the lack of information and resources needed to generate new ideas and subsequently transform them into successful innovations. Therefore, SMEs have to develop a tailor made innovation system, which fits to their special needs. The innovation system includes the various components and processes that must be taken into account within an organization. Each area contributes to the optimum innovation output and has to be coordinated in a holistic way with each other. The internal communication within the company as well as with partners outside the company between individuals and departments should be as smooth as possible and without any information loss, since there are mutual dependencies between individuals and departments which are responsible for its process.[20]

Therefore a systematic and methodological approach is required to lead the appearance of innovations away from pure arbitrariness to targeted decisions and economically successful implementations. Based on these decisions, it is important to define the position of the company and in which markets and which customers should be served with which products and services. In order to come to this conclusion, it is necessary to monitor markets and the competition. Therefore SMEs could be more successful or stay viable if they react quickly and with right measures to environmental signals of change. The consequences can be serious if companies do not recognize or misjudge the signs of small changes.

2.2.2 The role of SMEs in the automotive component industry

As already mentioned, SMEs are responsible for more than 66 % of all jobs in the European Union, but its share varies strongly over different industries and segments. Therefore we take a look on the role of SMEs in the automotive industry and especially

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[19] Gassmann & Sutter, 2011

[20] Kaschny, Nolden, & Schreuder, 2015

on the automotive component supplier industry. SME Over 90% of automotive component suppliers are SMEs, employing less than 250 employees. Many SMEs deviate from the industry tradition, where innovation emerges from OEMs, large Tier 1 supplier or large research labs at major companies. Some SMEs come from outside the existing automotive supply chain and challenge the existing supplier structure. This change come up, as a result of OEMs passing on the obligation of innovation to the supply chain.[21]

Most SMEs in the automotive industry act as second- or third-tier supplier, which means they deliver products to another supplier who delivers again the product plus a value added to the OEM. See Figure 2.

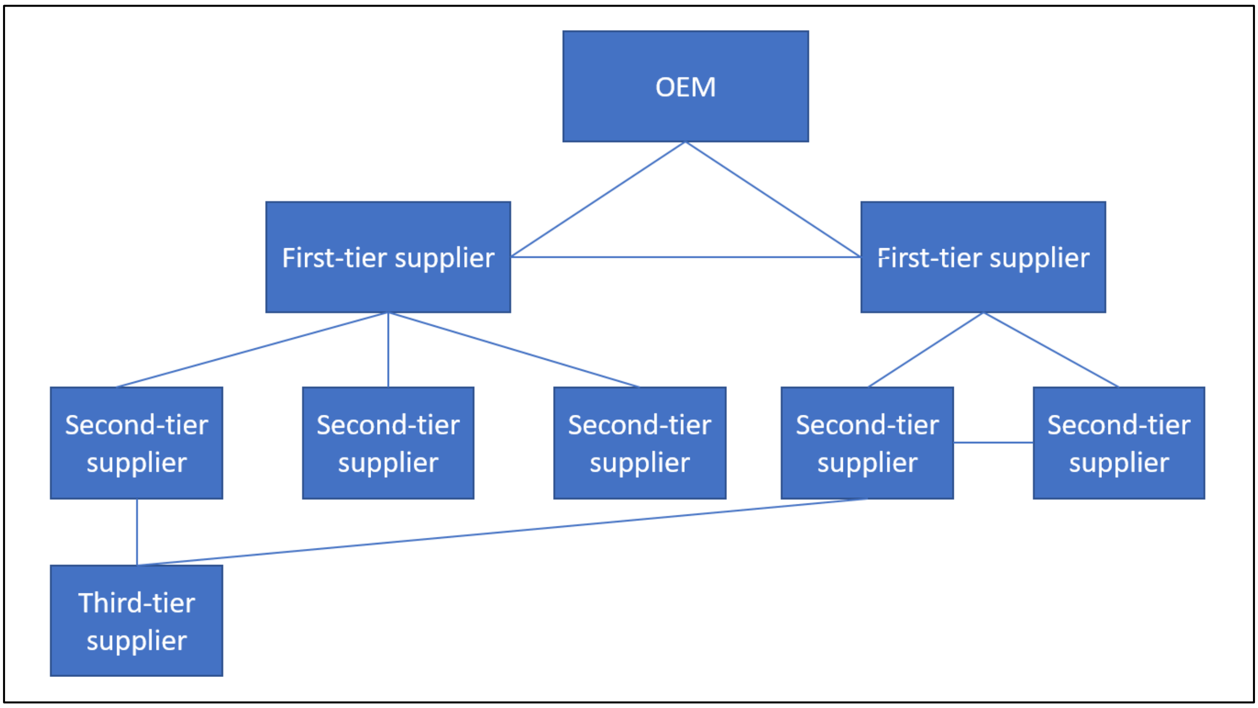

Figure 2: The automotive supplier value chain and its cooperation between suppliers in the network

From a SME's perspective, the organization of production networks may be seen as an implicit agreement between the lead supplier, often the first-tier supplier and a large enterprise[22] and the SME. On the one hand, lead supplier provides market and technical information, either from the OEM or itself, to the SME, with the objective that lower-tier suppliers will achieve the technical requirements set by the lead firm. SMEs supplier, on the other hand, invest in equipment, specialization and process knowhow with the expectation that the lead tier-supplier and OEM will continue to use SME's products.

[21] Low Carbon Vehicle Partnership, 2016

[22] > 250 employees and > 50m turnover

Exact figures, what is the added value of SMEs in the automotive industry are nearly impossible to calculate, because many SMEs are not fully depended in terms of turnover and others only make a small proportion of its entire business within the automotive industry. The best way to get accurate figures is to look on a detailed level, for instance for a specific state in a country. For example, in North Rhine Westphalia large corporations account for 70% of sales and about 50% of the workforce. A further 27% of the total turnover is covered by the large number of medium-sized suppliers with more than 100 employees, of the whole automotive supplier industry.[23] In addition, other companies (for example producers of metal products) act as indirect suppliers to the automotive sector, which are not included in official statistics.

This figure represents the huge portion of the total added value of SMEs in the automotive industry, since three-fourths of the total value is produced in the supplier industry. To the same extent as automobile manufacturers reduce their production depth, they transfer responsibility and trust to their suppliers. This puts pressure on the management of an ever more complex supplier network, whose processes must always be accurately coordinated. The choice of suppliers and the underlying business conditions are thus of decisive importance for the reliability of the entire value chain.

In Figure 3 the decline of the in house produced value added of German OEMs is evident.

[23] RWTH Aachen, 2014

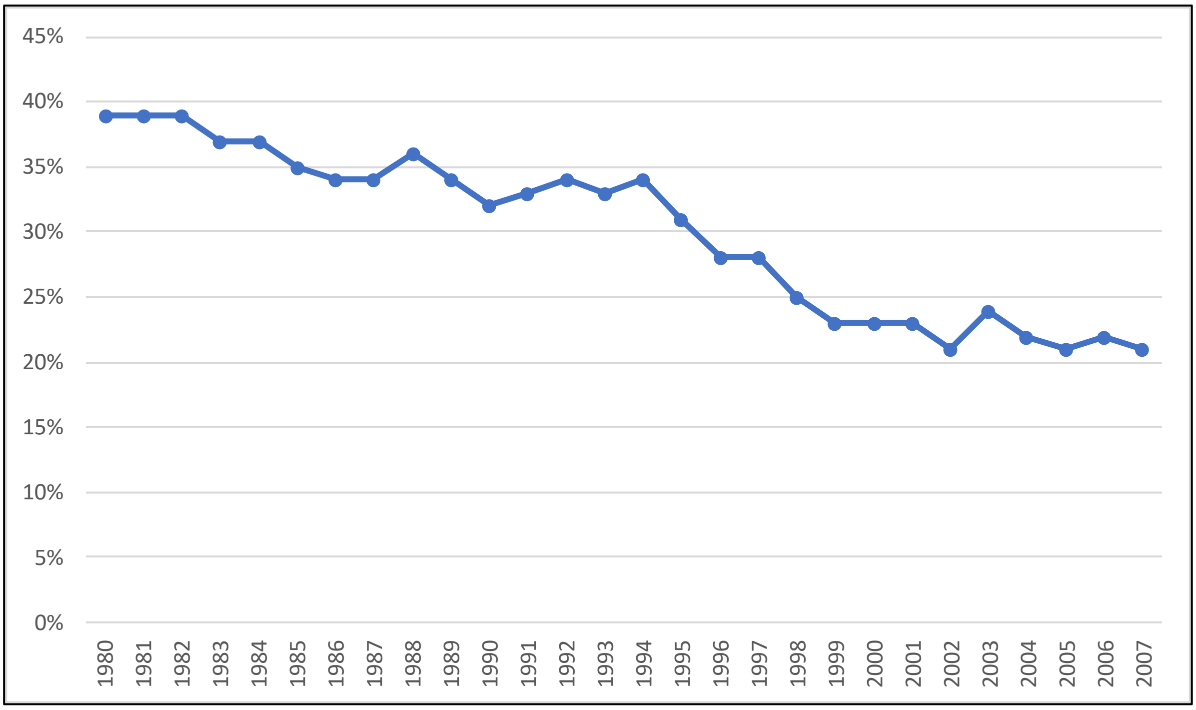

Figure 3: Vertical integration of German OEMs[24]

For more than 100 years the automotive industry, and therefore also valid for SMEs as automotive suppliers, has created competitive advantage mainly through engineering excellence, like process innovation (increasing efficiencies in the production process, like improvements in production technology or labour productivity), or product innovation (improving existing products or developing new products), or functional innovation, or chain innovation. But this will no longer be sufficient in the future, if you are engaged in typical internal combustion powertrain domains. In reverse this means for SMEs, their success and viability as a company depends not only on how fast they can start working on the four innovation types mentioned before and how much flexibility they have in improving their position in the value chain.[25]

Due to the changes caused by electric mobility, in particular SMEs have a risk if they do not prepare for future market developments in time. For companies, whose product portfolio has a high concentration on internal combustion engine components, the greatest need for action is to ensure the future viability of the company and the related jobs. At the same time, the growth market for electric mobility offers great opportunities for automotive suppliers, including SMEs, in order to be able to profit from the positive market development in the long term with a corresponding strategy. A good starting point

[24] VDA-Büro Berlin, 2008
[25] Wollschlaeger, Foden, Cave, & Stent, 2015

for this are the companies and institutions with a strong presence in the actual market, with strong competencies in the research and development of components of the electrified powertrain.

3 Automotive industry – quo vadis?

“I believe the auto industry will change more in the next five to 10 years than it has in the last 50…”.[26] These words do not come from an author to attract some readers, these words come from Mary Barra, Chairman and CEO, General Motors. The automotive industry is embossed by long lasting developments and investments, the average software life cycle currently accounts for 6–12 months, and 6–12 months for smartphones, while the life cycle of a passenger car accounts for approximately 6 years.[27] This means, that most electronics and software in a passenger car are some generations behind the actual state of the art when it comes to the end of its life cycle.

There are three key trends, which will shape the mobility of the future, both personally and commercially wise. The move to on-demand mobility, the impact of autonomous driving and the growth of electric powered vehicles.[28] With these new technology, OEMs and supplier will fall behind competition, if they stick to the traditional product life cycle of a passenger car.

The digitization proceeds and has already affected almost every industry within the past decades. The matchless speed at which digital technologies spread and percolate business, society and individual life puts mature companies under pressure. Within the automotive industry, digitization will bring new players to the table, at every link of the value chain, from SME suppliers to big OEMs. The technological focus will shift from physical to digital, this enables customers to bring in their future understanding of mobility, and makes them at the same time a valuable source of information.

These three mega trends in the automotive industry will lead to dramatic changes. On the one hand, established OEMs must adapt their business model, are confronted with new competitors and must build new competencies in the areas of electronics and IT, on the other hand suppliers must adapt their product and service portfolio and also their customer relationship.

In this context we take a look at how automotive supplier, especially SMEs, can innovate themselves into electrified powertrains models and mobility concepts of the future. Or

[26] Barra, 2016
[27] Bharadwaj , El Sawy , Pavlou, & Venkatraman, 2013
[28] Matus & Heck, 2015

future powertrains models and mobility concepts does not present a viable and prosperous field of activity at all.

