MASTER THESIS

Market Analysis for 48 V Automotive Testbed Systems

Christoph Schöggler, BSc. BSc.

Graz, June 2014

Graz University of Technology

Institute of Industrial Management and Innovation Research

Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer

DECLARATION OF ACADEMIC HONESTY

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, June 25, 2014 Christoph Schöggler, BSc. BSc.

ACKNOWLEDGMENTS

This master thesis gave me not only the opportunity to become acquainted with a contemporary topic, but I also had practical experience of working for an international company. I would like to express my appreciation to my supervisors Thomas Böhm, Hans Peter Schnöll and Jürgen Fabian from TU Graz for the useful comments and the qualified help for different subtasks of this diploma thesis. Furthermore I would like to thank Don Wright from AVL for introducing me to the topic as well as well as for his helpful remarks and engagement through the learning process of this thesis.

ABSTRACT

The present paper deals with the automotive 12 V/48 V on-board supply, which is a possibility for low-cost hybridization in order to fulfill CO_2 emission regulations for passenger vehicles in the EU. A SWOT-Analysis on the additional 48 V net is conducted in order to assess the potential of the technology. Thereby, technical advances, other possible applications, market development as well as competitive firms are identified. An online-questionnaire is used to survey different customers from AVL List GmbH, which helps to determine customer's needs, used technologies as well as future estimation of the industry. Finally, a graphical evaluation of the responses answer respective questions. Most companies have already invested in 48 V testing solutions or will do this in the following years. Based on the survey results, AVL can optimize the risk for decisions concerning investments and customer needs of 48 V-based test systems.

Since different research institutions and companies deal with the practical application of the 12 V/48 V on-board supply, the information changes rapidly. Therefore, scientific papers, product descriptions and online sources of state-of-the-art-companies, were used as primary sources for the research.

KURZFASSUNG

Die vorliegende Arbeit beschäftigt sich mit dem Automobilbordspannungsnetz 12 V/48 V, welches sich für eine Niedrigpreishybridisierung anbietet um der EU-Verordnung zum CO_2-Ausstoss von PKW nachzukommen. Eine SWOT-Analyse des 48 V Bordspannungsnetzes gibt Aufschluss über das Potential dieser Technologie. Dabei werden technische Fortschritte, weitere Anwendungsbereiche, Marktentwicklung sowie Mitbewerber ermittelt. Ein Online-Fragebogen wird genutzt um Primärdaten von Kunden der Firma AVL List GmbH zu ermitteln. Kundenbedürfnisse, verwendete Technologien sowie zukünftige Einschätzungen der Branche werden dabei erfragt. Abschließend gibt eine grafische Auswertung der Antworten Auskunft zu den jeweiligen Fragestellungen. Die meisten Unternehmen haben bereits in 48 V Testsysteme investiert oder werden dies in den kommenden Jahren tun. Basierend auf diesen Umfrageergebnissen kann AVL Entscheidungen bezüglich Investitionen und Kundenbedürfnisse von 48 V-basierenden Testsystemen optimieren.

Da sich verschiedene Forschungseinrichtungen und Unternehmen sehr stark mit der praktischen Umsetzung der 12 V/48 V Bordnetzspannung auseinander setzen, ändern sich die Informationen diesbezüglich sehr rasch. Daher wurden wissenschaftliche Publikationen, Produktbeschreibungen und Onlinequellen von renommierten Firmen, welche am Stand der Technik sind, als Hauptinformationsquellen genutzt.

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1 INTRODUCTION

This diploma thesis investigates the on-board supply of 48 V for low-cost hybrid vehicles. The initial situation (chapter 1.1) and the goals (chapter 1.3) represent the framework of the thesis.

1.1 Initial situation

Around the turn of the millennium the automotive industry was keen with the impending change of the vehicle's on-board supply from 12 V to 42 V; the changeover never happened due to contact erosion and a significant faster wear of switches. The number of electric devices on board such as heated seats, electrical windows and other accessories increased and wiring harnesses became heavier. A voltage level of 42 V would have reduced the cable cross-section due to the fact that the current would be much lower for unchanged loads. A bundle of wires in the driver's door of some luxury cars has about 60 wires and is about as thick as a wrist. A change to 42 V would have reduced the bulky bundle's cable cross-section by half. A so called idle shutoff would replace the engine flywheel with an electric motor to switch of the internal combustion engine (ICE) at traffic lights to cut fuel consumption and CO_2 emissions. Therefore, the starter-motor would spin the ICE up to idle speed again when the driver takes the foot of the brake pedal.[1]

Politics, higher safety standards and comfort in the automotive industry pushes the electrification of vehicles ahead. Therefore, different applications such as motor management systems, anti-lock braking systems or exhaust gas sensors are integrated in vehicles and established as a standard equipment. Today's 12 V on-board supply is not an affordable solution for this permanent increase of electronics in vehicles alone, which brings the automotive industry to a higher on-board supply.[2]

Two factors bring this 12 V on-board supply to its limits. First, the European Union's standard for cars and vans limits the CO_2 emissions to 95 g/km in 2020. To achieve this target increasing electrification is inevitable. Second, the demand for more innovations and features such as safety systems, entertainment systems, climate control and in-seat heating is increasing. Both requirements challenge the electrical system over the power limit of the 12 V system which is about 3 kW. Therefore, vehicle manufacturers introduced a 48 V power bus, which reduces the diameter of cables and offers to support higher loads of around 10 kW. Furthermore, the classical lead-acid battery type will most likely be replaced or combined with lithium-based batteries which offers more charge and discharge cycles. The electrical topology of a car will therefore undergo a significant change, where

[1] Cf. Popular Mechanics (2009), www.popularmechanics.com, date of access [27.10.2013].
[2] Cf. Schaefer (2001), p. 1.

the new 48 V on-board supply operates side by side with the conventional 12 V one. Both systems are connected over a bidirectional DC/DC-converter, which allows battery power shifting and distributing. High power loads will be supplied by the 48 V system, whereas the 12 V bus continues to provide power for remaining functions.[3]

Strict CO_2 targets and new storage technologies such as lithium-ion are the main reasons for a successful introduction of the 48 V system compared to the 42 V one. A 42 V on-board supply would have required three lead-acid batteries which would have been heavy and bulky. Therefore, the 48 V power net solution starts to supply high-power equipment such as heatings and compressors and not CPUs which run on 5 V or 3 V anyways.[4]

Due to quick and consistent changes in the automotive industry, addressing new technologies is essential for companies such as AVL List GmbH to stay competitive.

1.2 Company profile

AVL List GmbH, or Anstalt für Verbrennungskraftmaschinen List GmbH, is an independent company which was founded by Prof. Dr. h.c. Helmut List in 1948. AVL has more than 6.650 employees worldwide whereof 2.950 employees work in Graz where the headquarters is located. The company's scope of business ranges from the development of all kind of powertrain systems through instrumentation for engine and vehicle testing, to advanced simulation technologies to optimize powertrain systems. AVL has 45 affiliates worldwide, an export quota of 96 % and a turnover of 1.05 billion €.[5]

1.3 Goals

The major goal of this thesis is to give AVL List GmbH recommendations for actions based on the market development of the 48 V-technology in order to reduce risk for further investments and to meet customers' needs. Moreover, a SWOT analysis of the 48 V-technology should include results of a comprehensive secondary research to have a quick overview of the strenghts, weaknesses, opportunities and threats to estimate its potential. Other industries and applications, which are based on 48 V, should be identified to detect market niches. A primary research by an online questionnaire with AVL's customers should give specific answers about their used technologies and targets as well as requirements for different 48 V testbed systems.

[3] Cf. Hehn (2013), www.yudu.com, date of access [24.03.2014].
[4] Cf. Palmen (2014), www.ai-online.com, date of access [24.03.2014].
[5] Cf. AVL List GmbH (2014), www.avl.com, date of access [03.06.2014].

1.4 Systematic procedure

The theoretical part of the thesis starts with describing the initial situation, the goal of the thesis and the procedure of reaching the goals. Furthermore, a classification of this thesis into the innovation process is done to define the scope of the thesis. In addition, important steps of how to do a market research is acquired.

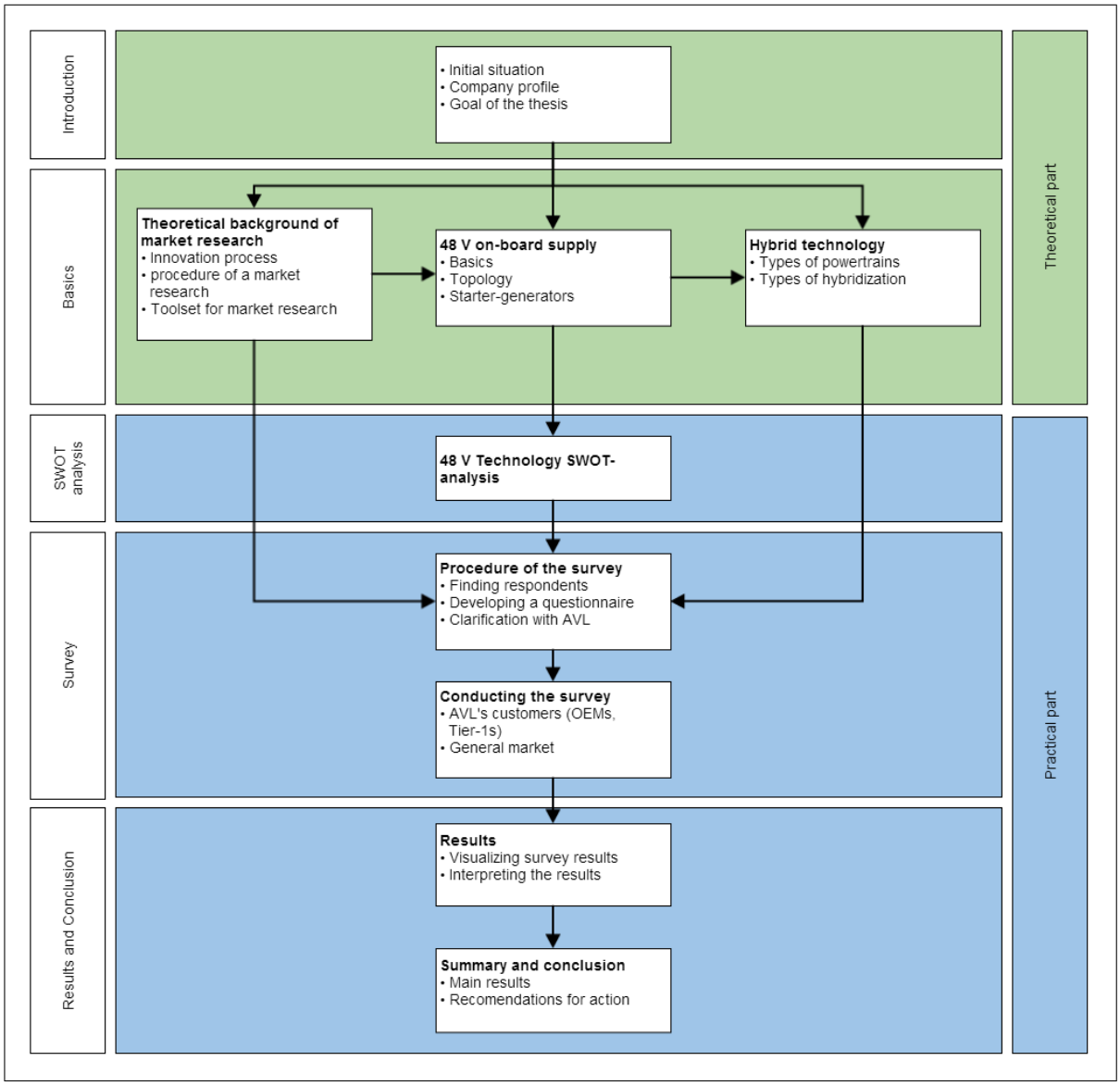

Figure 1.1: **Visual study design of the thesis.**[6]

A detailed secondary research about the 48 V on-board supply is gathered in a SWOT analysis to get an overview about strengths, weaknesses, opportunities and threats of the technology. Additionally, different types of hybrid technologies and powertrains are explored and summarized in order to have a practical coherence to the 48 V-technology. In the practical part of the thesis, the procedure of the

[6] Own illustration.

survey is planned and a questionnaire is developed in a way to meet the requirements of AVL. All results from the secondary research are factored into the development of the questionnaire. After conducting the survey with AVL's customers (OEMs and Tier-1s) as well as with the general market, results are visualized and interpreted. Finally, a conclusion is derived from the results and the most important facts are summarized at the end of the thesis.

2 THEORETICAL BACKGROUND OF MARKET ANALYSIS

In recent years, system complexity has increased in all scientific research topics. However, the higher level of complexity leads to new opportunities for ideas and potential to create innovations. Additionally, the fact that only separated development departments include innovation management has changed in some companies already. Therefore, innovation processes are used to solve various problems systematically and almost all involved should bring in creativity and knowledge.[7]

The first step of the innovation process according to Vahs/Burmester (2005), which is shown in Fig. 2.1, is the impact, which is in actual fact a discrepancy between the actual state and the target state. The target state can be derived from goals of a company (e.g. market leadership) and their strategies such as conducting specific R&D-projects. Therefore, a noticed problem due to a target-actual comparison is the impact for finding a solution. An exact investigation of the specific problem of an organization should be conducted. This analysis is inevitable to have permanent market success. Therefore, tendencies of development, customer needs, competitors, suppliers etc. should be analyzed continuously by a so called situation analysis. Consequent market orientation is a way to recognize risks for innovations at an early stage and thus it can gain a competitive advantage.[8]

It is definitely important to consider customer needs for a situation analysis, whereas a company should not only focus on the customer needs due to the fact that competitors have a determining influence on the market. Although a company is able to satisfy customer needs in a good way, this is not a guarantee for a competitive advantage because competitors might fulfill requirements even more precisely.[9] For a situation analysis/problem identification a detailed description and assessment of the actual state is indispensable to clarify the exact causes for the target and actual state. This should be carried out systematically in order to consider all relevant action fields whereas technology as well as the market are significant.[10] The phase of strategic search field analysis is to identify new business and innovation fields. For this, a SWOT analysis (see chapter 2.2.1) should support the identification process.[11]

[7] Cf. Kutzner (2011), p. 3.
[8] Cf. Vahs/Burmester (2005), p. 93.
[9] Cf. Kasprik (2002), p. 97.
[10] Cf. Vahs/Burmester (2005), p. 138.
[11] Cf. Vahs/Burmester (2005), p. 124.

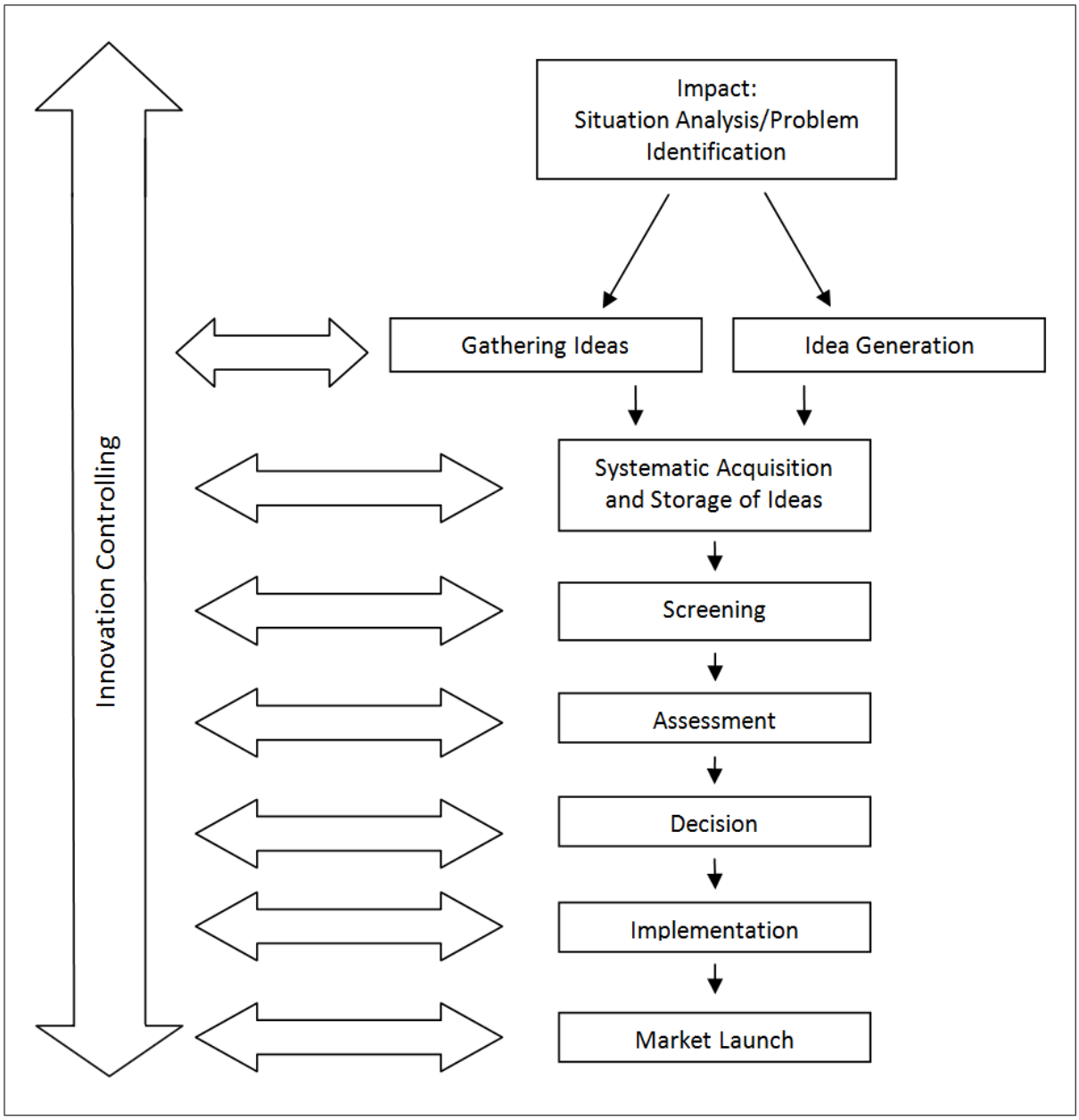

Figure 2.1: **Basic structure of an innovation process.**[12]

This thesis is a market research and focused on the situation analysis of the innovation process (see Fig. 2.1). For reasons of readability and coherence, further steps of the innovation process will not be described in this thesis.

2.1 Market research

Exact and timely information is required for every enterprise, independent of size or the number of employees, to achieve economic success. In the so-called "Information age", it is not enough to have

[12] Vahs/Burmester (2005), p. 92.

resources such as materials, equipment, talent, experience or finance. Therefore, it is important to have a permanent flow of the required information for the business. Some huge companies make market research on a very high level and know exactly what their customers want. A company, which sells drinks, knows for instance how many ice cubes the average customer put in a glass, the favorite way of how the drink is served to them and so on. It is obvious that not every company can afford an own research department to collect and monitor all this almost unmanageable amount of information nowadays. Nevertheless, business owners must know their markets, customer's needs and competitors to be successful.[13]

Market research is a topic which becomes more complex from time to time. Data from sources such as articles, surveys and statistics often cover many countries. Additionally, researchers to accommodate different languages are required. Moreover, the web has billions of facts, figures as well as unusable and wrong data. Therefore, a good market research is about asking the right question to the right people.[14]

In general, market research is applying common sense to find useful data to support the top management's and sales management's decision making process. Moreover, market research is not a one-time operation that gives answers for all time. However, it gives an up-to-date knowledge and avoids bold decisions based guesses and hunches.[15]

Good results from a market research is often a team effort, which means that most projects involve several participants. Furthermore, market researchers have nowadays different options to use for their research such as a desk research, telephone interviews, personal interviews, questionnaires, focus groups etc. Intuition, facts and experience are the main factors, which influence decisions of managers. It is natural to trust intuition and common sense for decision making if there is not enough time for a research or the risk of a wrong decision is low. Nevertheless, robust and reliable data is inevitable when decisions have a big impact on financial resources. Therefore, a comprehensive market research reduces business risk tremendously. Furthermore, market research is almost a standard practice in different cultures such as the United States and northwest Europe before making big decisions, whereas, Asians, southern Europeans and the developing world use rather intuition and hunch instead of market research. Market research can be applied on several fields of interest such as assessing the competition, determining staff satisfaction or just to obtain a better understanding of a product, a technology or the daily business. Anyhow, it depends on the financial implications of the decision how exact data should be analyzed.[16]

[13] Cf. Winmark Corporation (2014), www.wbsonline.com, date of access [10.06.2014].
[14] Cf. Hague/Hague/Morgan (2004), pp. xi-xii.
[15] Cf. American Management Association (1941), pp. 16-17.
[16] Cf. Hague/Hague/Morgan (2004), pp. 2-4.

2.1.1 Market research in business models

The product-market matrix from Igor Ansoff describes four business situations depending on product and market (Fig. 2.2). Four combinations of product-market situations have different basic approaches for a market research. If the product and its market are new, a market research could target to find unmet needs and to gain the understanding for unfamiliar markets. Is the product new but the market exists already, the market research can focus on finding the likelihood of adoption of new products. The combination of an existing product on an existing market requires for example a market research which investigates how to maintain a competitive edge. For the case that the kind of product exists already but the markets are new, a market research may focus on finding new territories and niches for products or services.[17] Furthermore, this combination requires significant market research that focuses on customer needs, buying patterns ,competitors, logistics. It is essential to conduct the market research very precisely due to the fact that faulty results or analysis could result in disastrous consequences.[18]

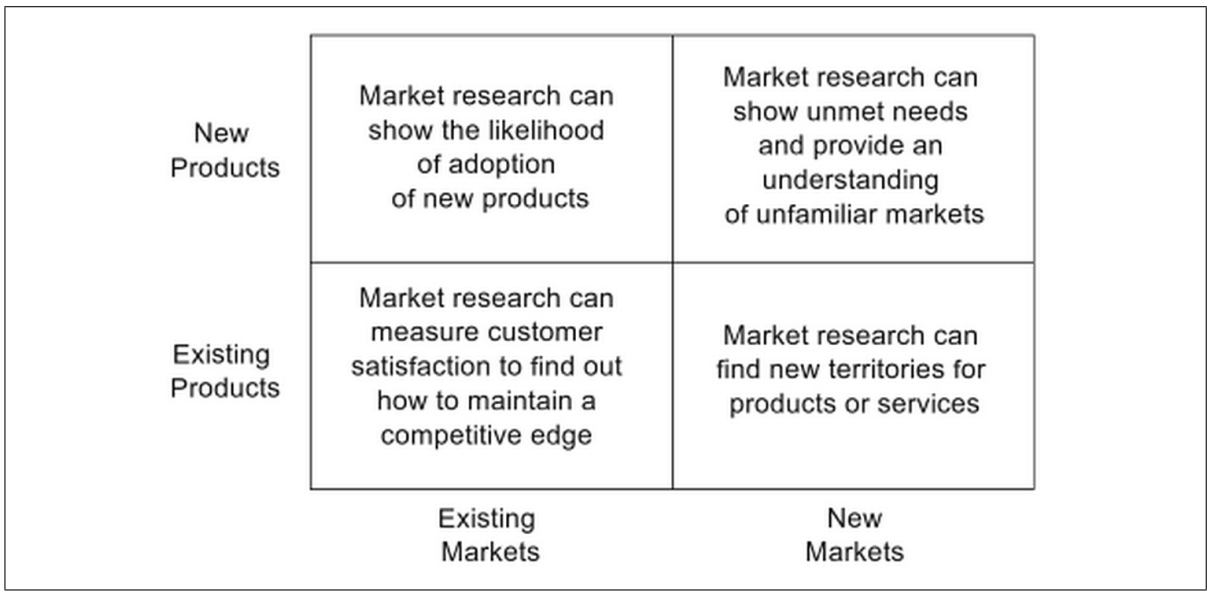

Figure 2.2: **Market research based on product-market situations according to Ansoff.**[19]

Theodore Levitt's life cycle (illustrated in Fig. 2.3) shows the demand of a product or service over the time. Market research plays a distinctive role at each of the stages (Youth, Maturity, Old Age). Therefore, in the Youth phase market research investigates the unmet needs for new products/services and supports to estimate the demand. Researched data is used to align specification and set prices. In the Maturity phase, results of a market research help to build a brand and competitive advantage. Market research for the last phase Old Age should basically include ways to

[17] Cf. Hague/Hague/Morgan (2004), p. 4.
[18] Cf. Syque Quality (2013), www.syque.com, date of access [13.06.2014].
[19] Hague/Hague/Morgan (2004), p. 4.

rejuvenating the product as well as finding new markets for it.[20] This thesis relates to the Youth phase of Levitt's lifecycle model.