3.1 Digitalization and electrification of the automotive industry

As already mentioned, there are three key trends, which will shape the mobility of individuals in the future. The move to on-demand mobility, the impact of autonomous driving and the growth of electric powered vehicles. All three trends could also be summed up as the digitalization and electrification of the automotive industry.[29]

3.1.1 Digitalization of the automotive industry

In the last years, the amount of digitalization in the automotive has increased substantially, this fact leads from significant dynamics in the automotive market up to changes in the entire business models, as automobile manufacturers strive to find a balance between the digital trends and their established competences and assets that relate to the physical world.[30] New technologies and customer demand are enabling and pushing the automotive industry to become part of the consumer electronics world. In the future in-vehicle information technology (IT) will be an essential element and an incremental unique selling proposition, demonstrated by several appearances of OEMs in the latest past.[31][32]

3.1.1.1 Business model change

Until the last decade, the business model of OEMs was straight forward: the OEM developed, manufactured[33] and sold vehicles for multiple purposes via a dealer network, which also provided after sales services like planned maintenance and repair services. The OEMs understood themselves as a provider of a vehicle.[34] This traditional business model is already outdated, while almost every notable OEM changed their business model to a provider of mobility services. Digitization and the so-called sharing economy

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[29] Kessler & Buck, 2017
[30] Burkhart, Krumeich, Werth, & Loos, 2011
[31] AUDI AG, 2016
[32] Daimler AG, 2017
[33] with a broad supplier network
[34] Biller, Chan, Simchi-Levi, & Swann, 2005

as a society trend joint together for change in the automotive industry, where the willingness to share gains growing attention with more and more OEMs entering the car-sharing market. Think of car2go from Daimler AG or DriveNow from BMW AG, which offer car sharing services in 26 respectively 12 cities in Europe, North America and Peoples Republic of China.[35] Vehicle ownership was for long time the only possibility to make use of automotive mobility. People have changed how they perceive and utilize mobility. Mobility is changing and the subsequent challenges need to be met by the OEMs. People of today have managed to decouple the idea of mobility from the idea of car ownership. Social media are solid substitutes and car sharing and transportation network companies like Uber, Lyft, RideWith and BlaBlaCar for instance are cheap and on demand ways to get around.[36]

3.1.2 Electrification of the automotive industry

For more than a century, the vehicle performance had been dominated the consumer demand about automobiles. Greater power, greater range, more space, and increasing luxury had been the dominant characteristics used to evaluate the value of automotive innovation. Starting at the end of the last century, contemporary EVs suffered from bad reputation. They were perceived to be heavy, weak, slow, and short ranged compared to ICE powered vehicles.[37]

Today, the performance characteristics of electrically driven vehicles are evident. The outstanding efficiency of electric machines in combination with their instantaneous torque have helped EVs to enter the automotive market as clean and powerful alternatives to ICE driven vehicles.

An Electrified vehicle includes modules like integrated electromechanical power trains, electric machines, power electronics, embedded software and controllers, traction batteries and other energy-storage devices. An in-depth look on those modules and components is taken in The potential components of future powertrains.

Future innovations in above mentioned areas in combination with lightweight materials technologies, will decide if electrification will lead to a disruptive shift in the transportation

[35] car2go Deutschland GmbH, 2017
[36] Dadich, 2016
[37] Emadi, 2015

and especially automotive industry. In fact, mass commercialization of electrified vehicles will require the development of powertrain components and controls that are inexpensive, rugged, lightweight, reliable and scalable.[38][39]

Type of EV:	**HEV**	**BEV**	**FCEV**
Propulsion	▪ Electric motor drives ▪ Internal combustion engine	▪ Electric motor drives	▪ Electric motor drives
Energy system	▪ Battery ▪ Ultra-capacitor ▪ ICE generating unit ▪ Integrated starter generator	▪ Battery ▪ Ultra-capacitor	▪ Fuel cells ▪ Battery / ultra-capacitor
Energy sources and infrastructure	▪ Gas stations ▪ Electric grid charging ▪ facilities (for PHEV)	▪ Electric grid charging facilities	▪ Hydrogen stations ▪ Hydrogen production ▪ Transportation infrastructure
Main characteristic s	▪ Very low emission ▪ Long driving range ▪ Higher fuel economy compared ▪ with ICE vehicles ▪ Dependence of crude oils ▪ Complex ▪ Commercially available	▪ Zero emission ▪ Independence on crude oils ▪ High energy efficiency ▪ High initial cost ▪ Commercially available ▪ Relatively short range	▪ Zero emission ▪ High energy efficiency ▪ Independence on crude oils ▪ Satisfied driving range ▪ High cost ▪ Under development
Unsolved issues	▪ Managing multiple energy sources ▪ Dependent on the driving cycle ▪ Battery sizing and management	▪ Battery and its management ▪ High performance propulsion ▪ Charging infrastructure	▪ Fuel cell cost ▪ Hydrogen infrastructure ▪ Fuelling system

Table 2: Overview of different EVs[40]

[38] Emadi, 2015

[39] Lorentz, Wenger, John, & Maerz, 2014

[40] Bayindir, Gözüküçük, & Teke, 2010

Furthermore, today's most important electrified powertrains are explained below, starting with HEVs, PHEVs, and EVs and FCEVs.

3.1.2.1 Hybrid electric vehicle

Hybrid electric vehicles are almost as old as motorized vehicles itself. Hybrid means in the context of automotive, powered out of two sources. In more detail, it means, that a HEV has on the one hand a conventional ICE with all its auxiliary units and is of course fuelled by gasoline or diesel and on the other hand an electric machine, which is powered by a traction battery or super-/ultra-capacitors. Although the concept of HEVs are already known for many years, it took until the introduction of the Toyota Prius to become a viable powertrain in the automotive industry. Originally introduced in Japan in 1997, the Toyota Prius was the first commercial HEV.[41]

Compared to a (ICE) vehicle, hybrid electric vehicles (HEVs) can improve fuel economy and lower greenhouse gas and tailpipe emissions. Improvements come from regenerative braking in coasting mode, shutting off the ICE when the car or light truck is stopped, allowing a smaller, more efficient engine (downsized) and decoupling the engine from the driving cycle. However, HEVs are inherently more complicated and expensive compared to ICE vehicles.[42] The main idea behind the hybrid concept is to support the conventional ICE in driving conditions, when ICE efficiency is low and to recover kinetic energy while breaking, because during breaking a conventional driven vehicle is just able to cut down fuel consumption to zero (coasting mode)[43], but beyond that kinetic energy is converted into heat. While the electric machine can be used as a generator during coasting mode, converting kinetic energy into electric energy. Under the term HEV, many different configurations of ICE and electric machine are imaginable and already available on the market. In Figure 4, different HEV configurations are illustrated. When a hybrid system is designed, each component has to be designed in coordination to work properly together, particular choices for of the drive line are influencing the performance of the vehicle, e.g., fuel consumption, emissions, drivability or others.[44]

[41] Lave & MacLean, 2002
[42] Lave & MacLean, 2002
[43] USA Patentnr. US4408293A, 1983
[44] Silvaş, Hofman, & Steinbuch, 2012

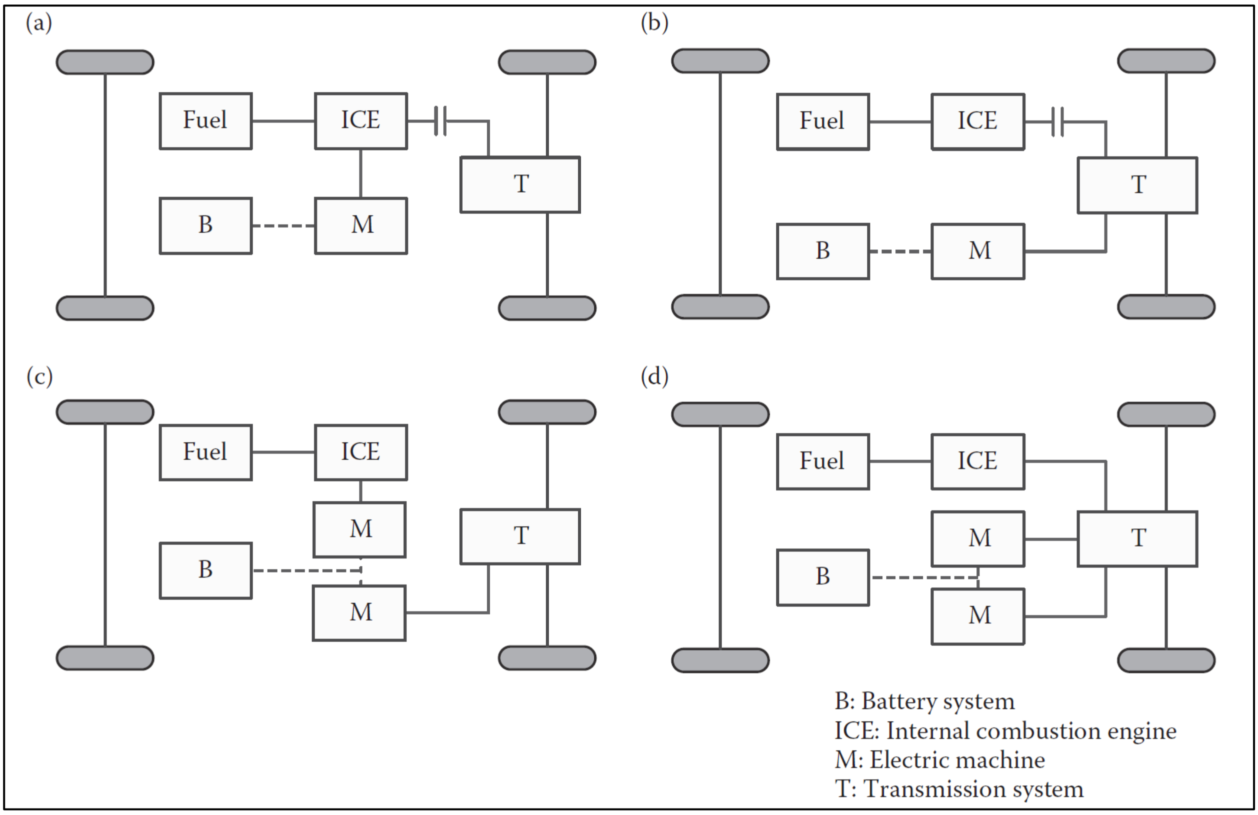

Figure 4: Different HEV configurations: (a) mild hybrid electric vehicle, (b) parallel hybrid electric vehicle, (c) series hybrid electric vehicle, and (d) series–parallel hybrid electric vehicle.[45]

Generally, all these topologies can be split into three categories: series, parallel and series-parallel topologies. The best use for a specific transportation form is compressed in Figure 5 illustrated.

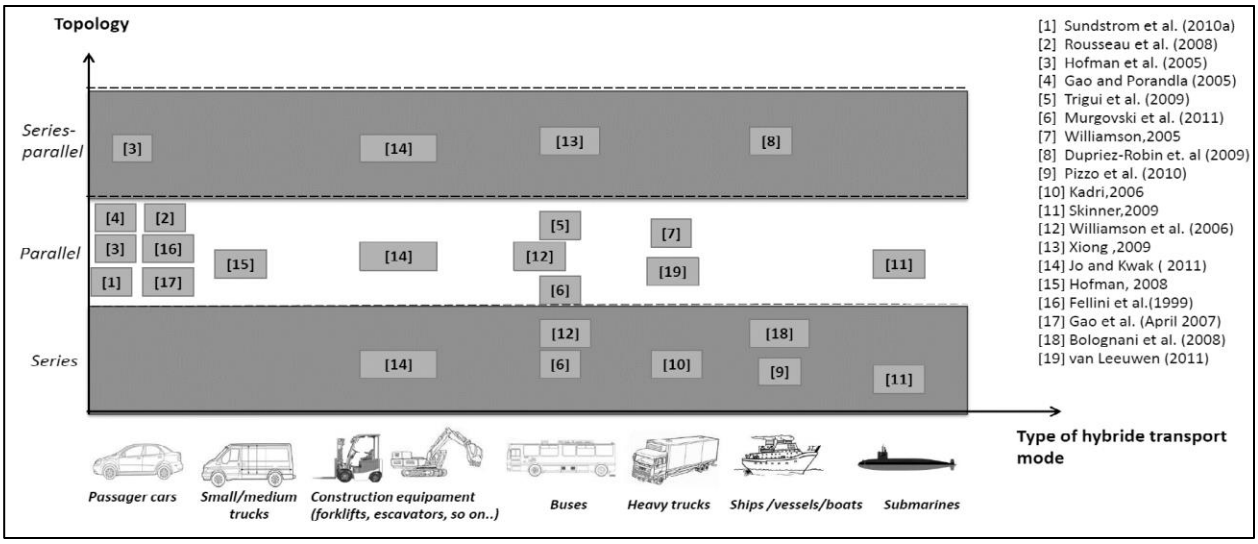

Figure 5: Overview of existing hybrid powertrains and the topologies they use[46]

[45] Emadi, 2015

[46] Silvaş, Hofman, & Steinbuch, 2012

3.1.2.2 Plug-in hybrid electric vehicle

Plug-in hybrid electric vehicles (PHEV) take in an exceptional position, therefore PHEVs are described separately to HEV, although from a technical point of view both are quite similar to each other. The main difference between a HEV and a PHEV is that, a PHEV can draw and store electric energy from an electric grid to supply electric propulsion for the vehicle. This allows a PHEV to replace petroleum energy with multi-source electrical energy, depending on the actual electricity generation mix, which is used to charge the PHEV.[47]

Furthermore, with a PHEV it is possible to replace petroleum energy to zero, if the covered distance and driving conditions exceed the PHEV's properties. The components and vehicle architecture of PHEVs are similar to conventional HEVs, shown already in Figure 4. Both combine an electric drivetrain and an internal combustion drivetrain which are coupled to each other. But beside that, a PHEV has the capability to plug into an electric grid to charge the traction battery. In practice, PHEVs have traction batteries with higher capacity in addition. On major drawback is, especially for PHEVs, compared to ICE driven vehicles, that the individual driven cycle and the possibility to charge the battery of the PHEV regularly, have a huge impact whether the PHEV has a positive or negative impact on the petroleum consumption.