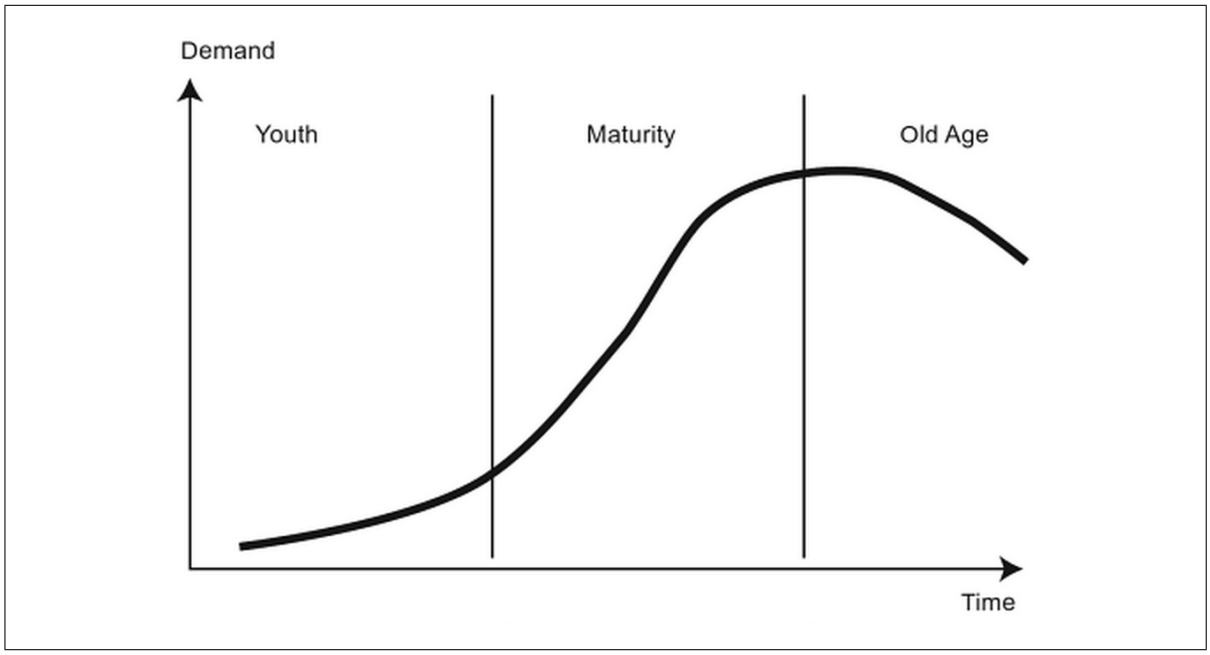

Figure 2.3: **Market research based on product-market situations according to Levitt.**[21]

In consumer markets, the market potential for a product is often a distinct proportion of a total population. Quantitative research is generally used to have a big number of samples, whereas qualitative research explores consumer perceptions and needs. The same techniques are used in business-to-business market research, however, differently due to a much smaller number of people to survey. Consumer as well as business-to-business markets are not often confined to single countries but rather to continents. Research always supports the decision making process and, therefore, it covers information about product specification, customer's requirements, pricing, distribution channels, forecasts, etc. For this reason, each of these require information from the market to reduce risk. Generally, market research can be used on several market-related facts, such as to assess the competition or to investigate the values of a brand, as long it pays off for the principal.[22]

2.1.2 Market research process

As shown in Fig. 2.4 a market research basically starts with a brief, which includes initial situation of the problem and what information is required in order to make a decision. It is important to define the problem carefully due to gain the probability of solving the problem.[23] If the researchers do not exactly understand what the outcome of the research should be, results will most probably turn out

[20] Cf. Hague/Hague/Morgan (2004), p. 5.
[21] Hague/Hague/Morgan (2004), p. 5.
[22] Cf. Hague/Hague/Morgan (2004), pp. 6-8.
[23] Cf. Hague/Hague/Morgan (2004), p. 13.

to be of little or no value. The responsible person who commissions the research has to be absolutely confident that the brief is clear and researchers will understand the problem.[24] Therefore, the goals have to be defined in order to derive strategies to fulfill the requirements. A research design or a proposal is a plan of how these goals should be reached. Hence, it covers the use of qualitative and quantitative methods as well as who and how (face-to-face, questionnaire, telephone interview, etc.) should be interviewed. Data collection by desk research, qualitative and/or quantitative research is the visible part of market research. After analyzing and interpreting the data, results and conclusions have to be presented in a meaningful way to support decision makers.[25] It is impossible to be absolute uninfluenced when interpreting the results. However, researcher must treat data as objective as possible due to the fact that misinterpreting would reduce the value of the results.[26]

Figure 2.4: **Market research procedure model (own illustration).**[27]

2.1.3 Primary research

Collecting new data that is non-existent or not available is called primary research. A primary research is mostly conducted if secondary data is not sufficient to make a decision. Gathered data via primary research is specified on concrete problems. The costs to conduct a primary research are much higher compared to a secondary research.[28] Primary research methods are surveys, focus

[24] Cf. McGivern (2009), p. 16.
[25] Cf. Hague/Hague/Morgan (2004), p. 13.
[26] Cf. McGivern (2009), p. 17.
[27] Cf. Hague/Hague/Morgan (2004), p. 12.
[28] Cf. Raab/Poost/Simone (2008), p. 26.

groups, observation or experiments. These surveys can be conducted by personal, telephone, postal or internet interviews etc. Another possibility is a focus group, which is a small meeting of customers. The meeting is led by a moderator and focuses on discussing the specific subject. Primary research can also be carried out by observation of specific procedures such as the customer's buying behavior. Furthermore, experiments can be used to test for instance new product in a regional market before it will be distributed in a wide range.[29]

2.1.4 Secondary research

A secondary research is focused on gathering existing data (secondary data) that can be processed into information for decision making. It is not always necessary to conduct an elaborate and time-consuming primary research. Hence, it is often the case that important data can be found within the company itself as well as through external sources such as books, reports, cost information, sales records etc. However, secondary research, also named desk research, is often not up-to-date, accuracy is questionable and it often does not apply to the specific problem.[30]

2.1.5 Quantitative and qualitative research

It has to be distinguished between quantitative and qualitative market research. Basically, quantitative research collects a large amount of data which will be statistically evaluated. Although a good market research includes both of these types, certain industries or marketing goals need only specific information and therefore require appropriate methods. Quantitative research is a logical approach that focuses on what people think based on a statistical and numerical point of view.[31]

Quantitative research focuses on measurement of market facts such as market size, purchase frequency, brand awareness, etc.[32] Answers to questionnaires and surveys with predefined questions and answers will be processed into a statistic. The survey can be conducted through post, online, telephone, etc. It has to be considered that the survey is fair and objective. Willingness to participate to this survey will often be gained by incentives like free products.[33]

A qualitative research does generally not rely on the quantity of data but on its quality. It focuses on how people feel and what choices they would make. It is basically based on interviews, which could be carried out face-to-face via telephone or video conference and so on. Furthermore, it is possible to do both or combine qualitative and quantitative research.[34]

[29] Cf. Young (2009), www.richardjyoung2.wordpress.com, date of access [12.06.2014].
[30] Cf. Wiid/Colin (2010), pp. 70-71.
[31] Cf. The British Library Board, www.bl.uk, date of access [10.06.2014].
[32] Cf. Hague/Hague/Morgan (2004), pp. 8-9.
[33] Cf. The British Library Board, www.bl.uk, date of access [10.06.2014].
[34] Ibid.

2.1.6 Market research data collection

Fig. 2.5 shows the different market research techniques, which have to be chosen carefully at the beginning of each project after defining the project's goals. If it is important to know about the buyer's general feel for a product, quantitative techniques can be useful. Laboratory tests are for example used to test different formulas for a new product by conducting a blind test. After the development and testing phase of a product, field tests are applied to test the product or a prototype in real conditions. Thus, objectives have to be considered before choosing an appropriate market research technique. Managers of smaller companies have to find compromises on market research techniques due to the fact that some are not affordable.[35]

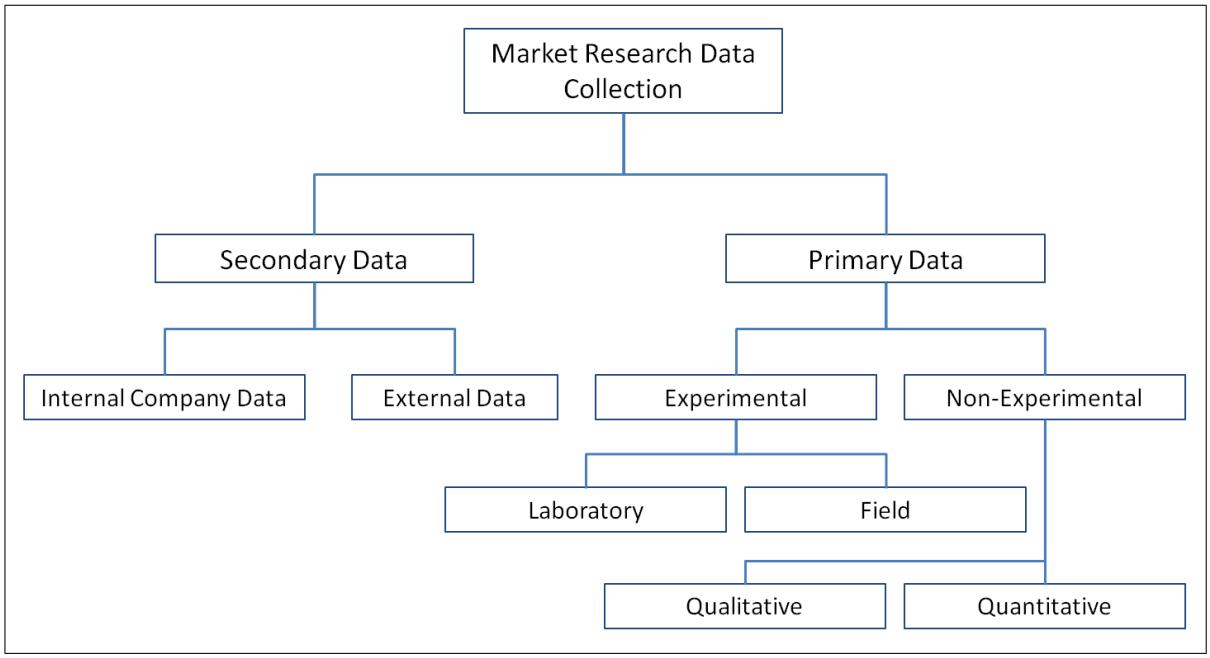

Figure 2.5: **Market research data collection possibilities (own illustration).**[36]

2.1.7 Budget

It is a big decision how much money should be spend on market research. Not investing in market research does not affect the present business situation. An approach is to spend a determined percentage of sales turnover into market research, which ensures there will be a budget allocated. This approach can also result in an in-house market research department. Another approach is to spend by need, whereas the budget will be determined on the basis of the specific situation. If it costs for example several million Euros to invest in developing and launching a new product, it is

[35] Cf. Winmark Corporation (2014), www.wbsonline.com, date of access [10.06.2014].
[36] Cf. Winmark Corporation (2014), www.wbsonline.com, date of access [10.06.2014].

absolutely worth spending a few thousand Euros on market research to minimize its risk and gain the success probability.[37]

2.1.8 Integration of market research

Global companies often have a strategic planning department, which is responsible for market research. Results of this department will mostly be reported directly to the top-management. Responsible persons are often not aware about the necessity to integrate market research into the broad corporate activities, which often let companies fail in this stage. Research staff must position themselves well in the organization to have access to any important information within the company. Therefore, connections to various departments in the company should be supported in order to generate desired results.[38]

2.2 Methods of data collection

It is inevitable to understand the problem really well before starting a primary research. For this reason, a SWOT analysis for the 48 V-technology is determined via desk research and ensures the understanding of the brief (chapter 2.2.1), which was required from AVL. A survey should clarify open questions that cannot be obtained by desk research.

Desk research

As mentioned in chapter 2.1.4, a secondary research, also named desk research, is a research method that costs virtually nothing due to the fact that secondary data can be collected without fieldwork. An expert desk researcher can find data from numerous sources to answer research goals. The reason that people spend a lot on primary research is that they do not know where to detect the required information. Another problem can arise where the information is not recognized as being useful. Therefore by putting in small amounts of effort to change this could obtain the information that is required. Besides external sources, it is worth to look into existing documents of the company that seeks data. Frequently, unconsidered old reports, market or sales statistics that are available in a company often include important answers. This is mostly because of devaluation of information that seems to be too simple to obtain.[39]

Data sources

[37] Cf. Cheverton (2005), pp. 62-63.
[38] Cf. Xi (2005), pp. 18-19.
[39] Cf. Hague/Hague/Morgan (2004), pp. 32-33.

Nowadays, there is a lot of information about competitors online, which can be very useful to extract. E.g. information about prices, products, unique selling points as well as how the companies do their marketing.[40] The problem of desk researching on the Internet is, to detect the important information from a huge amount of data. Therefore, a search strategy can help to find what the researcher is looking for. Sometimes, it can be enough to enclose a phrase with double quotations in search engines, which shows then only results of this exact string that the researcher typed in.[41]

Before the Internet existed, researchers received their information from the clippings services of libraries and agencies. Nowadays, newspapers are also available online, which makes this step much easier. Some websites of newspapers have an archive with all of their articles. Moreover, numerous magazines include complete articles about some companies or industries.[42] Additionally, there are databases of articles and reports on the Internet. Access to several data bases are mostly charged. Some websites offer material without the need to sign up, but readers have to buy the report before receiving it. Moreover, it is useful to go through government statistics such as Eurostat in Europe where researchers will find statistical data of businesses and social life. Directories provide details of companies such as profile, size, number of employees. One of the well known comprehensive general directories is Yellow Pages due to the fact that every company with a telephone number has already given some details. Some data is available online and for small fees researchers can order lists of companies' addresses and telephone numbers filtered by several factors.[43]

Limits

Although desk research can be very useful, it has its limits of receiving the right information. Therefore, gaps of a secondary research can be filled with the results of primary research. Desk research is unpredictable, at least for beginners or where the topic area is unfamiliar. For this reason, market research agencies do not offer secondary research due to the fact that different businesses and topics are difficult to evaluate. Thus, internal staff mostly conduct desk researches. Despite the fact that the Internet provides a huge ocean of data, it requires skill in searching as well as literal thinking to have a complete picture. Additionally, researchers should not forget to look in conventional libraries.[44]

[40] Cf. The Marketing Donut (2014), www.marketingdonut.com.uk, date of access [11.06.2014].
[41] Cf. Hague/Hague/Morgan (2004), pp. 35-36.
[42] Cf. Marchand (2007), www.entrepreneurship.org, date of access [11.06.2014].
[43] Cf. Hague/Hague/Morgan (2004), pp. 37-41.
[44] Cf. Hague/Hague/Morgan (2004), p. 46.

2.2.1 SWOT analysis

A SWOT analysis is a model to analyze an organization's strengths, weaknesses, opportunities and threats, whereas strategies can then be derived. Information from the company, competitors, market, environment, etc. can be gathered and put together to have a compact overview of a company.[45]

The SWOT analysis is a tool within the situation analysis to gather all relevant basics in order to facilitate the decision process for a company.[46] It is advisable to conduct a SWOT analysis in a group of four to six people, who have a good knowledge about the enterprise characteristics and its market situation.[47]

The framework of a SWOT analysis, illustrated in Fig. 2.6, forms a basic structure to identify a company's internal and external resources. Strengths and opportunities are helpful, whereby weaknesses and threats are harmful for a company.[48]

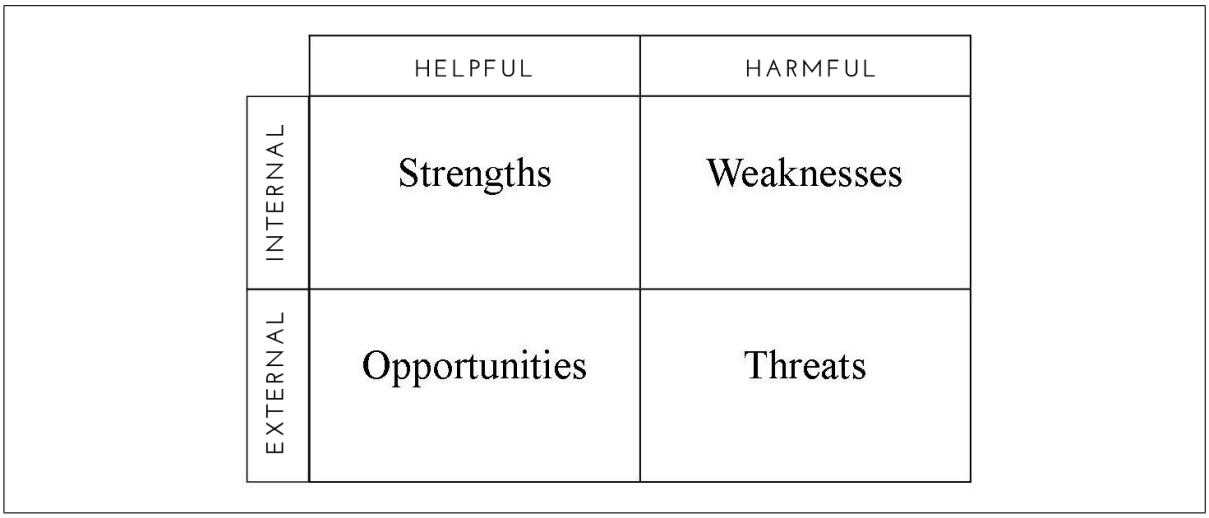

Figure 2.6: **SWOT analysis.**[49]

An advantage of a SWOT analysis is to identify and merge strengths, weaknesses, opportunities and threats. Additionally, it is an incentive to analyze the current situation and, consequently, to derive strategies and tactics. Moreover, new ideas are developed often, and the work with different people offers a great group experience. A disadvantage of the SWOT analysis is that it often results in long lists of facts. Moreover, it is less detailed and mostly ignores priorities. Furthermore, in later stages of the planning and implementation processes, often the results of the SWOT analysis are ignored by managers.[50]

[45] Cf. Böhm (2009), p. 2.
[46] Cf. Pahl/Richter (2009), p. 5.
[47] Cf. Wittmann/Leimbeck/Tomp (2006), pp. 34-35.
[48] Cf. Dabbs (2013), www.mattdabbs.com, date of access [28.04.2014].
[49] Dabbs (2013), www.mattdabbs.com, date of access [26.04.2014].
[50] Cf. Bertheau (2005), pp. 128-129.

It is important to be very accurately with meaningful statements when conducting a SWOT analysis. These statements should be prioritized and shortened to the most relevant factors. It is important to be realistic and consider even unpleasant truths. Moreover, it is advisable to use a SWOT analysis in conjunction with other strategy e.g. tools to receive a comprehensive picture and a broader view.[51]

A SWOT analysis can also be used for a product. Therefore, a company should consider the factors strengths, weaknesses, opportunities and threats before investing time and money in any development project. A SWOT analysis that is based on a product provides information of how a product will be held up on the market and also the product's ability to meet a new demand of consumers. It shows also the advantages and disadvantages of producing products of a distinct technology.[52]

The practical application of a SWOT analysis about the 48 V-technology is shown in chapter 4.4.

2.2.2 Self-administered questionnaires

The word 'questionnaire' has several meanings in the market research. It means either a questionnaire for self-completion or a questionnaire, which is administered by interviewers (face-to-face, telephone, etc.).[53] Research via questionnaires is the most often used method to do market research.[54]

The questionnaire is used to conduct a structured interview of a series of questions. The purpose of a questionnaire is to carry out a standardized interview. In most surveys it is beneficial to ask all respondents in the same way to ensure that the results are representative.[55] A self-administered questionnaire is the most inexpensive and fastest way to conduct a survey. Additionally a link or a file can easily be mailed to potential respondents in order to carry out a very consistent survey. A disadvantage for questionnaires that can be self completed is a very low response rate as well as no opportunity for clarification in real time.[56]

A low response rate, which may affect the validity of the research, is often the case in surveys. Therefore it is inevitable to prepare and construct the questionnaire well in order to minimize non-response.[57] Transmission form, rapport establishing, content, purpose, length and design of the questionnaire, reminders and other influencing factors have to be considered.[58]

Data sources

[51] Cf. Mind Tools Ltd (2014), www.mindtools.com, date of access [13.06.2014].
[52] Cf. McGriff (2014), www.ehow.com, date of access [07.05.2014].
[53] Cf. Brace, p. 95.
[54] Cf. Raab/Poost/Simone (2008), p. 47.
[55] Cf. Brace (2004), pp. 2-4.
[56] Cf. Queensland Government, www.health.qld.gov.au, date of access [13.06.2014], pp. 4-5.
[57] Cf. Gould (2011), www.library.bcu.ac.uk, date of access [27.12.2013].
[58] Cf. Leung (2001), www.cochrane.es, date of access [28.12.2013], p. 189.

First of all it has to be considered that companies or people get probably numerous questionnaires from students and other market researchers. Additionally, people are basically always short in time, which makes it very important to keep the questionnaire as short as possible. It is also crucial that the questionnaire is relevant to the potential respondents who are asked to complete the questionnaire because people give up very quickly if they are not able to answer the first few questions. A logical structure from one question to another is advisable. If it is possible to have some sort of personal contact in advance, a positive influence on the response rate is clearly evident. If respondents have forgotten to answer or were busy, one or two polite reminders by e-mail or phone are recommendable.[59] At the end of the questionnaire it is important for respondents to receive recognition and gratitude. Before sending out questionnaires they must be pretested on a small sample of people due to the fact that it is almost impossible to get it right the first time round. Answers and comments should be carefully analyzed to improve the questionnaire before the actual survey begins.[60]

Introduction

A crucial factor for cooperation of respondents is the introduction to a survey.[61] It is very important that the text of the introduction section clearly indicates all the facts which the respondents need to know. The introduction should always include following facts:[62]

- The purpose/reason of the questionnaire
- The usefulness for the respondents (incentives)
- Contact details
- Length of the questionnaire
- Latest date for completing the questionnaire

The time to complete a questionnaire is easy to estimate if there is no routeing and just a simple flow path. It can vary significantly due to different speed or the time for consideration of the respondents. However, it should not differ too much from the given time. If the length for filling out a questionnaire is not given in the introduction or is not clear, respondents do not know when it will finish. In addition, respondents become annoyed if they have assumed a shorter time to complete a questionnaire. By noticing that the time difference of respondents vary considerably, the

[59] Cf. Gould (2011), www.library.bcu.ac.uk, date of access [29.12.2013].
[60] Cf. Leung (2001), www.cochrane.es, date of access [28.12.2013], p. 189.
[61] Cf. Brace (2004), p. 173.
[62] Cf. Gould (2011), www.library.bcu.ac.uk, date of access [27.12.2013].

writer should try to mention it in the introduction.[63] Respondents should be treated honestly and respectfully to increase willingness of participating in surveys.[64]

Incentives

It is important to offer people, who give their answers to the survey, some kind of incentive. If they get something in return, it distinctly motivates them to participate. If it is obvious that respondents are interested in the results as well, an offer to share the results afterwards with them makes it more attractive to fill out the questions. Therefore, it is important to make this clear in the introduction that people have a benefit by answering the questions.[65]

There are some other possibilities to make a questionnaire more attractive to potential respondents. The printing quality for a questionnaire on a paper should be high and the used paper should be a bit thicker than standard paper. An appropriate use of different colors, for example to separate instructions from questions, can also increase attractiveness of paper based as well as online questionnaires whereas colored paper should be avoided in general.[66]

Types of questions

No interviewer is needed for paper based or electronic questionnaires for self-completion. Respondents are not influenced by the researcher, however, self-completion studies often suffer from a low response rate. Self-completion questionnaires have the advantage that respondents have enough time to consider their answers accurately. However, this my not always be desirable, if the interviewer wants to get the respondents first reaction. A disadvantage of self-completion questionnaires is that respondents mix up the question sequence sometimes which was considered by the questionnaire writer. Self-completion questionnaires do not have to be sent by e-mail to additional effort such as downloading the attachment, saving, sending back is required. Another possibility is to offer access via a website. Therefore, most practitioners use online questionnaires that can be filled out quickly on a website. Thus, online questionnaires allow complex routing, can align questions and responses, and do not need time-consuming data entry compared to paper-based questionnaires.[67]

Open-ended questions should generally be omitted in questionnaires due to the fact that it needs much more time than yes-no questions or rating scales. If it is not avoidable to ask an open-end question, it is at least important that this is not in the first few questions in order to avoid loosing respondent's interest. The space for the answer should not be too big like half a page long because

[63] Cf. Brace (2004), pp. 176-177.
[64] Cf. Brace (2004), p. 173.
[65] Cf. Gould (2011), www.library.bcu.ac.uk, date of access [27.12.2013].
[66] Cf. Brace (2004), p. 154.
[67] Cf. Brace (2004), pp. 36-39.

it would likely scare respondents away. Rating scales are easy to answer if there are not too many choices, which means about five at the maximum.[68]

Wording

The questionnaire writer is responsible that the respondents easily understand the questions. The questionnaire should support respondents that they give their best opinion that they can. If respondents do not understand the questions well, intimidation or threat could be reasons to become uninterested and alienated of it. Furthermore, researcher could understand some terms differently that respondents. It has to be ensured that no ambiguity is in the questions, which would lead to different and mostly useless answers. If respondents are for instance asked if their parents work full time and the given answers are yes or no, it will be impossible to give the right answer for people with only one parent working full time. For this reason, it is essential to detect ambiguity before surveying respondents.[69] Thus, questions shouldn't be too complicated, abstract or too long. It is important to avoid abbreviations or words, which probably are not known by some respondents, because they are differently qualified to understand specific questions. Hence, neutral vocabulary and grammar should be used.[70]

If a long series of questions with rating scales from positive to negative e.g. from interesting to dull are in a questionnaire, it is advisable to change the answers from negative to positive - for example, useless to useful. This might lead to a more careful consideration and avoids going through quickly with the tendency to choose the same answer several times.[71] Mistakes in grammar or spelling makes the questionnaire look unprofessional and gives the impression of low importance. Therefore, it is advisable to check it several times and let someone else check it too.[72]

Errors

Several steps in conducting data collection through a questionnaire can be done wrong. Basically, there are two types of error, which are called sampling error and non-sampling error. The smaller the number of respondents the higher the sampling error. Quadrupling the sample size leads to a reduction of the error by half. However, surveying a higher number of people increases costs. Mistakes that are made by the creation of the questionnaire, data entry processing or by the interviewer result in the so-called non-sampling errors. In contrast to the sampling error, non-sampling errors

[68] Cf. Gould (2011), www.library.bcu.ac.uk, date of access [27.12.2013].
[69] Cf. Brace (2004), pp. 113-119.
[70] Cf. Gould (2011), www.library.bcu.ac.uk, date of access [28.12.2013].
[71] Cf. Leung (2001), www.cochrane.es, date of access [28.12.2013], p. 189.
[72] Cf. Gould (2011), www.library.bcu.ac.uk, date of access [27.12.2013].

can be reduced without any additional expenses if the writer knows how to write an appropriate questionnaire.[73]

Pilot questionnaire

It is essential to check the questionnaire on mistakes, possible answers and usability due to the fact that even the most experienced researchers make mistakes sometimes. Additionally it is recommendable to carry out a pilot test before the real survey starts. Piloting should be an integral part of carrying out a survey to refine the questionnaire and avoid unnecessary mistakes. Mostly, people do not plan a time frame to conduct a pilot test for the survey, which leads often to bad results and feedback. At least a so-called informal pilot test, where colleagues of the researcher try out the questionnaire, should be done. It has to be considered that colleagues are often familiar with the subject or even with the questionnaire. Furthermore it is advisable to extent the pilot test to a larger number of respondents to make sure it delivers useful data. If at this point in time, an unusually high number of respondents answered "Don't know", the question should be reconsidered.[74] Basically, anything such as wording, lay-out, instructions, questions should be piloted due to the fact that almost anything can go wrong.[75]

Analysis and interpretation

It is necessary to spend a significant amount of time on evaluating and analyzing the gathered data from answers of questionnaires. It is advisable to think about how to analyze responses of the questionnaire before conducting the survey. Received data could be useless if it cannot be analyzed or meaningful evaluated.