In The ICE of a PHEV has a completely different usage scenario compared to conventional ICE driven vehicles. The ICE of a PHEV is not used in specific individual driving cycles for weeks or even month. This has to be considered for many different aspects, like corrosion due to condensed water within the engine. Also, the functionalities under cold conditions have to be adapted to the specific needs. Because when the ICE is started most of the time, because of lack of total power of the electric motor, for instance in case of overtaking. Then the ICE has to deliver 100% power out of cold conditions, this leads to excessive wear.

Figure 6 the drivetrain of the BMW i8 with its main modules are visible. While the rear axle is driven by a three-cylinder ICE and an electric motor/generator in series configuration, the all-wheel drive is realized by an all-electric front axle. The battery package is located in the shaft tunnel, where in conventional all-wheel drive vehicles the

[47] Bradley & Frank, 2009

cardan shaft is located. A detailed overview of the main components of a PHEV is given in 3.2.1.1.

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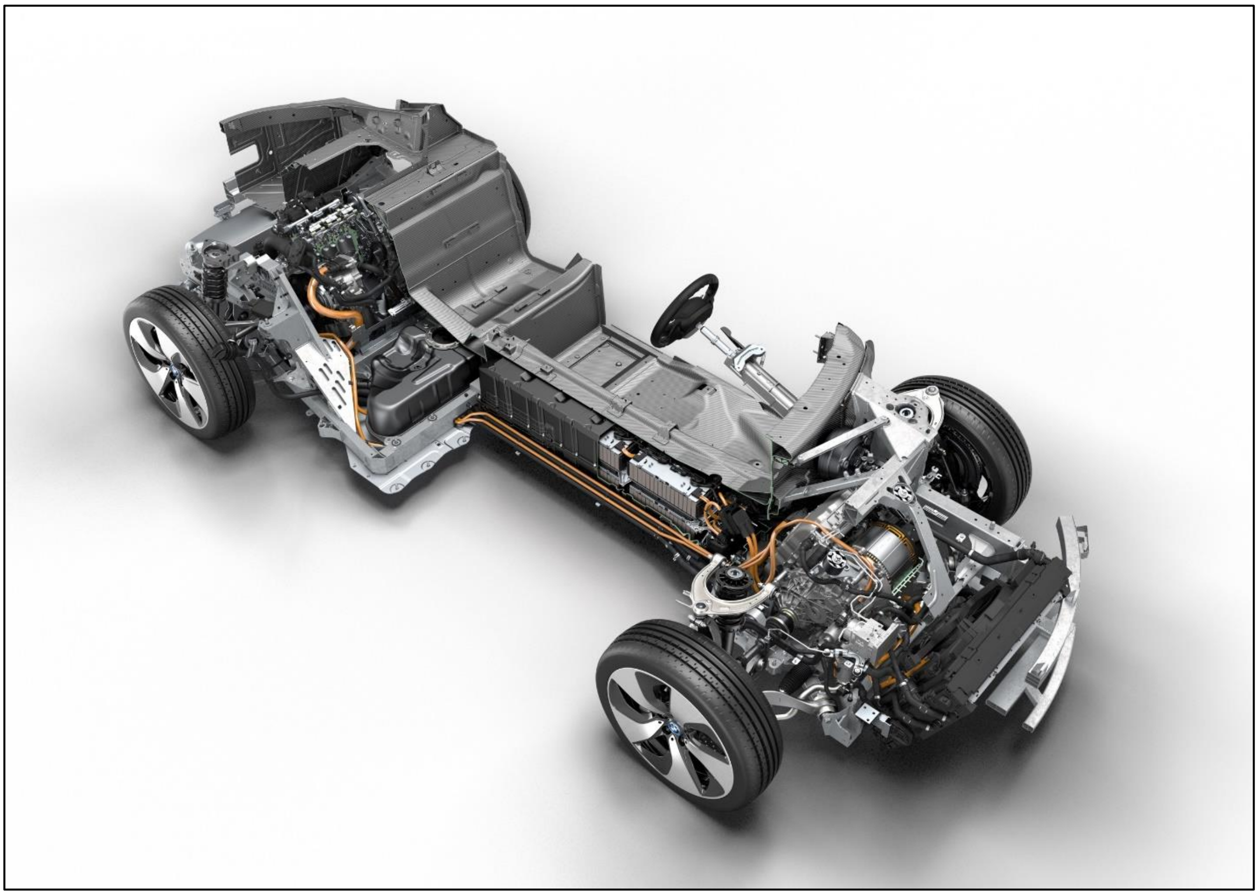

Figure 6: BMW i8 PHEV

For instance, if the daily covered distance is far beyond the capability to drive electric mode and or no possibilities for daily charging in an electric grid are given, PHEVs can have worse petroleum consumption than ICE driven vehicles, because of the additional weight and friction losses due to the hybrid powertrain (electric motor, traction battery, power electronics etc.).

3.1.2.3 Battery electric vehicle

The Battery electric vehicle was even invented before the conventional ICE driven vehicle, although the full commercial success has been missing until today.

A BEV differ a lot from ICE driven vehicles and also from HEVs, since the energy for powering the vehicle is not stored in fossil or non-fossil liquid fuels and the energy is not converted into rotational power by burning it. The energy is stored as well chemically but in battery cells which are combined to battery modules and finally in a battery pack which is integrated into the vehicle. Trough power electronics the DC of the battery is converted into AC which is used by the electric motor. One or more electric motors drive through a shaft the wheel or are directly integrated into the wheel (wheel bub motor).

Some other vehicle components, beside the powertrain, are also different compared to conventional vehicles, like the climate compressor, because there is no belt drive in a BEV, the climate compressor needs to be electric driven. And yet other components like breaking system, steering system, and other comfort equipment is identically to conventional vehicles.

Figure 7: BMW i3 with its main powertrain architecture

Although the BEV was invented before the ICE driven vehicle, the latter has dominated individual mobility and the vast sector of overall transportation for the last century, except transportation systems, where current collector are feasible and economic for instance railway transportation. But even in railway transportation both technologies electric motor and internal combustion engine have a fight and it depends on specific parameters which technology is preferable. So why is that?

While the electric motor is well developed and relatively inexpensive to produce, also power electronics developed very well over the past decades. Besides that, electric motor together with power electronics have an efficiency above 90% over a wide spread area of usage.[48] We can conclude that until today the battery has been the weakest element, which hindered a breakthrough success of the BEV.

In the beginning of the BEV until the end of the last century, battery technology was the hindering factor. Energy density, both in terms of stored energy compared to volume as well as stored energy compared to weight, did not meet the requirements of the customer and was not suitable for daily use. Over the past 30 years battery technology developed rapidly. Above mentioned obstacles are no longer valid, especially Lithium ion technology pushed the limits of energy density and make them suitable for passenger transportation. Battery packages, which fit into a standard 5m vehicle, with up to 100 kWh are available today.[49] And even light and heavy duty trucks with a range of up to 200 km, which should be enough for a typical daily delivery tour and overnight recharging are feasible with a potential market launch of this technology at the beginning of the next decade.[50] Figure 8 illustrates the battery pack and electric drive train layout of Mercedes' design study.

[48] Hu, Murgovski, Johannesson, & Egardt, 2013
[49] Tesla, Inc., 2017
[50] Daimler AG, 2017

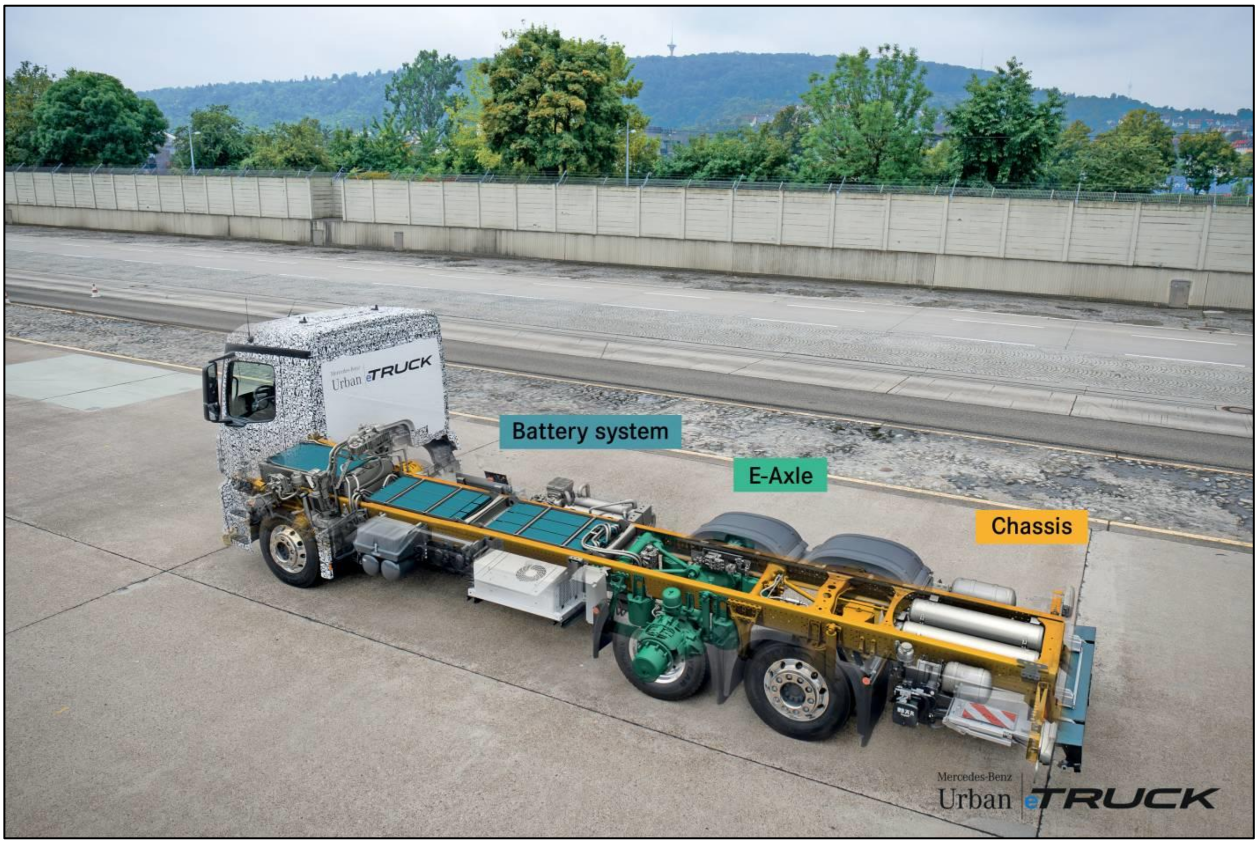

Figure 8: Mercedes-Benz Urban eTruck[51]

From a technical point of view, nothing hinders BEV from a breakthrough success. But costs of battery cells, respectively battery modules are not yet cost efficient for mass market. The most important and characteristic figure in terms of economy of batteries is cost per kWh.

Battery costs already dropped significantly, but are still on a level, where every extra kWh hurts a lot. Within six years, from 2010 to 2016, battery pack prices for OEM fell roughly by 80% from approximately $1,000/kWh to $227/kWh. As already mentioned, although that huge drop, battery costs are still on a level that make BEVs more costly than comparable ICE-powered variants. Actual developments show a further decrease of battery pack prices below $190/kWh by the end of this decade. And leading researcher see potential for pack prices to below $100/kWh by 2030.

However, actual prices of in production BEVs are still above the average price of a new vehicle purchase. But with above mentioned outlook, battery costs continue to trend downwards, a clear path exists towards BEV and ICE model price parity in selected

[51] Daimler AG, 2017

segments in the next decade. In Figure 9 the cost per kWh for OEM battery packs is plotted over time. Please note that time scale is discontinuous.