Closed-ended questions can rather easily assessed due to the percentage of the different response's probability. Results from open-ended question are often complicated to evaluate but those should be slightly generalized by the response frequency. Therefore, it is not possible to determine an exact percentage of what respondents answered but a trend or the majority's inclination can be detected.[76]

[73] Cf. Brace (2004), p. 1.
[74] Cf. Brace (2004), pp. 163-183.
[75] Cf. Oppenheim (1992), pp. 48-49.
[76] Cf. Queensland Government, www.health.qld.gov.au, date of access [13.06.2014], p. 20.

3 HYBRID TECHNOLOGY

The strategy of increasing electrification while retaining the conventional combustion engine is currently followed by several manufacturers. This so called "hybrids" range from "micro hybrids"to "full hybrids", in which a combustion engine and an electric motor are interconnected to extract advantages from both. Moreover, full hybrids can even fully power the vehicle only by its electric motor, although only for short distances due to a limited battery capacity. An increasing electrification of conventional vehicles leads to less direct emissions and reduces the noise level. Thus, there are environmental advantages over conventional vehicles, which are one main source of the air (particulate matter, nitrogen dioxide) and noise pollution. Plug-in hybrids make it possible to use external energy sources which have not played a major role in transport at all. Renewable energy sources such as photovoltaics, hydro power as well as wind power allow a reduction of traffic related CO_2.[77]

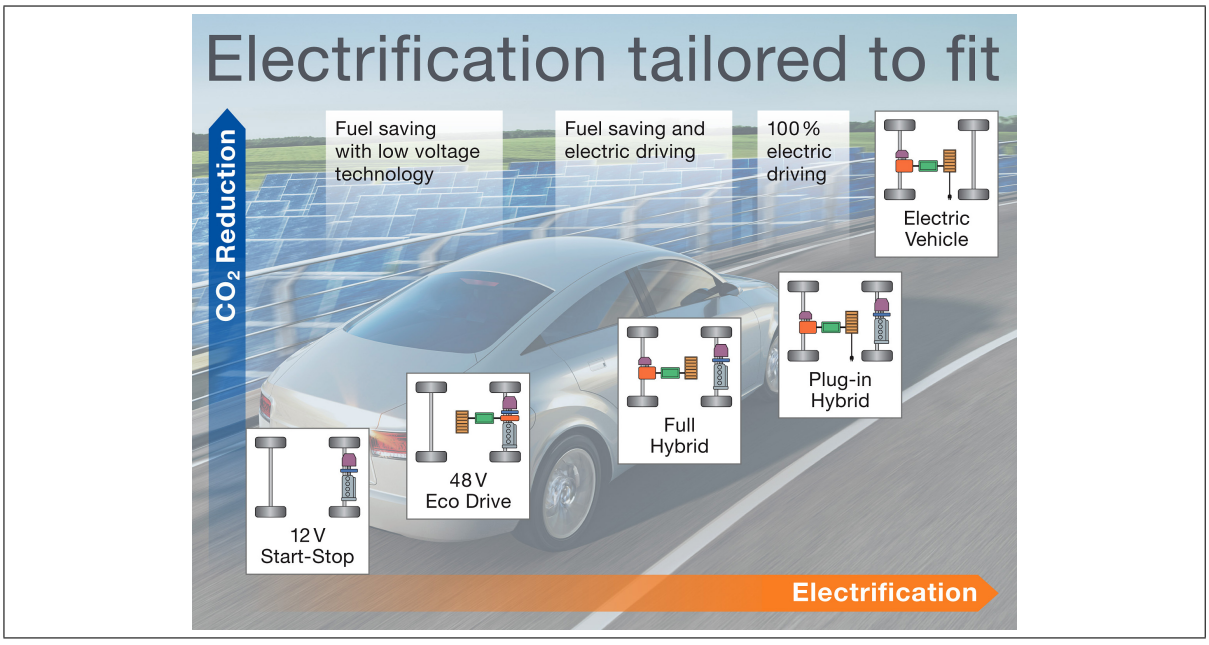

Figure 3.1: **Way of CO_2 reduction by electrification.**[78]

Moreover, it is inevitable to focus on close tailoring to end user requirements and attractive pricing during increasing electrification. This is why a lot of firms see new 48 V systems as a remarkable advance. Fig. 3.1 shows the way how to reduce CO_2 by increasing electrification. It starts from the established 12 V-technology with start-stop systems to the low-cost 48 V hybridization. A further

[77] Cf. Lambrecht/Helms/Pehnt (2013), www.ifeu.de, date of access [15.10.2013].
[78] Continental AG (2013), www.continental-corporation.com, date of access [15.10.2013].

increase of electrification would lead to full hybrid vehicles, plug-in hybrid vehicles and finally to electric vehicles.[79]

Alternatively fueled vehicles like electric vehicles or fuel cell vehicles produce zero carbon dioxide emissions, less noise and have a better security of supply of fuels. Although alternately fueled vehicles have their advantages, there are still hurdles like costs, range, refuelling time and the missing refueling infrastructure to overcome.[80]

3.1 Types of powertrains

Hybrid electric vehicles (HEVs) amalgamate conventional internal combustion engines with electric motors. A decided advantage is the improved fuel efficiency over cars which are operated by combustion engines only. Hybrid cars can be recharged from regenerative braking, electric motors and/or petrol engines, which avoids plugging in the vehicle as contrasted with electric vehicles (EVs). Hybrid models can be classified by their drivetrains (series, parallel and series-parallel) which offer various advantages and disadvantages.[81]

3.1.1 Series hybrid

A series drivetrain means that only the electric motor provides power to turn the wheels. Therefore, the electric motor receives electric power from either the battery or from a generator which is driven by a combustion engine.[82] This means a series hybrid has no mechanical connection between the combustion engine and the electric motor.[83] The battery is charged by the engine/generator and also by regenerative braking.[84] Regenerative braking, a technology that allows to absorb kinetic energy from braking actions is used to recharge the battery.[85] Fig. 3.2 shows the components and flow of the mechanic and electric power to understand the system.[86]

The electronics draw power from the battery pack to drive the electric motor while driving at slow speeds. In the acceleration phase, the combustion engine drives the generator to add power to the battery pack. In a series drivetrain the combustion engine tends to be smaller due to the fact that it only has to fulfill medium driving power requirements, whereas the battery pack is generally larger

[79] Cf. Continental AG (2013), www.continental-corporation.com, date of access [15.10.2013].
[80] Cf. Society of Motor Manufacturers and Traders (2013), www.smmt.co.uk, date of access [13.01.2013].
[81] Cf. Randall (2013), homeguides.sfgate.com, date of access [01.10.2013].
[82] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].
[83] Cf. Murphy (2011), p. 7.
[84] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].
[85] Cf. Randall (2013), homeguides.sfgate.com, date of access [01.10.2013].
[86] Cf. Rebergue (2009), europe.epid.fr, date of access [01.10.2013].

and more powerful than the one in parallel hybrids. Thus, costs are accordingly higher for series hybrids.[87]

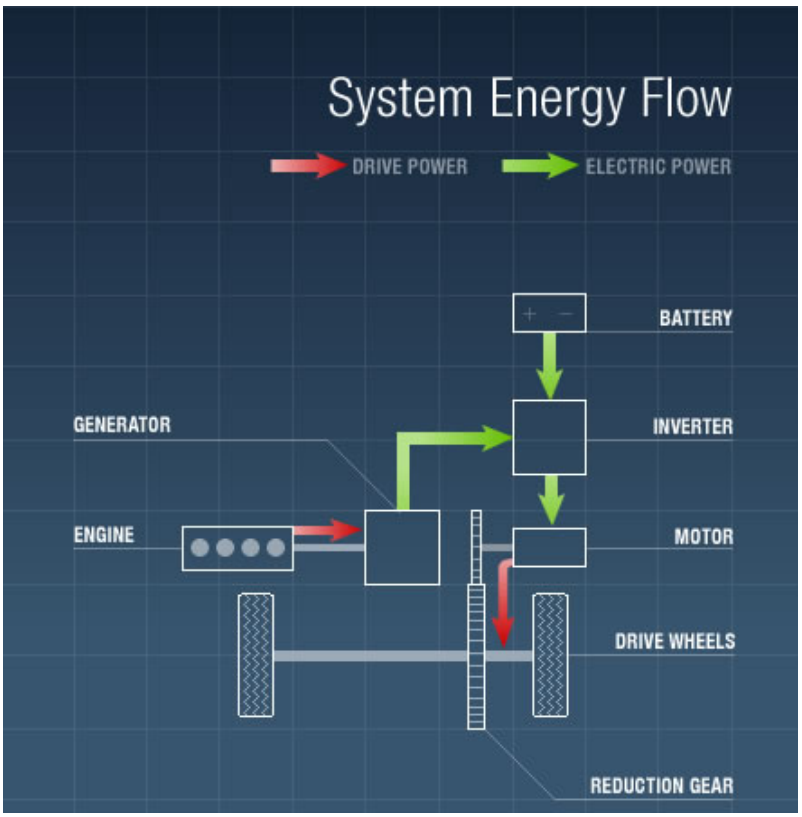

Figure 3.2: **Basic design of a series hybrid.**[88]

The combustion engine must operate all time to run the generator if the system doesn't include a battery.[89] Series hybrids perform at their best in varying power demands of stop-and-go driving, because the combustion engine is not coupled to the wheels.[90] This means the drivetrain reaches its highest efficiency under urban and suburban conditions.[91]

The series hybrid design is perfect for a plug-in hybrid (see also 3.2.4) which includes a battery which has enough capacity to drive a remarkable electric-only range and that can be recharged from external sources.[92]

[87] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].
[88] Rebergue (2009), europe.epid.fr, date of access [01.10.2013].
[89] Cf. Murphy (2011), p. 7.
[90] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].
[91] Cf. Randall (2013), homeguides.sfgate.com, date of access [01.10.2013].
[92] Cf. Murphy (2011), p. 7.

3.1.2 Parallel hybrid

The combustion engine and the electric motor of a parallel HEV which are directly coupled to the wheels, eliminate the inefficient converting process from mechanical power into electricity. Therefore, parallel hybrids are efficient on highways and less efficient in stop-and-go driving compared to the series hybrid.[93]

To coordinate the engine and motor working together a control device is needed. This computer can actuate it either independently or simultaneously depending on the power demands.[94]

Due to the power flow in this system, it is named a parallel hybrid system as illustrated in Fig. 3.3.[95] During acceleration, the combustion engine transmits power to the wheels and is supplemented by the electric motor when necessary. While the vehicle is cruising at a steady speed, the wheels are powered by the combustion engine which charges the battery with its additional power. In the braking phase, the energy of the braking wheels is used to recharge the battery pack by the electric motor which acts as a generator.[96]

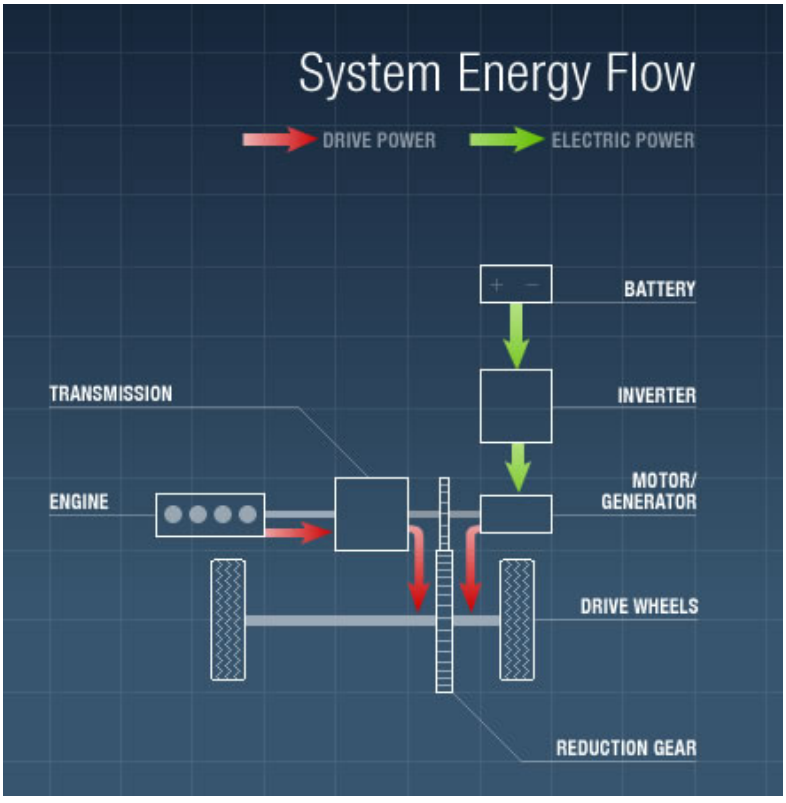

Figure 3.3: **Basic design of a parallel hybrid.**[97]

[93] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].
[94] Cf. Randall (2013), homeguides.sfgate.com, date of access [01.10.2013].
[95] Cf. Rebergue (2009), europe.epid.fr, date of access [01.10.2013].
[96] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].
[97] Rebergue (2009), europe.epid.fr, date of access [01.10.2013].

A large battery pack is needed for driving electric-only or assisted propulsion, and also to operate ancillary systems such as brake boosters, air conditioning and power steering when the combustion engine is turned off.[98]

3.1.3 Series-parallel hybrid

The series-parallel hybrid drivetrain, which became known through the Toyota Prius, combines the two structures of the series and the parallel drivetrain.[99] The series-parallel HEV contains the features of both series and parallel HEVs and can operate in those modes separately. Therefore, fuel efficiency and drivability can be improved, however, it depends on the vehicle's operating mode.[100]

Fig. 3.4 shows the energy flows in a series-parallel hybrid system. It operates basically as a series HEV at lower speeds, while at fast driving, the combustion engine takes over and energy loss is low and optimized. The series-parallel system is generally more expensive than pure series or parallel hybrids because it needs a generator, a larger battery pack and a more complicated computing system to control the dual system.[101]

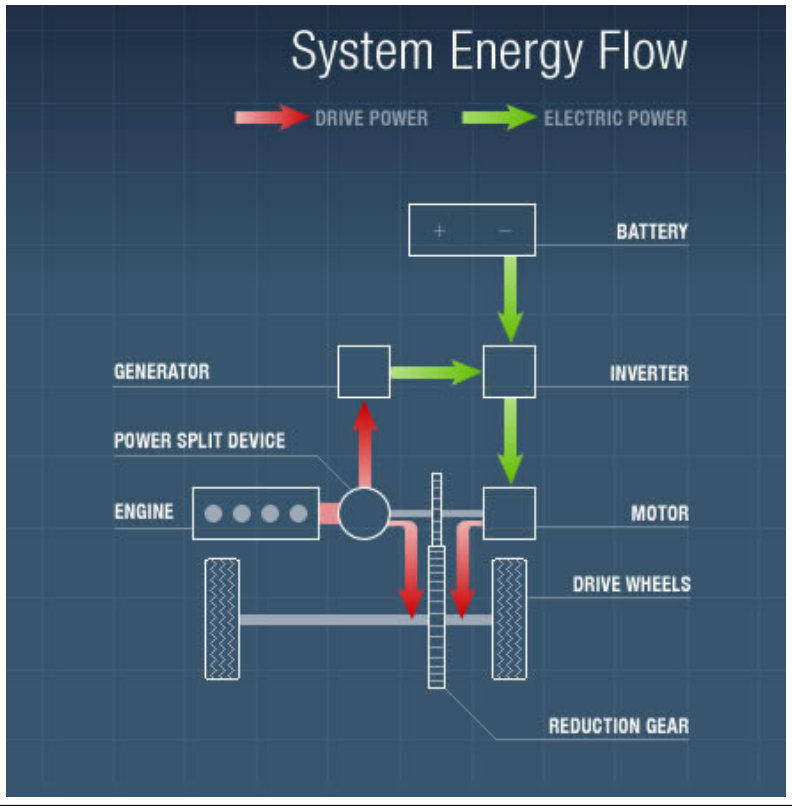

Figure 3.4: **Basic design of a series-parallel hybrid.**[102]

[98] Cf. Murphy (2011), p. 7.
[99] Cf. Boschert (2006), p. 31.
[100] Cf. Mi/Masrur/Gao (2011), pp. 14-15.
[101] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].
[102] Rebergue (2009), europe.epid.fr, date of access [01.10.2013].

The Toyota Hybrid System is a series-parallel input-split hybrid in which the power from the combustion engine and the electric motor is split via a planetary gear set which allows both, or that either drive the road wheels. Therefore, the size of the combustion engine can be reduced and provides a kind of continuously-variable transmission.[103]

A planetary gear set is composed of a sun gear, a ring gear and several planet or pinion gears. As shown in Fig. 3.5, all gears are mounted together in the same plane. The sun gear is the innermost gear which has its teeth on its outer surface and the ring gear, concentric with the sun gear, has its teeth on its inner surface and is the outmost gear of the planetary gear set. The planet gears are spaced evenly around the outer surface of the sun gear and the inner surface of the ring gear. All of the three gear types have their own shaft or carrier on which they can rotate.[104]

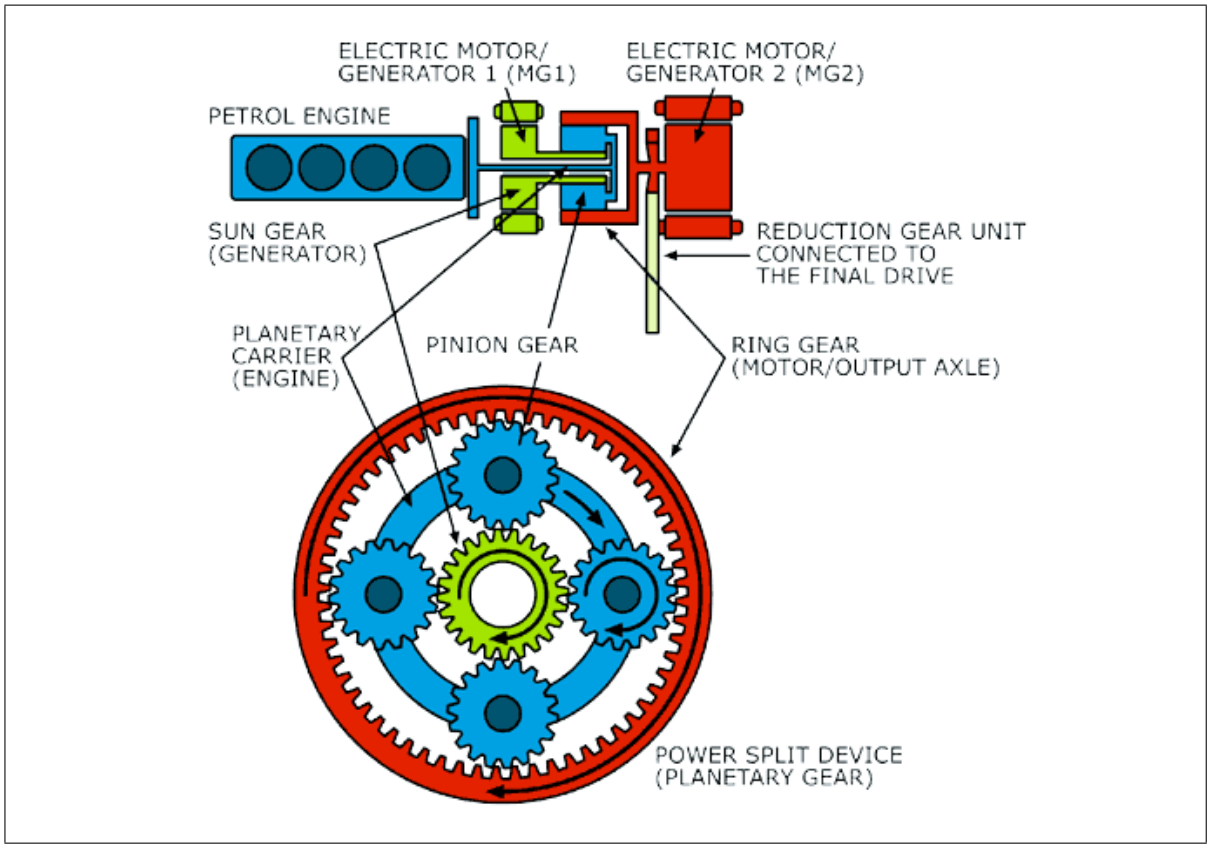

Figure 3.5: **Power-split transmission.**[105]

This assembly of gears can change the direction as well as the rotational speed and can multiply the torque of two drive systems.[106] The torque it can handle is relatively large as compared with the size of the planetary gear set due to the fact that the load is spread through numerous gear teeth. Moreover, no synchronizer mechanism is necessary when a gear change is needed due to

[103] Cf. Murphy (2011), p. 7.
[104] Cf. Erjavec (2004), p. 41.
[105] Sadeghi/Rezaii (2011), liu.diva-portal.org, date of access [08.10.2013], p. 17.
[106] Cf. Hunter (2007), p. 173.

the constant mesh of gears.[107]The series-parallel HEV is a popular solution due to a high degree of freedom in control.[108]

3.2 Types of hybridization

There are several types of hybrid vehicles with two power sources, whereas the combinations petrol and electric motor or diesel and electric motor will be the most important combinations for the following years. The the three main types are called micro, mild and full hybrid.[109]

3.2.1 Micro hybrid

Micro hybrids are not strictly hybrids due to the fact that electricity from the battery is not used to drive the car. The included start-stop system does enable a slight reduction in fuel consumption and CO_2 emissions. When the car stops, the combustion engine switches off, for instance at traffic lights, and re-starts only when acceleration is required by the driver. Then the engine is promptly re-started by the alternator, which draws power from the car's battery pack. Recouped energy during braking is received by the battery in turn.[110] However, all hybrid systems feature regenerative braking to recover kinetic energy.[111]

3.2.2 Mild hybrid

Mild hybrid vehicles can be split into two types which are parallel hybrids (chapter 3.1.2) and series hybrids (chapter 3.1.1). The same start-stop system as a micro hybrid as well as the electric motor to support the combustion engine during the acceleration phase are used for a parallel mild hybrid. However, the car usually cannot be propelled by the electric motor alone. The motor is powered by a battery which is charged either by recuperating braking energy or by the engine when it over-performs marginally at cruising speed. A series mild hybrid powers the car by an electric motor. The battery for the motor is charged by a combustion engine or during braking phases.[112] The costs for mild hybrid vehicles are rather inexpensive. However, less substantial fuel economy benefits are provided compared to full hybrid vehicles.[113]

[107] Cf. Hunter (2007), p. 173.
[108] Cf. Mi/Masrur/Gao (2011), p. 15.
[109] Cf. Lexus - Toyota Motor Corporation (2013), www.lexus.eu, date of access [09.10.2013].
[110] Ibid.
[111] Cf. Murphy (2011), p. 7.
[112] Cf. Lexus - Toyota Motor Corporation (2013), www.lexus.eu, date of access [15.10.2013].
[113] Cf. U.S. Department of Energy (2013b), www.afdc.energy.gov, date of access [10.05.2014].

3.2.3 Full hybrid

Fully hybrid vehicles are better in fuel consumption but have higher costs than mild hybrid vehicles.[114] Full hybrids can be propelled by the electric motor and/or the combustion engine and are characterized by their enhanced battery capacity. Thus the car can be driven on electric power alone. The electric motor(s) enables to recuperate kinetic energy during braking phases by acting as a generator. The internal combustion engine is only switched on when extra power is required or to recharge the battery pack. Otherwise the vehicle uses the electric motor only. At lower speeds, the combustion engine produces low levels of torque, whereas the power increases at higher speeds.[115]

3.2.4 Plug-In

Fig. 3.6 illustrates a comparison of components of hybrid electric vehicles, plug-in-hybrid-electric vehicles (PHEVs) and battery-electric vehicles (BEVs). PHEVs and BEVs use in general a larger motor, a greater amount of batteries and a smaller or no ICE than HEVs.[116]