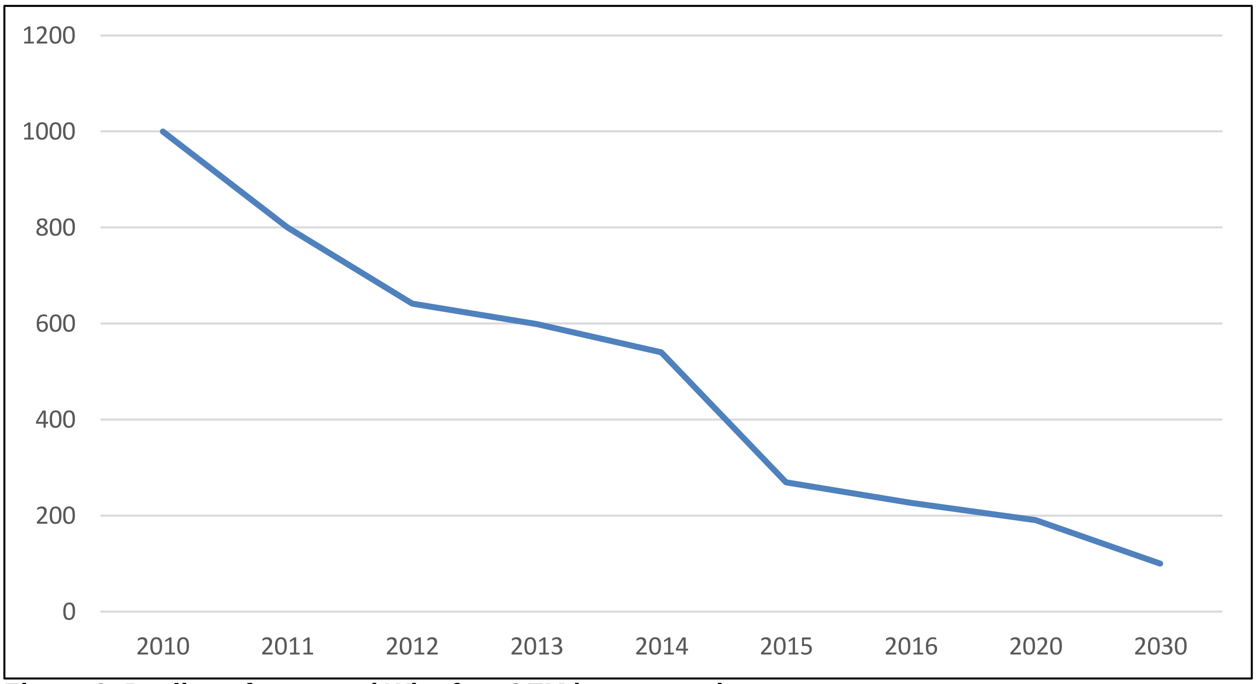

Figure 9: Decline of cost per kWh of an OEM battery pack

From a design point of view, a dominant design of a BEV gets tangible. The battery pack is located underneath the passenger compartment. This has mainly two reasons, first due to its heavy weight, the battery pack has to be as located as low as possible in the vehicle to get a low centre of gravity, second a battery back can be designed in many different forms, also as a cuboid with low high. As a result, the whole vehicle is built higher than a conventional driven vehicle, but, this fact leads to a high seating position, which is preferred by many people.

3.1.2.4 Fuel cell electric vehicle

In the last decades, different OEMs and partnerships had been focusing on the application of fuel cells in vehicles. In contrast to a traction battery of a BEV, the fuel cell converts electric energy out of chemical energy rather than storing it and continues to do so as long as a fuel supply is maintained. Compared to the BEVs, a FCEV has the advantages of a longer driving range without a long battery charging time, because of the high energy density, both in terms of stored energy compared to volume (energy density J/L, volumetric) as well as stored energy compared to weight (specific energy, J/kg, gravimetric), which exceeds the density capabilities of fossil fuels. Figure 10 shows exactly the problematic of actual BEVs, the huge advantage of fossil fuels and the potential of hydrogen based fuels.

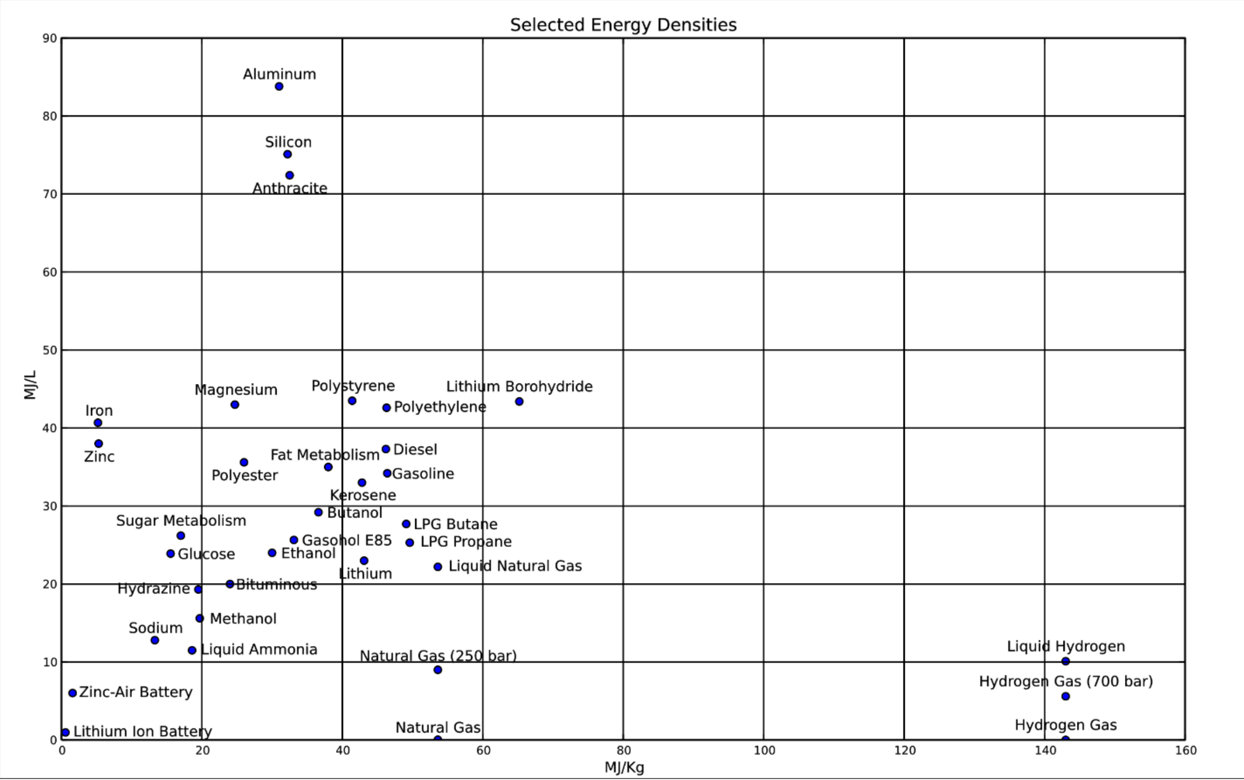

Figure 10: Selected energy densities

While fossil fuels, like Gasoline and Diesel have outstanding properties regarding energy storage capacity, both gravimetric but even better volumetric, actual leading battery designs which build on Lithium ion technology have very poor energy storage capabilities. Hydrogen based fuels have a big potential, because their gravimetric storage capacity is outstanding and their volumetric capacity is acceptable, if it is stored compressed or liquefied. As already shown in Figure 10, there a several ways of storing hydrogen based fuels. As a gas, as compressed gas and in liquid form. Stored as gas, hydrogen has a very poor volumetric energy density, which makes it inappropriate for mobility solutions. Hydrogen as compressed gas is more suitable for mobile application, but appropriate gas tanks are challenging to make them safe in case of crashes. Third, hydrogen could be liquefied, but to handle the pressure it has to be cooled down, and stored in cryogenic tanks. Beside the outstanding storage capacity, there are several drawbacks. First, the tanks have to be very well insulated, which is a big effort, second insulation can never be perfect, so there are continuous losses during storage, and third, it takes up to 46% of its stored energy to liquefy hydrogen.[52] Beside these well-established methods, there are also storage methods in metal hydrides and embedded in carbon nanotubes possible.

[52] Bossel, 2006

The heart of an FCEV is its fuel cell. Generally spoken, the fuel cell converts the chemical stored energy into electric energy. In detail, a fuel cell is an electrochemical device which is able to convert the stored chemical energy of a fuel directly into electrical energy. There is just one step from conversion the chemical to electrical energy, in comparison to the multi stage process from chemical to thermal over to mechanical and finally to electrical energy in internal combustion engines, offers some advantages. For example, the current internal combustion engines technology generation could be harmful to the environment (CO_2, NO_x, respirable dust etc.) and are predominantly contributing to many global concerns, such as climate change, ozone layer depletion, acidic rains, and thus, the consistent reduction in the vegetation cover. Furthermore, this technology depends on the finite world supplies of fossil fuels.[53]

Compared to the internal combustion engine (ICE) vehicles, a FCEV has the advantages of high energy efficiency and zero local emissions due to the direct conversion of free energy in the fuel into electric energy, without a combustion. Fuel cells, on the other hand, provide an efficient and clean mechanism for energy conversion. Additionally, fuel cells use renewable sources and CO_2 neutral energy carriers like hydrogen, for sustainable and in theory CO_2 neutral energy cycle. As a result, they are seen as the energy conversion devices of the future. The static nature of fuel cells itself also means almost silent operation with almost no moving parts and therefore no noise or vibration, while their inherent flexibility allows one the one hand a simple construction and on the other hand a broad range of applications. For instance, portable, stationary and transportation power generation. In general, fuel cells are able to provide locally clean, efficient and flexible chemical-to-electrical energy conversion.

Polymer-electrolyte-membrane and proton-exchange-membrane fuel cells (PEMFC) in particular are the most promising types, which are already in an early commercialization stage, which means that they are already commercially available, but not yet price competitive in the automotive sector, neither for OEMs nor for consumers. Nonetheless, further development and research are required in order, to reduce their costs, enhance their durability, and further optimize and improve their performance.[54]

[53] Sharaf & Orhan, 2014
[54] Sharaf & Orhan, 2014

A fuel cell is built out of three active components, a fuel electrode (anode), an oxidant electrode (cathode) and an electrolyte located between them. The electrodes are made of porous material which is covered with a catalyst layer, often out of platinum or gold. The basic operational process within a typical fuel cell is the following: molecular hydrogen (H_2) is delivered from a gas-flow stream to the anode where it reacts electrochemically. The hydrogen oxidizes to produce hydrogen ions and electrons. The hydrogen ions go through the acidic electrolyte while the electrons are forced through an external circuit all the way to the cathode. At the cathode, the electrons and the hydrogen ions react with the oxygen supplied from an external gas-flow stream to form water.

One of the biggest challenges that face fuel cells commercialization is the fact that we are still producing 96% of the world's hydrogen from hydro carbon reformation processes. Producing hydrogen from fossil fuels (mainly natural gas) and then using it in fuel-cells is economically disadvantageous since the cost-per-kWh delivered from hydrogen generated from a fossil fuel is higher than the cost-per-kWh if we were to directly use the fossil fuel. Thus, promoting renewable-based hydrogen is the only viable solution to shift from a fossil-based economy to a renewable-based, hydrogen-facilitated economy. Hydrogen storage mechanisms that provide high energy density per mass and volume while maintaining a reasonable cost are actual the most intensive research developments. No matter which hydrogen storage technology will be used, has to be completely safe because hydrogen is a light and highly-flammable fuel that could easily leak from a regular container. Metal- and chemical-hydride storage technologies are proofed to be safer and more efficient options than the traditional compressed gaseous and liquid hydrogen mechanisms, described above, but intensive research and development are needed to reduce the relatively high cost of the hydride storage technologies and to further improve their properties.

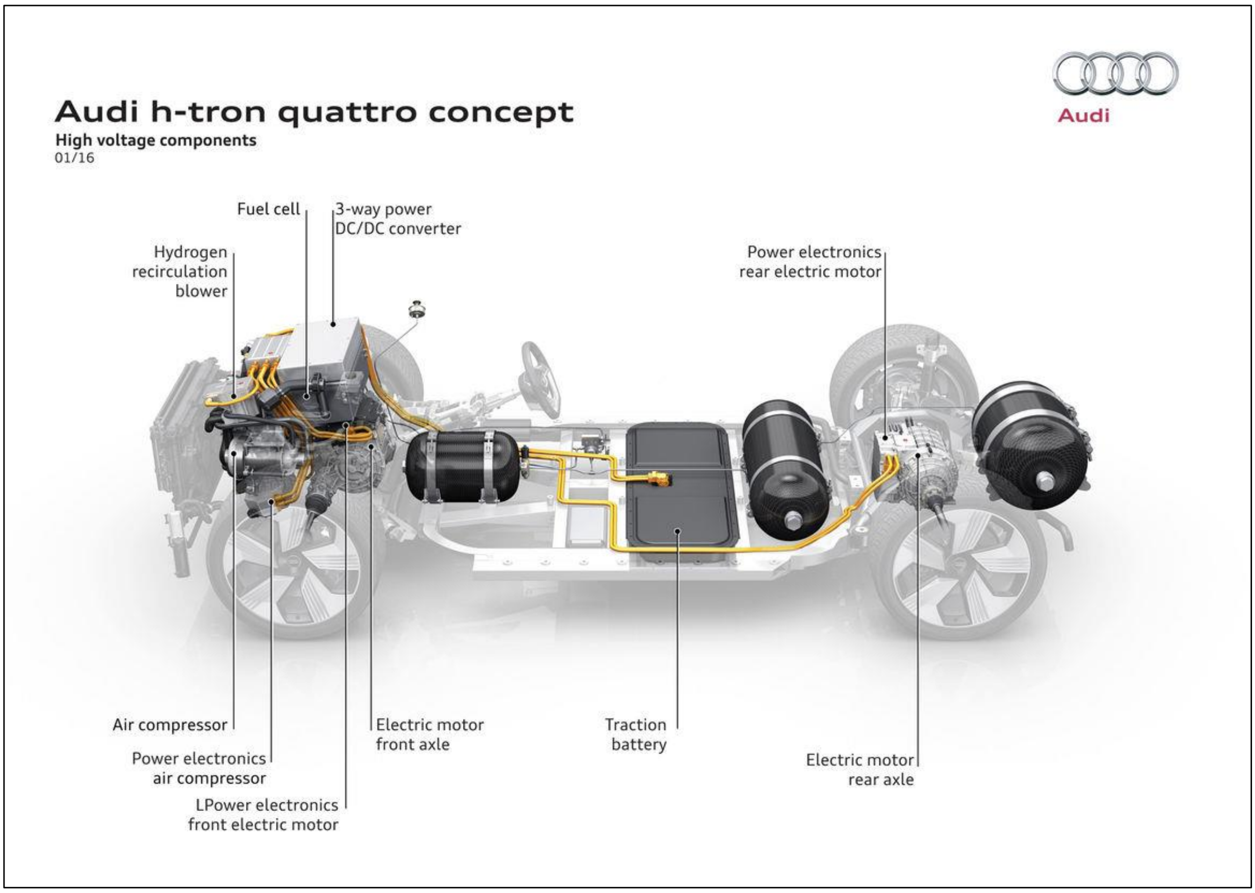

Figure 11: Audi h-tron, FCEV[55]

It is actual not feasible for a single company or consortium to set up a hydrogen infrastructure, due to too setup cost. Therefore, it needs the efforts of the whole society.[56][57]

3.2 The potential components of future powertrains

In this subsection, the key components of the potential future drivetrain are described and their potential for actual component manufacturer in the automotive industry is discussed. There are many manufacturing techniques which are used for ICE component manufacturing, which can be used as well for manufacturing these key components.