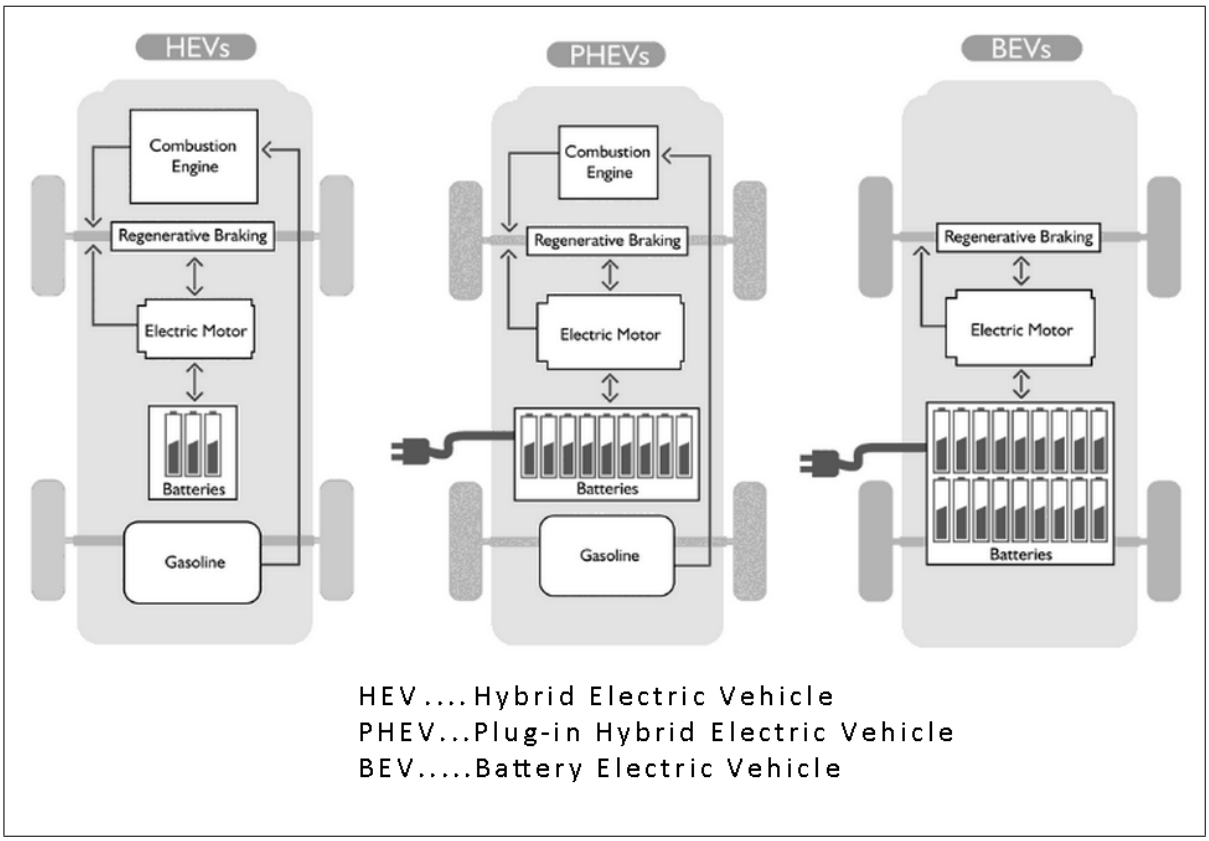

Figure 3.6: **Main components of hybrid, plug-in hybrid and battery electric vehiceles.**[117]

[114] Cf. U.S. Department of Energy (2013b), www.afdc.energy.gov, date of access [10.05.2014].
[115] Cf. Lexus - Toyota Motor Corporation (2013), www.lexus.eu, date of access [15.10.2013].
[116] Cf. Boschert (2006), p. 30.
[117] Boschert (2006), p. 30.

The basic idea of plug-in hybrid vehicles is to plug-in the car to an electric outlet and receive electric power from external sources. If the battery is too low, an ICE takes over fuel consumption begins. Due to the fact that plug-in hybrids provide both technologies in a large format, weight, space and the high costs are still crucial problems.[118]

3.2.5 Battery electric vehicle

A battery or a series of batteries in an electric vehicle provides energy to power the car. It is an environmental friendly alternative to ICE propelled vehicles. Electric vehicles have in general a faster acceleration but can drive shorter distances than vehicles with internal combustion engines. The charging time is very long compared to filling up the conventional vehicle's fuel tank. However, no exhaust will be emitted.[119]

Components of an electric vehicle (EV) are different, whereas electric motor, electronic control module, a traction battery, a battery charger and management system, a regenerative braking system are the major ones. An EV is propelled by a traction motor which is controlled by an electronic control module. Advances in high-power electronics let AC (alternating current) motors take up the commonly used DC (direct current) motors for variable-speed applications and are therefore now more widely used. DC motors are in general easier to handle and less expensive but mostly often heavier and larger than AC motors. The electronic control module regulates the amount of current and voltage which is received by an electric motor. Operating voltages can for instance be 360 V or even higher.[120] Driving conditions such as extreme temperatures and habits like high driving speeds, which increase the required energy to overcome drag have a negative influence on the driving range of EVs.[121]

3.3 Summary of hybridization

New designs such as series and parallel are becoming increasingly offered on the market.[122] The power from the electric motor and the ICE can be combined in different ways such as serial, parallel or serial-parallel hybrid. Parallel hybrid is the most common design for hybrid electric vehicles which connects the engine and the e-motor mechanically to the wheels. Series hybrids are sometimes found in PHEVs which use only the electric motor to propel the car.[123] Improving mileage and reduced harmful emissions are the main purposes of acquiring a hybrid car. Several hybrid models offer dual

[118] Cf. ZEIT Online (2013), www.alternative-energy-news.info, date of access [13.12.2013].
[119] Cf. Electric Cars (2014), www.alternative-energy-news.info, date of access [10.05.2014].
[120] Cf. Dhameja (2001), pp. 2-3.
[121] Cf. U.S. Department of Energy (2013a), www.afdc.energy.gov, date of access [12.05.2014].
[122] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].
[123] Cf. U.S. Department of Energy (2013b), www.afdc.energy.gov, date of access [10.05.2014].

drivetrains by merging advantages of series and parallel designs which operate as series hybrids at low-speed and as parallel hybrids under high-speed conditions.[124] A series-parallel hybrid operates as a series at lower speeds and for fast driving, as a parallel hybrid. This leads to higher costs due to larger battery packs, complicated computing system etc.[125]

[124] Cf. Randall (2013), homeguides.sfgate.com, date of access [01.10.2013].
[125] Cf. Hybridcenter.org, www.hybridcenter.org, date of access [01.10.2013].

4 48 V ON-BOARD SUPPLY

The introduction of a second voltage level at 42 V as an additional on-board supply besides 12 V in passenger cars was a big discussion in the nineties. Due to the fact that engineers developed intelligent power controls, installed buffers and limited power consumption, the 42 V on-board power supply did not succeed. The needs are already higher than the current on-board power of around 5 kW. Start-stop systems with 12 V are already at its limits, which is just the beginning of further electrification of cars. Therefore, on-board power supplies in power ranges of 10 to 15 kW are needed. To fulfill that with the conventional 12 V supply, some 1000 A of current and cables with diameters of 10 to 15 mm would be necessary. As a result, it would not only be costly, heavier but also difficult to manufacture and install. Furthermore, a high current would cause heavy losses considering that power is the product current in the square times resistance ($P = I^2 \cdot R$).[126]

New comfort and driving assistance systems, especially start-stop-systems for small cars and electric steering systems for luxury vehicles, require additional energy for vehicles in the future. Moreover, politics make demands on carbon footprints. For this reason particular requirements are imposed. Today's 12 V on board supply reaches its limits due to the fact that this power supply provides only 3 kW at the maximum, whereas luxury cars need already up to 14 kW, which could be solved by a new on-board power supply. The 48 V on-board power supply can provide a connected load of up to 12 kW.[127]

4.1 The voltage level

The 48 V on-board power supply for passenger vehicles is to improve the CO_2 emission reduction and to meet a higher energy demand for new high power loads. A higher level of electrification also involves a risk. A power interruption could lead to dire consequences, which makes a reliable power supply for power steering, Electronic Stability Control (ESC) or other driving assistance systems inevitable.[128]

The easiest way to increase the electrical capacity is to raise the amperage, which requires thicker cables and generates more heat. The other possibility is to increase the level of voltage, which must be sufficient to support future electrical components. Moreover, it is important to keep costs low, why it is appropriate to integrate a sub-60 V system.[129] Therefore, the highest nominal voltage

[126] Cf. Langheim (2012), www.cesa-automotive-electronics.blogspot.co.at, date of access [05.11.2013].
[127] Cf. Handelsblatt GmbH (2012a), www.handelsblatt.com, date of access [06.08.2013].
[128] Cf. Gall et al. (2013), p. 459.
[129] Cf. Timmann/Renz/Vollrath (2013), pp. 45-46.

below the shock protection limit of 60 V is presumably 48 V.[130] The voltage level of 48 V represents a good compromise for an on-board power supply as can be seen in Fig. 4.1).[131]

The usual operation voltage area without any functional restrictions is between 36 V and 52 V, while under and upper voltage areas most likely have functional restrictions. 60 V must not be reached or exceeded due to the fact that the vehicle does not have a shock protection. Therefore, a safety margin from 54 V to 60 V was determined. Due to the fact that there is no protection needed, the 48 V system can basically be treated as a 12V system. However, there are some effects at higher voltages such as 48 V which might require additional protections. Arcing is such a critical effect, which sets surrounding materials to fire because of the high temperatures of the plasma of approximately 6000 °C. For this reason, failure modes such as a short circuit, the loss of common ground, a short circuit between the two voltage levels or broken wires have to be considered carefully.[132]

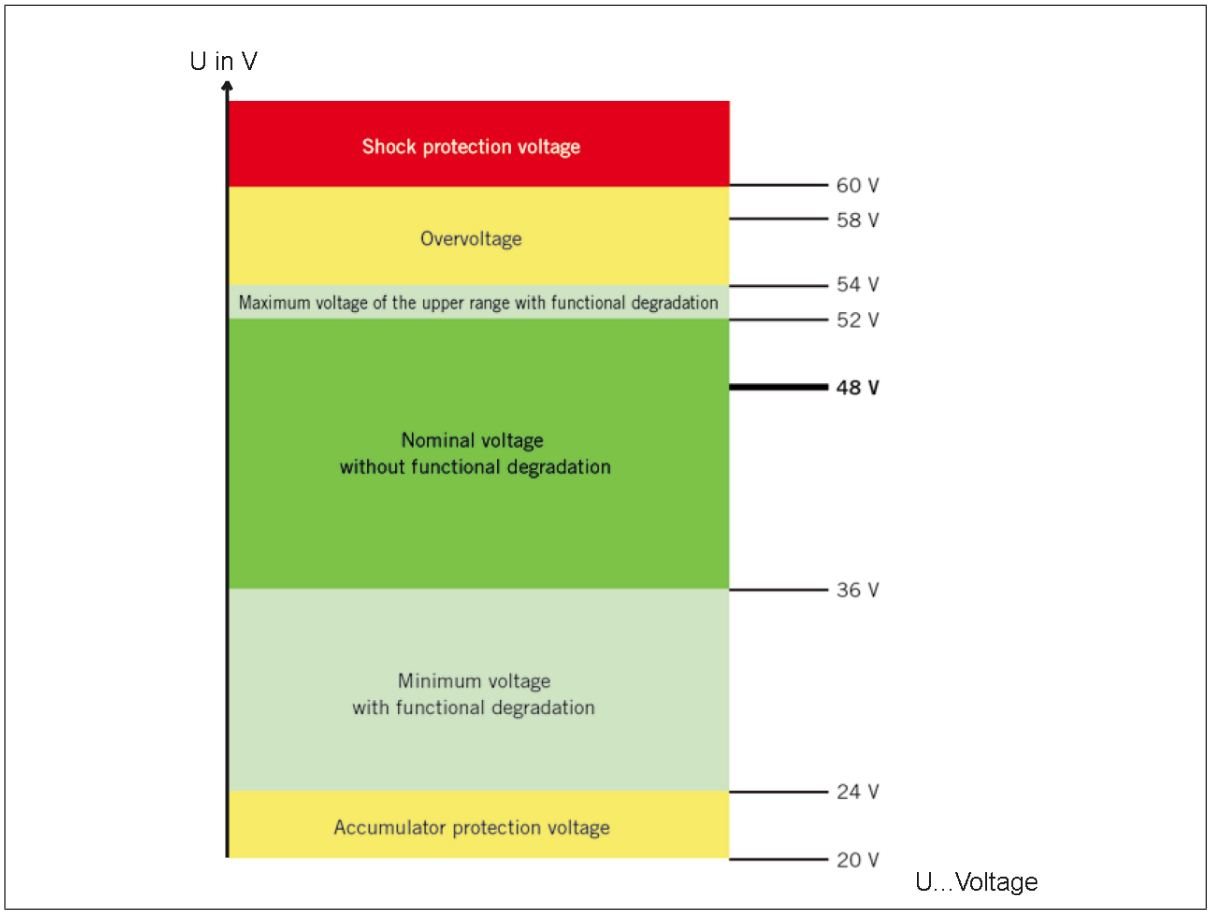

Figure 4.1: **Definition of voltage ranges.**[133]

[130] Cf. Dörsam et al. (2012), p. 11.
[131] Cf. Timmann/Renz/Vollrath (2013), pp. 45-46.
[132] Cf. Kuypers (2014), delphi.com, date of access [26.04.2014], pp. 2-3.
[133] Dörsam et al. (2012), p. 12.