3.2.1.1 Key component electric engine

The torque required for driving a vehicle is generated exclusively for electric vehicles by an electric machine. The task of the electric machine is to convert electrical into mechanical energy (motor operation) or mechanical into electrical energy (generator

55 (Audi AG)
56 Korosec, 2015
57 Ball & Weeda, 2015

operation). With the exception of linear actuators, an electric machine always consists of a stationary stator and a rotating rotor. The proper conversion of the electrical energy takes place in the air gap between stator and rotor. Electrical energy is supplied to the system from the outside in motor operation. Magnetic fields acting between the rotor and the stator cause forces that produce a usable torque.

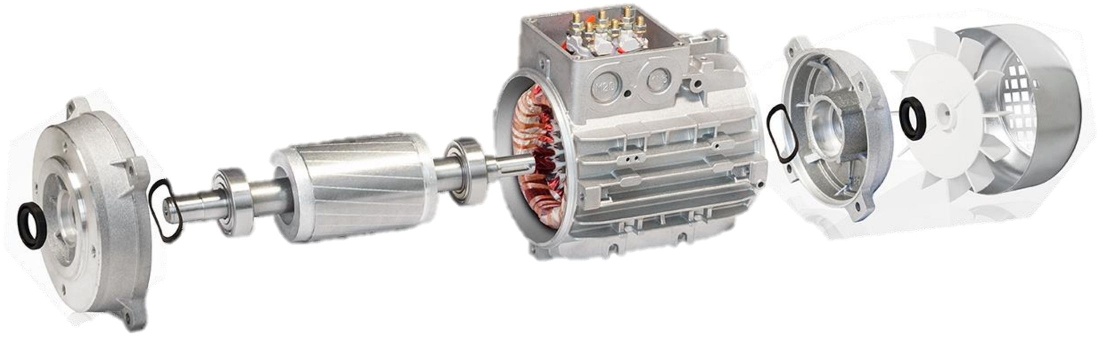

Figure 12: Construction of an asynchronous machine[58]

Figure 12 shows the construction of an electric motor for passenger cars using the example of an asynchronous machine. The electric motor consists of a housing in which the stator is located. The required magnetic field is generated via the windings of the stator. A magnetic field is induced in the rotor of the asynchronous machine and a rotational force is generated according to the principle of the current-carrying conductor. While permanent-magnetic material is used in the rotor of the permanent-magnet synchronous machine, conductors for the magnetic excitation or windings for the external excitation are installed in the case of asynchronous and externally-excited synchronous machines. The rotor is mounted on a rotor shaft for all motors and is mounted in the housing via corresponding rolling elements.

[58] Tomet srl

3.2.1.2 Key component traction battery

The battery is a central component of a BEV and also a main component of fuel-cell vehicles, since it affects both the vehicle characteristics, especially range and weight and the vehicle costs decisively. Figure 13 shows the structure of a battery system. In principle, a battery consists of individual cells, which are connected in series or parallel to cell modules. The individual cell modules are monitored and controlled via cell management. The battery system is made up of several cell modules, which are installed with a corresponding insulation in a battery housing. The entire battery is monitored and controlled by the battery management system. In addition, each battery system has a cooling system for automotive use because the operating temperature of the battery has a great impact on the performance and durability of the battery.[59]

The most important evaluation parameters of a battery, in the context of an automobile, are energy density, power density, lifetime, cost and safety. The energy density of a battery indicates how much energy a battery type can absorb with respect to the mass and thus indirectly determines the electrical range to be reached at a given battery weight. On the other hand, the power density expresses how much energy can be emitted from the battery in a given time to allow sufficient acceleration of the vehicle and maximum recuperation of braking energy.

Compared with the lead acid battery (PbA), which only achieves a power density of up to 40 Wh per kg, nickel metal hydride batteries (NiMH) have a twofold higher energy density of 60 to 90 Wh per kg. However, these battery types are currently only installed separately in hybrid or low-cost electric vehicles. The state of the art battery today are lithium-ion batteries (Li-Ion). These have a comparatively high energy density of up to 200 Wh per kg and are therefore suitable for use as traction batteries in electric vehicles. Lithium-polymer batteries (Li-polymer) offer an increased life and cycle life at a lower price by replacing the liquid electrolyte with a polymer. However, the temperature sensitivity at low temperatures limits their use currently. In addition to these two lithium batteries, Lithium-Sulphur (Li-S) and lithium-air (Li-air) batteries, which have not yet matured and are only available in the future, have a further increased energy density of up to 850 Wh per kg and several thousand Wh per kg are possible.[60]

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[59] Hofmann, 2014

[60] Hofmann, 2014

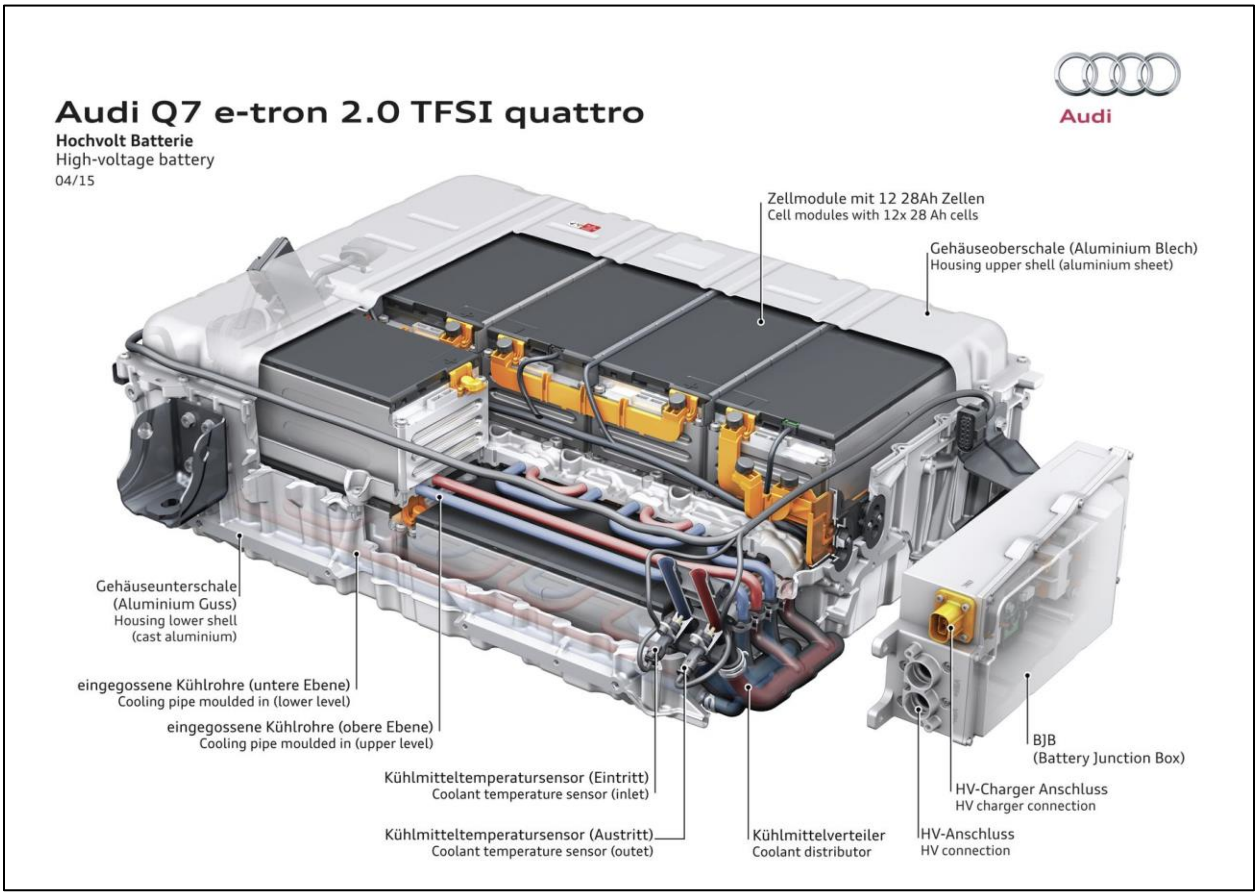

Figure 13: Construction of a battery pack with its main components[61]

In addition to the increase in the energy and power density, the focus of actual battery and cell development is on the enhancement of the calendar lifetime and at the same time high cycle lifetime. The cycle life is defined by the number of charging and discharging operations until the capacity decreases to 80% of the nominal capacity or an increase of the internal resistance by 100%. The calendar life is limited by aging processes which also occur when the battery is not loaded at all or is submitted to high or low temperatures. Further research and development activities in the field of batteries are the reduction of costs as well as the increase in battery safety. Overall, the lithium battery types currently represent the most suitable electrochemical storage for electric vehicles due to their high-power density, their high energy density at feasible costs in combination with the still potential for further development in all three categories.

3.2.1.3 Key component fuel cell stack

FCEVs generate the electrical energy which is necessary to operate the electric motor from the chemical reaction of hydrogen and oxygen to water within the fuel cell. This can

[61] Audi AG

either directly feed the electric motor via an inverter or store the energy in a traction battery or a high-performance capacitor (super capacitor). This form of a fuel cell hybrid drive is used more frequently, since power peaks can be better covered and a recuperation of kinetic energy during braking is possible. In addition to battery-operated electric vehicles, fuel cell vehicles also have a fuel cell stack, peripheral components such as the hydrogen and air module and the hydrogen tank. The fuel cell stack is the core component of an FCEV and consists of fuel cells, which are connected in series. The series circuit is necessary, since only a small voltage drops (approx. 1 V) per fuel cell. Altogether a stack consists of approx. 300 to 450 cells, so that an operating voltage of approx. 300 to 450 V is present. The fuel cell is an electrochemical energy converter. The chemical energy, bound in hydrogen, is converted directly into electrical energy. The fuel cell basically consists of a negative anode and a positive cathode. Both are separated by a semipermeable membrane. The anode is supplied with hydrogen, which is oxidized with the help of a catalyst. At the cathode, on the other hand, oxygen is reduced. As protons move from the anode to the cathode and connect to the oxygen ions present there, the voltage drops between the two electrodes.

Depending on the used electrolyte, different types of fuel cells are possible. The Proton Exchange Membrane (PEM) fuel cell is the best choice for automotive applications at the moment, because it is characterized by good starting characteristics, high power density, variable power output and robust design. The PEM fuel cell has a thin polymer film as a solid electrolyte. The low working temperature of 50-80 ° C has a beneficial effect on service life, maintenance and cold start behaviour. On the other hand, platinum or gold has to be used as a catalyst in order to ensure a stable and sufficiently high conversion of the reactants, this results in higher unit costs. The catalyst material is also sensitive to impurities caused by carbon monoxide, which blocks the adsorption of hydrogen on the platinum surface, degrading performance and lifetime are results of this phenomenon. Future developments will therefore focus on improving the catalyst material.[62]

[62] Ball & Weeda, 2015

4 Actual assessment of SMEs about automotive industry and drivetrain technologies

In the following chapter the outcomes of a conducted survey of SME in the automotive component supplier industry are presented. First the methodology of the conducted survey as well as the data collection process are described. Followed by the results of the conducted survey. In order to answer the questions underlying this study, this work is based on the methods of empirical social research.

4.1 Methodology of the empirical study

As underlying methodology of the empirical study, the oral questionnaire was chosen. The individual interviews were conducted with guidelines. It is an open, semi-standardized survey. Open refers to the possibility of the interviewee to express himself freely and to reproduce what seems important to him regarding the subject. Semi-standardized refers to the interviewer's approach. There are no pre-formulated questions and no order in the survey. During the interview, a guide is provided, in order not to forget relevant aspects during the interview. If the conversation situation is necessary, the interviewer can be called upon, otherwise the interviewee will be asked to tell as freely as possible. If the relevant points do not appear or are incomplete, the interviewer can ask further. This ensures that all interesting topics are also addressed without disturbing the flow of the story flow unnecessarily through pre-formulated questions. As a starting point of the interview, there is only provided information on the purpose of the interview, that all data are strictly confidential, as well as an indication of the sound recording during the interview. Then the interviewees are asked to tell everything they can think about "disruptive technology in the automotive industry", “impacts of disruptive technology on future business” and “potential strategies for disruptive technologies”. The aim is that the interviewee expresses him- or herself as freely as possible to the subjects, thereby providing an insight into his relevance to the topics as well as background and experience.

4.2 Data collection and analysis

The potential interviewees are selected according to criteria of representativeness, so no random samples are taken. Rather, they are typical cases. For this reason, potential interviewees were contacted or called based on preliminary considerations. The percentage of respondents who were not willing to accept an interview was 22 percent. The rest was decidedly cooperative and an appointment for the interview usually arranged quickly. The recorded interviews must be transcribed as the first step of the analysis. As the recording technique, the literal transcription is chosen, however, with restrictions that will be further refined. The transcript is made per interview into a document with line numbering, in order to be able to source the data accurately later. The individual documents are numbered with uppercase letters for this purpose. The text was first rendered word-wise. The evaluation is carried out according to the summary content analysis. The first step of the summary consists of the paraphrasing. The second step is the generalization. The paraphrases must now be generalized to an abstraction level. The resulting compressed statements can be taken as a category system. The resulting category system can now be interpreted in the context of the questionnaire and the individual interviews can be compared with each another.

4.3 Results of the empirical study

This chapter presents both quantitative and qualitative results. The results must always be considered in the context of the specific study and further criteria for an interpretation should be used. The results of the study are presented and classified into thematic sub-categories. Those sub-categories are as mentioned before:

- disruptive technology in the automotive industry
- impacts of disruptive technology on future business
- potential strategies for disruptive technologies

Beginning with disruptive technology in the automotive industry, illustrates the eight most important technology trends in the automotive industry. By far the most mentioned trend with over 50% was the BEV. Followed a respectful gap followed by not specified more precisely hybrid electric vehicles, connectivity and digitalization, FCEVs, big data, autonomous driving

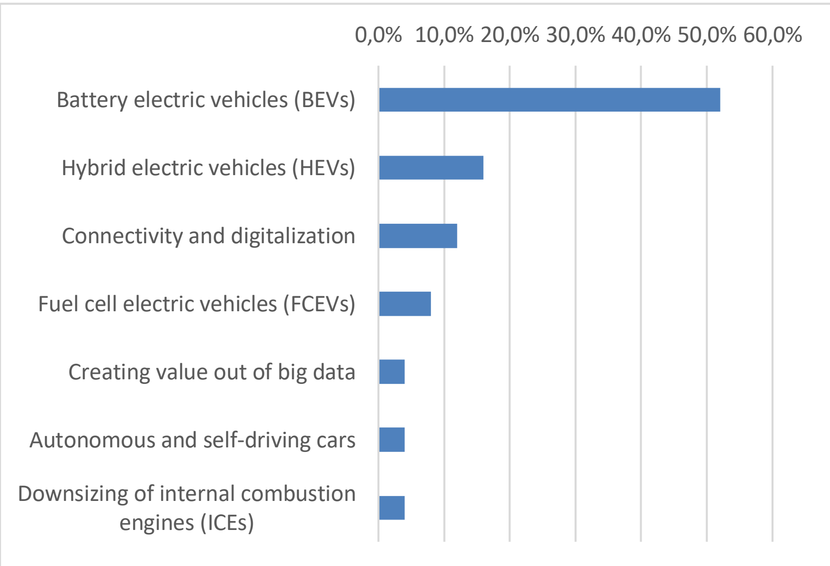

Figure 14: Technology trends in automotive industry

and further downsizing of ICEs. Statements like "… many of our contacts at OEMs, which were engaged in ICE development switched to other departments who deal with either hybrid applications or even all electric vehicles …", "… at all exhibitions and trade fairs we participated the overwhelming topic were the future development of battery electric vehicles and any form of electrification …" underline the stated results.

Figure 15 shows the prediction of the development of ICEs' market share. Bars which are coloured in blue stand for medium term development, the bars in red for long term development. In medium-term positive and negative development of ICEs' market share is balanced and the vast majority sees no significant change, according to the opinion of the interviewees. The opinion of the interviewees changed, when asked about the long-term development of ICEs' market share. Only 8% of all respondents see a positive market share development and also a significant drop in respondents who see a neutral development. Over three-third of all interviewees see a negative (12% a strong negative) development of market share in long-term. Typical statements are: "… despite all negative prognoses we don't see actually any negative trend in demand of ICE components, quite contrary we have the biggest pile of orders since years …", "… the probability that we will see the peak volume of ICE components is quite high, but the decline will be not as dramatic as it was forecasted …".

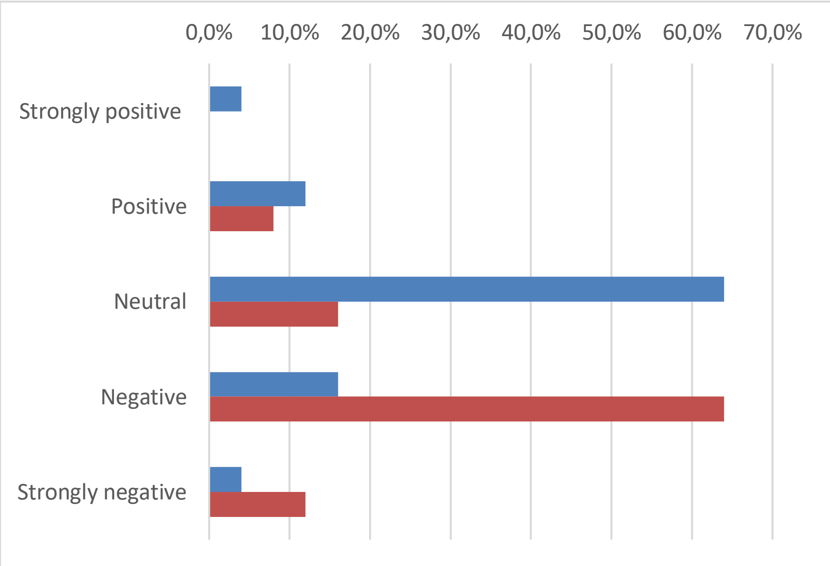

Figure 15: How will the market share of ICEs develop

The expectations of the impact of electric mobility on the actual and future business is illustrated in Figure 17, divided in actual, short and long-term impact. The blue bar illustrates the actual impact on business in the automotive component industry. The red bar shows the results on medium-term perspective and the green bar for long-term impact. The interesting result out there, while 80% of the interviewees state there is actually very low impact on business caused by electric mobility, on long-term perspective

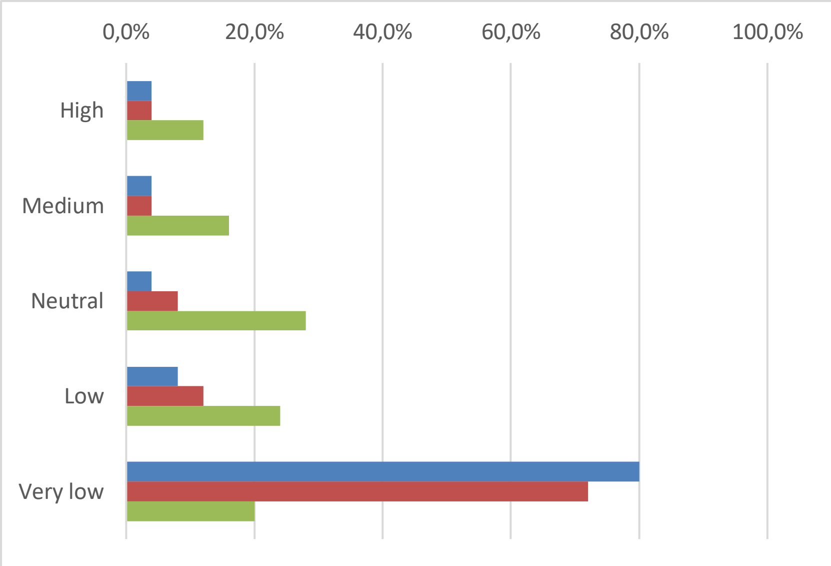

Figure 17: Impact of electric mobility on actual and future business

this opinion goes down to 20% and the majority (56%) sees a neutral to high impact on their business. This leads to the conclusion, that every second supplier is aware of an impact of electric mobility on their business. Statements for example: "… the effect on our future business is absolute crucial, not only some other competences are needed, also our direct customer, actually big first-tier supplier, like Continental or Schaeffler, will change, so we need to reorganize and expand our customer relationship …", "… with the appearance of electric vehicle the complexity of a vehicle is reduced dramatically, this will lead to a fight for revenues between OEM and all kind of supplier …".

Over 72% of all respondents see BEV as a disruptive technology for the component manufacturing industry. 16% stated that FCEV and 12% think that any form of hybrids electric vehicle could be disruptive for their industry. While the disruptive character of BEVs is recognized, interestingly FCEV are not seen as disruptive as BEVs by far. "… definitely battery electric vehicles have the biggest potential to disrupt the whole component manufacturing industry, especially those who are solely engaged in combustion engines, at battery electric drivetrains are players involved who SMEs cannot compete with at the moment …", "… beside BEVs, I do not

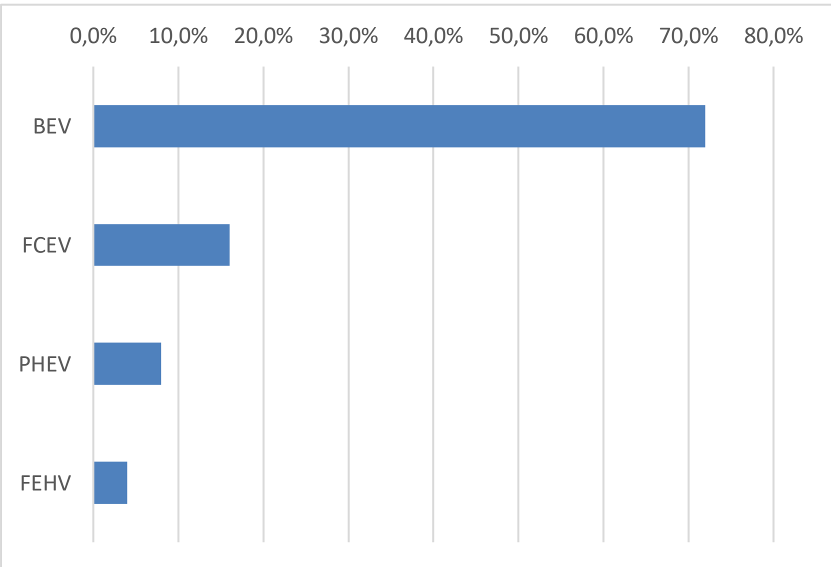

Figure 16: Most disruptive technology in component industry

see any technology with such a potential to disrupt our industry, neither fuel cells nor any hybrid configuration …”.

Over one quarter of the interviewees pursue no specific strategy, due to increased electric mobility. Another quarter of the interviewees plan to work out a diversification strategy to cope with potential rise of the electric mobility. 16% see the most potential in a collaboration strategy, which is not further specified. Again 16% of the interviewees selected technology leveraging as their favourite strategy. Technology leveraging will be further discussed in chapter 5. And finally, 12% will go for a licensing model to fight against potential decline in revenues. “… diversification, diversification, diversification, there are plenty of other markets out there where we can bring in our knowledge and competences to get new revenue streams …” and “… we do not need to reinvent the wheel, we have to focus on our strengths and assets we already have and stay agile and flexible, from my point of view we do not need a specific strategy change …”, those were typical answer out of the survey.

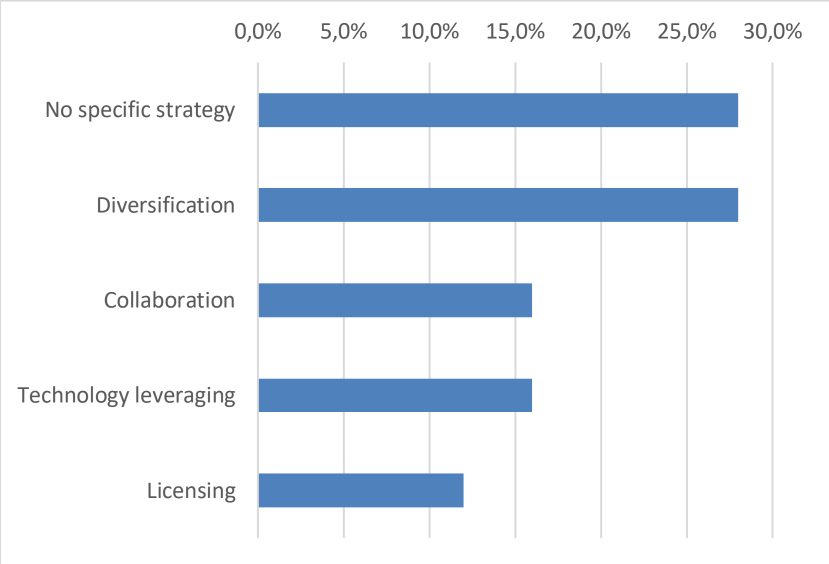

Figure 18: Strategies to pursue regarding the increase in electric mobility

4.4 Interpretation of the results

Summarized we can state out of the conducted empirical study, that most of the interviewees see no dramatic change in the ICE component sector. However, on a long-term perspective over three-fourths see a negative respectively strongly negative progress of ICEs. We can state that, a kind of awareness of the potential downfall of ICEs is already spread over the decision-maker of components manufacturer in the automotive industry.

These findings are also supported by the second aspect of the empirical study. Almost 90% of the interviewees assume that there is low or even very low impact of electric mobility on the actual business. This opinion switches when the period of the impact is extended in the future, while this opinion goes down to 44%. However, although there is a significant switch in the opinion, still nearly every second decision maker has the opinion there is low or very low impact of electric mobility on the long-term business performance. This assessment could be very dangerous for the future existence of the company, because even big OEMs have no complete picture of the technology distribution of the future power- and drivetrain, therefore it is dangerous to be bad or even not at all prepared for disruptive changes.

This is even more remarkable because more than half of respondents said that the BEV is the biggest technology trend in the automotive industry, followed by HEV with just 15%. This is a kind of ambivalent result, which cannot be interpreted correctly. Again, over 70% of the interviewees have the opinion, that BEVs are the most disruptive technology for the automotive component industry. While FCEVs and HEVs are not seen as disruptive technologies, at least for the component manufacturer.

Analysed regarding potential strategies against these disruptive tendencies, over a quarter of all respondents have no specific strategy for this case, which means they belief they have right strategies in place to cope with this change in the industry. Another quarter sees diversification as an effective strategy to fight against the decline of work scope. Each with 16%, not specified collaboration and technology leveraging, are named as striking strategies, and also licensing was named by over 10% of the respondents as an effective strategy.

5 Innovation strategies for affected SMEs

In the following chapter, different innovation strategies are presented and discussed. They originate either from literature research or from the empirical study, conducted with general managers of SMEs or department manager of components manufacturer.

The initial starting point in formulating a company's technological innovation strategy is to get a realistic view of the status quo and to assess its current position and the definition of the firm's strategic direction for the future. As results of a well-defined technological innovation strategy, the firm is able to leverage and enhance its existing competitive position, and in addition to that, the strategy pretends the direction for future development of the firm. As already mentioned, when it comes to formulating the technological innovation strategy, the first process step to assess honestly and precisely where actually the firm is standing. After that, the definition of a challenging strategic objective. The main characteristic of this strategic objective is s gap between the already existing resources and capabilities and which so ever required to achieve the objective.[63]

To assess the current external position of the firm, several standard tools are available, like for instance the Five-Force Model from M. Porter or stakeholder analysis tools. Also for assessing the internal position of the company standard tools are available, like the value-chain analysis.

5.1 Identifying core competencies

An important step towards a coherent technological innovation strategy is the identification of core competencies and capabilities. Although competency and capability are not completely the same, in this chapter, the terms competency and capability are used interchangeably, but I will describe how core competencies are gained through integrating different basic capabilities.

Core competencies of a firm are typically considered expertise which differentiate the firm strategically from its competitors. Core competencies are not just specific core technologies for example. Core competency develop from the ability of a company to combine and coordinate multiple primary competences in which the firm is excellent into key elements of specialized expertise. Competencies are a combination of different abilities, such abilities like managing the market area, building and managing an effective

[63] Hamel & Prahalad, Strategic Intent, 1991

infrastructure or, and this is especially very important for the case of component manufacturer in the automotive industry, technological, manufacturing or operational abilities. Three checks could be done, to identify core competencies easily. The first one, a core competence can provide potentially access to a broad variation of markets. Second, a core competence can make a substantial contribution to the benefit for the customer in the end product and third, a core competence is hard to imitate for others.[64]

Especially in periods of industries, when conditions are changing fast, it can be enormously valuable for a company to develop a core competency responding to change. As already mentioned, core competencies are not exclusively linked to any specific technology or product, but rather to abilities that enable the company to quickly adapt its organization and procedures in response to new opportunities or threats. Such a core competency is called dynamic capabilities. These dynamic capabilities qualify companies to quickly adapt to emerging markets or disruptive technological changes.[65]

5.2 Technology leverage

A technological competence, created by a bundle of technological resources, can provide a large number of products or services. A technology can be applied to many different market applications and can generate many different products, for instance laser technology, which is embodied in a wide range of products, beginning with fibre optic networks until cutting tools, which can be sold to a broad variety of customers, from IT to surgeons.[66]

Regardless of this potential portability of technologies to different applications, technologies are often not fully leveraged and therefore not all value and benefit are pulled out from them. Many different empirical studies support the theory that resources are often not fully leveraged and companies have funds of not fully employed productive services, for example, studies showed that large corporations have wider range of technologies than products. The productive potential of technological competencies may go beyond the borders of a company, because of its product-market strategy.[67]

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[64] Hamel & Prahalad, The Core Competence of the Corporation, 1990
[65] Eisenhardt & Martin, 2000
[66] Dougherty, 1992
[67] Burgelman, 1994

This missed potential value extraction means one the one hand lost profits for the company and on the other hand missed value for overall society. To apply technology leveraging in a company, the full process of technology leveraging has to be understood and corporate processes have to be implemented.[68]

As we will see technological competence leveraging has a big potential especially for SME component supplier in the automotive industry. Why is that?

In Figure 19 the two main steps of technological competence leveraging are presented. The first step is de-linking, this means characterization of technology, in order to identify the transferability of the technology. De-linking is the abstraction of a technology in its own right and to separate it from its embodied products. While re-linking is about applying the technology to new products that address new customers.

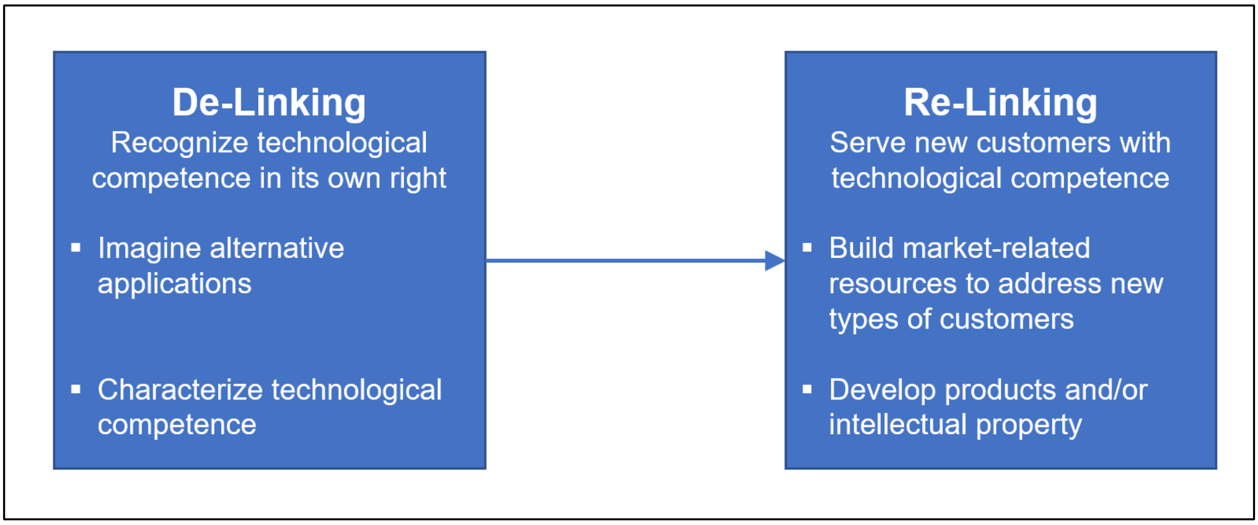

Figure 19: Technological competence leveraging[69]

But re-linking is more than just applying the de-linked technology to new application, it involves also building up resources, which are necessary to penetrate the potential market in order to provide technology to new customers and also involves the development of either new physical products or intellectual property. As already mentioned there are basically two options to profit from technological leveraging, first option is to use the de-linked technology to develop products or services internally or with partners. The second option is to license the technology to other manufacturers. As already mentioned, to be successful in technology leveraging, market related resources

[68] Danneels, 2007
[69] Danneels, 2007

are necessary. If it is too costly or would take too much time to build them up, the licencing option would be definitely the better option.[70]

The conceptual framework of the whole process is described below:

1	Define the technological competence, which is the ability to make a certain physical product
2	Identify the portability of the technology (generic or specific)
3	Technology leveraging by applying technological competence to new types of customers
4	Technology de-linking, the uncoupling of the technology from the original product
5	Technology re-linking, the re-coupling of the technology for new applications
6	Create complementary market-related resources
7	Allocation of generic resources to the de-linked technology
8	Transformation of the generic resources into specific resources
9	Give incentive to the new applications
10	Create customer competency to serve certain customers
11	Generate Second-order marketing competence

Table 3: Conceptual framework of technological competence leveraging[71]

The process of leveraging technological requires competence across multiple markets, and that is the main reason, why the potential value which is offered by leveraging technology often could not be yielded. The process requires explicitly to execute every step, from de-linking technological competence from its current product application and to re-link the competence to serve new markets. In many cases the existence of a technological competence to serve current customers and the nonexistence of a competence to gain access to new customers headed into a fail of the leveraging process and no profits could have been gained, rather losses occurred. Not only de-linking and re-linking are important, also the steps of resource allocation and subsequently the transformation into specific resources are crucial for successful leveraging.

[70] Danneels, 2007
[71] Danneels, 2007

5.3 Collaboration Strategies

Companies may choose solo development of a project for a variety of reasons. First, the company may see no need or benefit to collaborate with other organizations, if it possesses all the necessary capabilities and resources for a specific development project. A company may also choose to develop a project in-house, because it is anxious that a collaboration would put its proprietary technologies at risk, or if it pursues to have full control over the development.

But a collaboration with other organizations on development projects or manufacturing projects may offer a variety of advantages for a company.

First, collaborations can enable a firm to get necessary complementary skills or resources more quickly than developing them on its own. It is common that a company misses some of the complementary assets which are required to embody the technological competence into a commercial product. Maybe in a given time, the company would be able to develop those complementary skills internally, but doing it internally may extend the development or the time to market. Doing it the other way and collaborate, a company may get access to important complementary skills rapidly by forming strategic alliances or licensing arrangements for instance.[72]

Second, a company, which gets some of the complementary competences or resources it needs from a partner rather than building them on its own, can help a company to reduce its working capital and improve its flexibility. Especially in markets which are characterized by rapid technological change, like actually the automotive industry, such procedure can be important or even essential for survival. Technological changes force product markets to a swift transformation. Especially, when technology is immature and progress steps are huge over product generation, short life cycles are obligatory, companies will be in advantage, if they are not committed to fixed assets that may become obsolete quite rapidly.[73]

And finally, third, companies who collaborate with partners may use it as an important fund of learning for the company. If the partnership is built on trust, close contact with other companies may enhance the transfer of knowledge between the companies and this leads the creation of new knowledge and finally creates the perfect nutrient solution

[72] Hamel, Doz, & Prahalad, Collaborate with Your Competitors - and Win, 1989
[73] Schilling, 2013

for future innovations. If companies put their technological resources and capabilities together, these companies may be able to enlarge their knowledge bases and are more competitive than without collaboration.[74]

5.3.1 Types of collaboration

In the following passage, the different types of collaboration are described and their major advantages and disadvantages are named.

5.3.1.1 Strategic Alliance

Companies may use strategic alliances to get access to missed critical capability or to leverage its own capabilities in another company's development efforts. Companies form alliances, when they have different capabilities, which are needed to develop a new technology or to gain access to a new market to bundle their capabilities and/or resources to develop the product or market jointly to be faster and/or less expensive. But it is also possible and reasonable that companies, which have similar capabilities may join forces of development activities for instance to share the risk of a venture or to join forces of marketing and sales activities to speed up market penetration. Another possible motivation, for large companies to form a strategic alliance with a small company, is to become a partial access in the development efforts of smaller firm. On the other hand, small companies may profit from alliances with large companies through greater capital resources, distribution and marketing capabilities, or credibility of the larger company.[75]

With the forming of strategic alliances, companies can enhance their overall flexibility, by getting a limited stake in a new technology and the flexibility, either increasing the stake or discontinue the engagement and shift the resources to another venture. Another advantage of alliances is, that companies may use the window of opportunity in an early stage, which may be fully upgraded in the future. Especially in business environments which change fast, alliances could help a company to access missing capabilities rapidly. Companies may use alliances to learn from each other and develop new competencies and transfer knowledge between the companies.

But there are also drawbacks of alliances, for instance if the partner does not share the same languages, routines culture and coordination, the transfer of knowledge, especially

[74] Baum, Calabrese, & Silverman, 2000
[75] Teece, 1986

complex knowledge, is constrained and not efficient. It needs serious commitment of resources, like dedicated people, traveling budget and active knowledge management to make alliances successful for both partners.

5.3.1.2 Joint Venture

A Joint venture is a specific type of strategic alliance. As already mentioned a strategic alliance could be any type of formal or informal relationship between two or more firms. A joint venture comes usually with establishing a new separate legal entity, which means a significant equity investment from each partner. The invested capital and other resources but also potential profits and losses are specified in contractual agreements.

We can distinguish joint ventures regarding the share of equity of the partners. There are parity shares of equity and imparity shares of equity possible. For example, parity means if every partner has the same amount of share (50% each if there are two partners, 33,33% if there are three and so on). Imparity means the number of shares of the partners are not equal (for example, 60% to 40%). It is also possible to distinguish regarding the sector in which the partners are working. There are horizontal joint ventures, where the partners are active in the same sector. In the case of vertical joint ventures, the partners are active in upstream or downstream value-added stages. If the partners come from related industries, the joint ventures a concentric one and finally conglomerate joint ventures consist of partners from completely different industries.

5.3.1.3 Licensing

A license is an authorization granted by the licensor, the owner of a patent or an intangible asset, to another company free of charge or against payment of a license fee to manufacture and or distribute a particular product (right to a patent) of the licensee within a particular territory and period.

In other words, a license is the authority to use the right (for example a patent or copyright) of another. Usually the licensee has to pay a licensing fee to the licensor for the use of the license. But there are several examples, where patents, copyrights etc. are free of charge. In the cost accounting, license costs are either deducted as separate individual costs of production, if the license has been granted for the production of certain products, or as special selling costs of the distribution, when the license was granted for the sale of the licensed products.

The licensor gains the advantage, that licensing may an accurate instrument for a company to penetrate its technology in wider area. See technological competence leveraging.

On the other hand technology licencing from other companies is usually cheaper for a licensee, compared to an in-house development of a new technology. As discussed in in technology leveraging, the development of a new product could be both expensive and risky. A company may gain access to a technology via licensing, which is already technically or commercially proven.[76]

There are two types of licenses.

First a so called flat-rate license, when the fee is paid in the form of a fixed amount for a specific period (year, month etc.), regardless if the license is used or not, for example the effective distribution of goods produced under license.

Second, so called quota license, when the license fees are fixed to the proportionally usage. Most common are piece licenses. In the case of the piece license, the fee is paid per usage or output unit. There are many different variants of the base of the license fee possible, for example the license fees are proportional to the sale of the licensed product or the calculation of the license fees is based on the profit.

There are also license agreements possible where those two types are combined.

5.3.1.4 Outsourcing

Outsourcing are activities related to relocation of value-added activities of a company to suppliers. Outsourcing represents a shortening of the company's value chain or service depth. The production, development and services of a company are often reduced by the use of qualified and highly specialized suppliers for components and services. By concentrating on the core activities, cost advantages can be realized and the company's own operational and own strategic market position is improved. It is strategically important that key technologies and competences are not abandoned in the context of outsourcing, as this could lead to an unwanted dependency on the upstream supplier.

That is actually how SMEs in the automotive industry are contracted. In addition to the threat of disruptive technologies in the ICE sector, if the volume of production decreases,

[76] Schilling, 2013

because of simplification of the drivetrain, OEM will be more carefully when it comes to outsourcing, because they have to keep the employment on its actual level. Only if there are no other options, layoffs are executed.

5.3.1.5 Collective Research Organizations

In some industries, organizations have incorporated so called cooperative research organizations. These collective research organizations may have many different forms, like trade associations, university-based centres, or private research corporations. Collaborative research organization may enable companies to share the development expense and help the industry retain its competitive advantage.

This can be also an option for components supplier in the automotive industry. When some SME form together a collaborative research organization.

In Table 4 the discussed forms of collaboration are listed and their character regarding speed, cost, control, leveraging potential, developing potential and accessing new competences are defined.

	Speed	Cost	Control	Potential for Leveraging Existing Competencies	Potential for Developing New Competencies	Potential for Accessing Other Firms' Competencies
Solo Internal Development	Low	High	High	Yes	Yes	No
Strategic Alliances	Varies	Varies	Low	Yes	Yes	Sometimes
Joint Ventures	Low	Shared	Shared	Yes	Yes	Yes
Licensing In	High	Medium	Low	Sometimes	Sometimes	Sometimes
Licensing Out	High	Low	Medium	Yes	No	Sometimes
Outsourcing	Medium/High	Medium	Medium	Sometimes	No	Yes
Collective Research Organizations	Low	Varies	Varies	Yes	Yes	Yes

Table 4: Summary of trade-offs between different modes of development[77]

[77] Schilling, 2013

5.4 Recommendations for SMEs

For the established companies in the automotive supplier industry, the change of conventional drive technologies towards electric mobility involves both opportunities and risks at the same time. In particular, suppliers of conventional drive components have to adapt themselves to comprehensive changes. In addition, electric mobility also has an impact on suppliers of all vehicle domains as well as companies in other sectors. In order to ensure sustainable growth and the long-term existence of the company, electric mobility must be explicitly taken into account in the overall company- and its technology-strategy.

In a first step, the company's position with regard to electric mobility should be analysed. The technology and product strategy of the company is a starting point for this in its market environment. The technology development strategy can distinguish between a reactive technology development, which is usually triggered by customer queries, and a proactive technology development. For companies with a specialized product portfolio and a reactive technology development, there is a long-term threat especially for those suppliers with specialization in conventional drive components. In addition, new business segments, which will occur with electric mobility, may not be recognized or just too late.

In addition to the technology and product strategy, the current position within the value chain should also be taken into account when analysing the company's position in the field of electric mobility, as companies of downstream value-added stages could also be affected by changes caused by electric mobility. In a second step, the impact of electric mobility on the specific company should be analysed. Due to the currently uncertain market development for electric vehicles, a scenario-based forecast of the effects on sales and earnings for the respective company has to be carried out. Based on this, the evaluation and prioritization of the electric mobility as well as the resulting potential technology fields for the company should be carried out in a further step. This decision forms the basis for determining the strategic direction of the company.

With regard to the battery system, a selective development of individual components is generally recommended. Due to the current dominance of Asian suppliers in the production of battery cells and the sharp fall in the price of battery cells, the production of battery cells is currently not considered as viable. Concerning the upstream value-added stages, regional concentration is problematic because of the localization of the production capacities for battery cell components. On the other hand, there are potentials for the production of battery modules and the battery pack, including the necessary components. Production of battery pack and modules is carried out today either by the OEM or by the supplier of the cells. The supply of OEMs with components for module and battery pack production therefore offers a possibility to expand the product portfolio. A further approach is to cover the production of the battery module and the pack in connection with a purchase of the battery cells, thereby acting as a system supplier for the OEM. Against the backdrop of the current value-added strategies of the vehicle manufacturers, this approach is associated with a high risk, but offers the highest value-added potential for suppliers. The decisive factor for the success in the market will be the realization of the unique characteristics against the already established battery suppliers (for example Panasonic, Samsung and LG Chem).

Also in the field of the electric motor, the production of components can be used to develop value-added potentials for suppliers. At present, the production of electric motors is either fully covered by the OEMs or by system suppliers like Bosch or Continental. In medium term perspective, it is to be expected that, in particular, vehicle manufacturers are increasingly purchasing individual components or modules from corresponding suppliers. Components suppliers, which specialize in individual components (for example sheet metal, magnets, shafts), could benefit from development. In addition, a further reduction of the vertical manufacturing integration of OEMs allows the supplier to supply pre-assembled modules (for example stator, housing, rotor). Since the established system suppliers already have a strong market position for electric motors for electric and hybrid vehicles, it is currently not recommended for new players especially SMEs to build system competences for electric motors. However, alternative electric motor concepts (for example switched reluctance machines) for electric vehicles are currently being investigated in research projects. If these technologies are going to be implemented in the market in the future, companies which are able to build appropriate competencies at an early stage can gain competitive advantages over system suppliers.

In power electronics, current value-added strategies are comparable to those of electric motors. Production is carried out either by OEMs (for example BMW or Nissan) or system suppliers like Bosch and Continental. The production of the components (for example capacitors, diodes) is usually carried out by specialized suppliers, which generally supply not only the automotive industry. Potentials for opening up new value-added areas are the integration of value-added stages upstream of component production. For example, modules such as control electronics or the power module could be produced by suppliers. In addition, there are also value-added potentials in the field of the production of peripheral components such as the cooling system. Due to the increasing integration of power electronics into the drivetrain, the development in the direction of a system supplier is only recommended for companies with competences in electric motors and an adequate overall system understanding.

In order to develop new technologies, companies with an active technology development strategy, there are basically different options for action. In addition to internal based competences build up, external and joint competence building with co-operation partners should also be taken into account in electric mobility. The reason for this is on the one hand the interdisciplinary character of electric mobility, which requires in many areas cross-domain knowledge. And on the other hand, the research and development risks that exist in the field of electric mobility and the related financial risks can thus be shared among several companies. Depending on the development phase, cooperation with different partners such as research institutes, development service providers, suppliers or customers could make sense.

Especially for small and medium-sized enterprises, the formation of company networks or the participation in cross-company research and development activities, for example in the context of public projects, are often problematic and involves a great deal of effort. In addition, there are often no direct business relationships and thus, as a rule, no communication channels with the vehicle manufacturers, so that an information deficits exist between SMEs and OEMs. The reduction of information deficits as well as the greater involvement of SMEs in the research and development networks should therefore be pursued by the larger automotive suppliers as well as the car manufacturers in order to exploit the innovative potential of these companies. In addition, existing networks, for example different cluster etc., could play an important role in the reduction of information deficits and can actively promote information through various instruments, for instance specific events.

6 Discussion and Summary

The overall objective of the thesis was to describe the possible future development of drive train technologies of the automotive industry and to model the future electric mobility value chain and to derive strategies and recommendations to strengthen the market position of SME component manufacturers of today's internal combustion engines. First the theory of disruptive technology was presented and its implications for SMEs in general discussed and in a second step a detailed look was made on the disruptive potential of electric vehicles for OEMs as well as for SMEs in the component manufacturing industry.

In a first assessment, the actual automotive industry was analysed, with its major trends namely digitalization and electrification of the automotive industry. While digitalization will affect primarily OEMs, the electrification of the power- and drive train, will affect both OEMs and Supplier at all points of the actual value chain, from the biggest suppliers like Bosch to SME suppliers. It was the project investigated the current situation of the automotive industry and analysed the effects of electric mobility on SME component manufacturers.

The necessary theoretical fundamentals of disruptive technology and SME were developed and its usual position in the general value-added chain of the automotive industry was presented. Based on an industry-specific value-added chain, the main value-added stages of ICEs were described and the current situation of the automotive industry was characterized in terms of value creation structures and depths. Subsequently, the structure of a conventional drive (ICE) train was examined. The entire vehicle was divided into the main modules drive train, powertrain, electrics and electronics. The corresponding systems and modules were identified for each of these domains. In a further detailed level, the system and module components were listed at component level. The production structures for conventionally driven vehicles were compared with potential future production structures. In a further step, the distribution of value added, both to the individual drive train systems and modules as well as between vehicle manufacturers and suppliers, was examined.

The aim of this work was to map the product structure of an electric vehicle and its derivatives which we can sum up under the term electrification of the automotive or especially the drivetrain and to identify the processes required for production and the resulting structures. In addition, the production steps for the key components electric motor, battery, power electronics and fuel cell have been described in more detail. This part includes the identification of the competence requirements for the production of the key components of the electric motor, traction battery, power electronics and fuel cell. Based on this, the opportunities and risks of electric mobility for the SME component supplier in the automotive industry were presented and recommendations for action for companies were derived in order to strengthen the market position of SMEs in the future electric mobility industry.

A major part of the thesis is the conducted empirical study, its results and the conclusions which can be stated out of the results. The objective of the empirical study was to get a clear picture, how decision maker of component supplier, which are mainly SMEs, think about the actual transition of the automotive industry, the implication on the industry and in particularly on the own sector coming from this transition and how they will react on the situation they are confronted with. The results in were kind of ambivalent, because on the one hand, the vast majority identified the electrification of the powertrain as a big trend in the automotive industry, and also sees the technology as a potential disruptive technology, however on the other hand, almost half of the respondents assess no significant impact on the future business. This in fact only leads to the conclusion that respondents are inadequately informed about the effects of electric mobility on the drive- and powertrain and its implication for actual supplier. This result reinforces the impression that there is not yet enough awareness training done in the past, and that there is still a lot of training to be done in the future to create the right level of awareness. Actually, the creation of awareness is one objective of the thesis.

The last section of the thesis deals with innovation strategies and recommendations derived from them for affected SME. However, it must be pointed out that the strategies and recommendations described in the thesis reflect just a small section of possible strategies and actions and therefore the thesis gives only a rough indication for further consideration. With the awareness and determination for a strategic change, the study of specialist literature as well as intensive consultation and exchange are essential for a successful elaboration and implementation of the strategy.

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List of Abbreviations

AC	Alternate current
AG	Aktiengesellschaft
BEV	Battery electric vehicle
BMW	Bayerische Motoren Werke
CEO	Chief executive officer
CO_2	Carbon dioxide
DC	Direct current
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
GM	General Motors
H_2	Hydrogen
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
IT	Information technology
J	Joule
kg	Kilogram
km	kilometre
kWh	kilowatt hour
L	Litre
Li	Lithium
NiMH	Nickel–metal hydride
NO_X	Nitrogen oxides
OEM	Original equipment manufacturer
PbA	Lead-acid
PEM	Proton exchange membrane
PHEV	Plug-in hybrid vehicle
SME	Small and medium-sized enterprise
SUV	Sport utility vehicle
V	Volt

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