4.2 The system topology

A dual voltage battery system for micro hybrids usually consists of a 12 V lead-acid starter battery and a 48 V lithium-ion battery. The 12 V battery continues to supply the vehicle starter with power whereas the 48 V battery capture energy quickly from regenerative braking systems and provides energy to higher loads such as active chassis technologies and air-conditioning.[134] Falling prices of power electronics have reduced barriers to install multiple voltage systems, which offers to increase the vehicle's efficiency without full hybrid or plug-in electric configuration.[135]

Figure 4.2 shows a schematic for an on-board supply with two different voltage levels (14 V and 48 V) connected over a DC/DC-converter. The converter can handle errors like losing the connection to earth on the 48 V-side without having overvoltage on the 14 V-side. However, a disconnection of the earth could be a problem for the communication network when the higher voltage is applied to the data transmission line. This may destroy components and could lead to fatal consequences.[136]

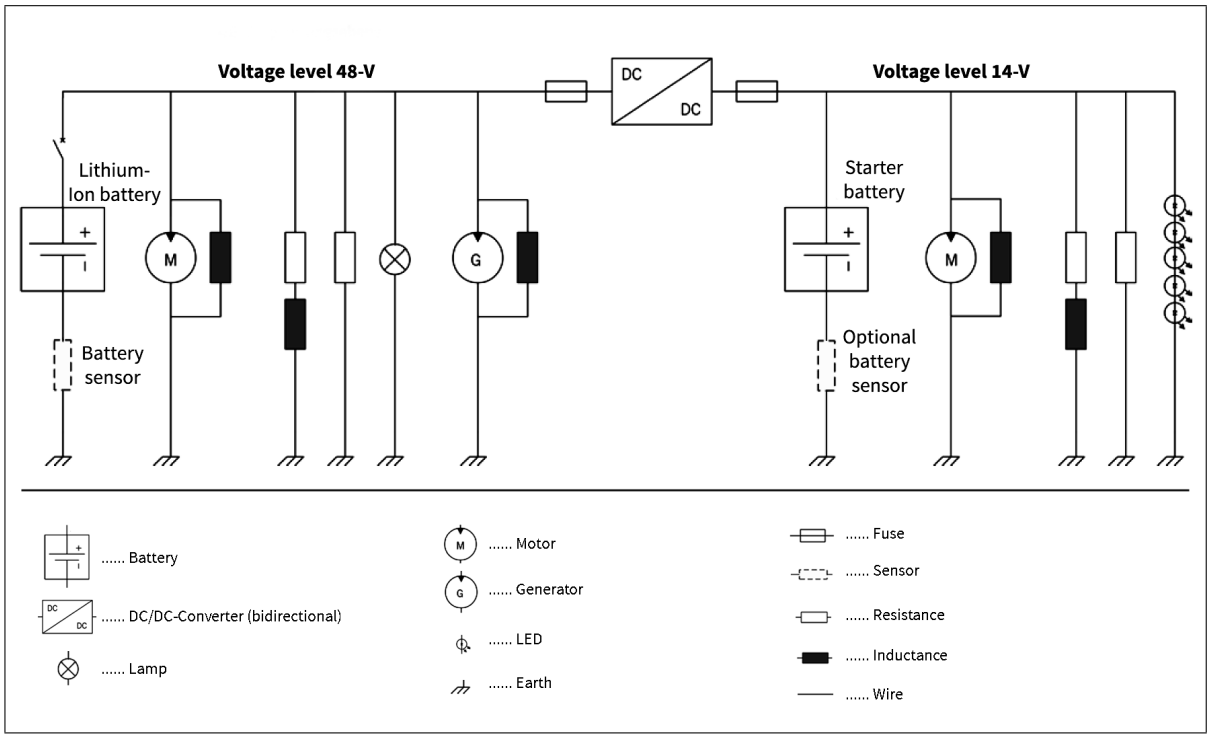

Figure 4.2: **System topology of two voltage levels connected by a DC/DC-converter.**[137]

Using two different voltage levels in a vehicle is a new challenge for engineers. Not only electric components for the new voltage level of 48 V can cause problems, even established devices in the conventional voltage level of 12 V or 14 V can be fraught with problems due to the fact that those

[134] Cf. Green Car Congress (2014b), www.greencarcongress.com, date of access [23.03.2014].
[135] Cf. Navigant Research (2014), www.navigantresearch.com, date of access [25.03.2014].
[136] Cf. Gall et al. (2013), p. 460.
[137] Müller/Strauss/Tumback (2011), p. 460.

are communicating with control devices, which are supplied by the higher voltage level. For that reason reliability for communication systems is essential.[138]

Figure 4.3 shows an overview of devices which are supplied by 12 V when there is only one voltage level in the vehicle (left side) and a possible migration with an additional 48 V net (right side). It is just a rough example of the conventional on-board supply level of 12V. This means, a possible configuration of electric systems in a vehicle by using two different on-board power supplies (12 V, 48 V) is illustrated. Electric systems with high power loads like the electric cooling fan or the electric heating, which have a consumption of up to 1 kW each, are supplied by the 48 V on-board power supply. The higher voltage level enables the electrification of functions which were not electric before like a climate compressor. Different applications like boosting or steering assistance can be integrated due to the higher voltage level of 48 V. Therefore, a broad adoption is expected.[139]

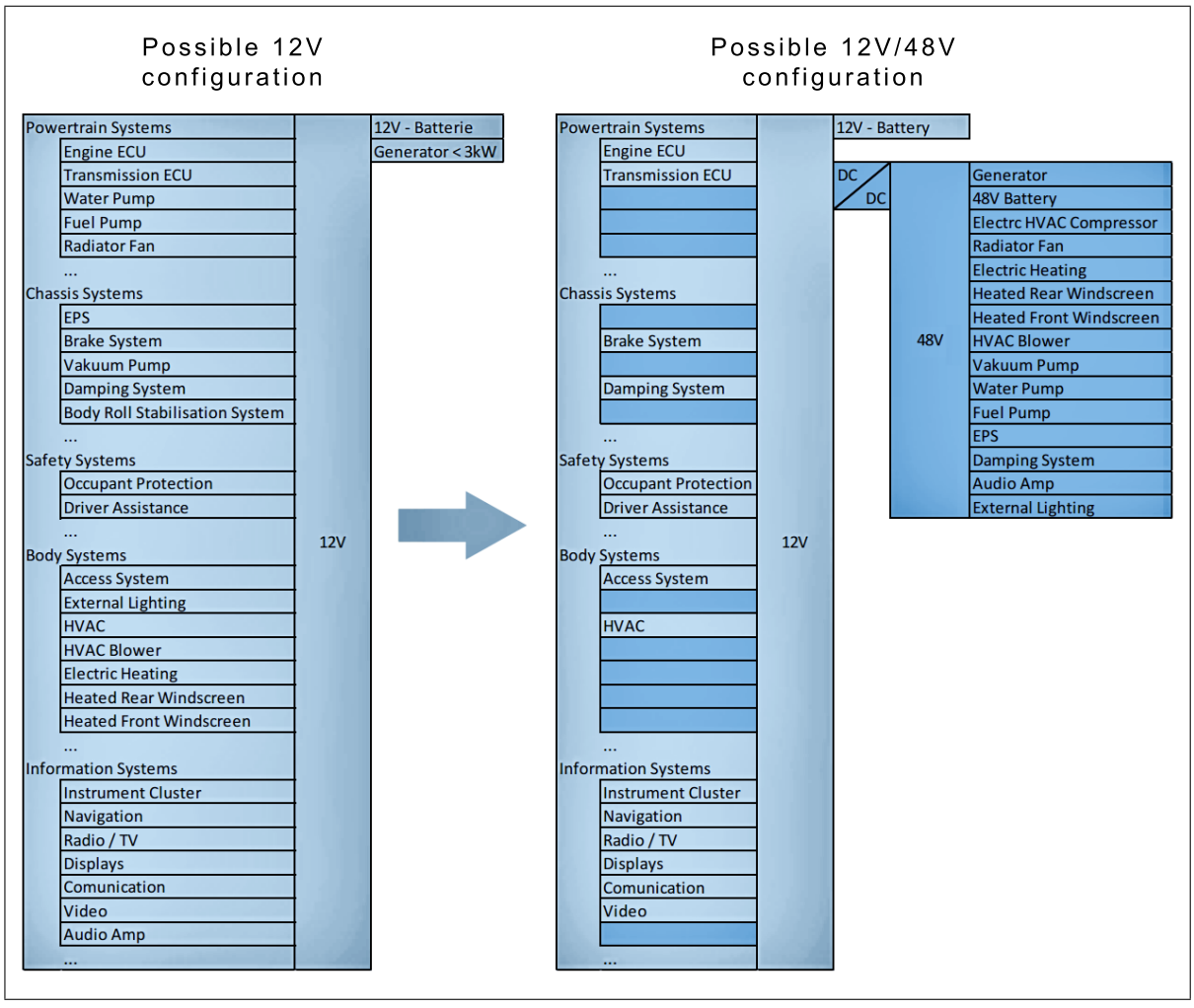

Figure 4.3: **Possible migration for a 12 V/48 V configuration.**[140]

[138] Cf. Gall et al. (2013), p. 460.
[139] Cf. Dörsam et al. (2012), p. 14.

4.3 Starter-generators

A combustion engine must be turned by an electric starter motor at a certain speed to suck fuel and air to the cylinders and to compress it.[141] The belt-driven starter-generator (BSG) and the integrated starter-generator (ISG) are the two feasible variants for 48 V starting systems.[142]

4.3.1 Belt-driven starter-generator

A BSG, shown in Fig. 4.4 on the left side, is an electromechanical system which is mainly composed of an induction motor, a belt-drive system and electronic controls. A hydraulic tensioner prevents significant movement during starting and controls the system in the accelerating and the decelerating phase.[143] The tensioner system has to be well-conceived due to the fact that BSG spins in both directions. The BSG can supply the ICE with torque, or the kinetic energy of the ICE can be recuperated. A high performance 48 V battery ensures that there is enough power to supply the BSG. Also a conventional 12 V pinion starter is still part of the configuration to safeguard the starting capability for very low temperatures. The nominal power of the BSG is approximately 10 kW and can be integrated to existing engine designs (place of the conventional alternator) with a few modifications.[144]

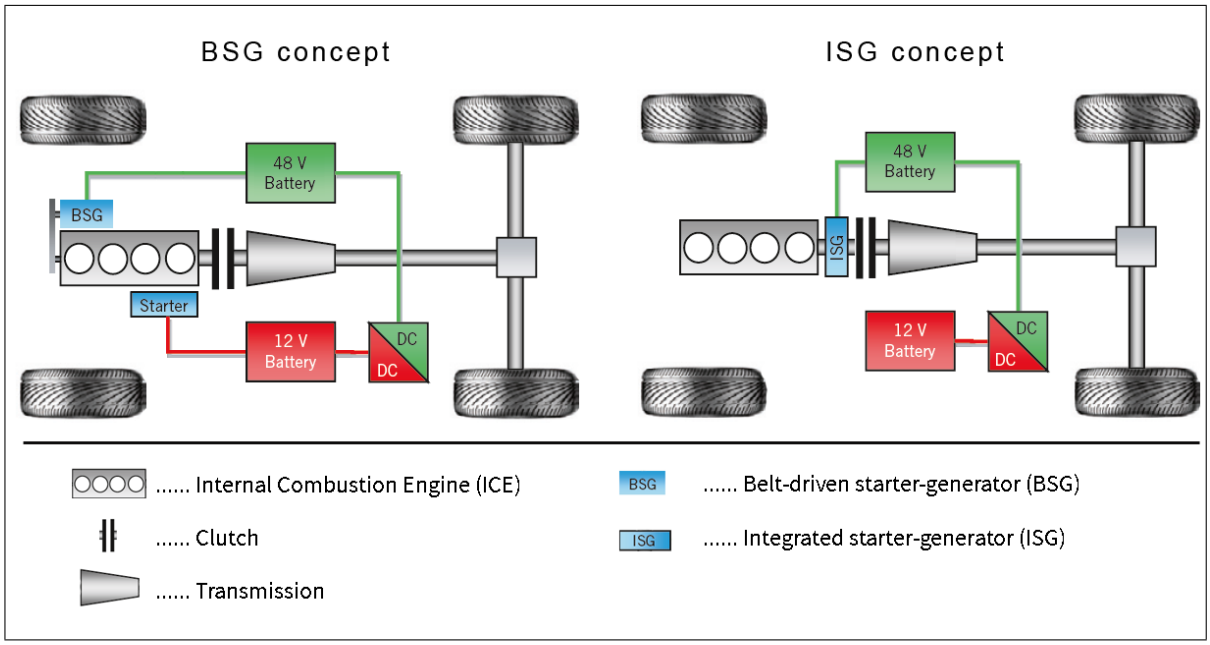

Figure 4.4: **Possible migration for a 12 V/48 V configuration.**[145]

[140] Cf. Müller (2014), p. 11.
[141] Cf. How a Car Works (2013), www.howacarworks.com, date of access [04.06.2014].
[142] Cf. Timmann/Renz/Vollrath (2013), p. 46.
[143] Cf. Denton (2013), p. 250 f.
[144] Cf. Timmann/Renz/Vollrath (2013), p. 46-47.
[145] Cf. Timmann/Renz/Vollrath (2013), p. 46.

4.3.2 Integrated starter-generator

A substitution of the starter and the generator in future cars can be made by the so-called integrated starter-generator, which converts mechanical power into electrical power and vice versa. It is installed between the engine and the transmission. This solution recovers braking energy, cuts fuel consumption (up to 15 %) and supplies the axles with more power.[146] The ISG is even capable of starting the ICE at cold temperatures. Therfore, the pinion starter can be omitted.[147]

The ICE's start up with an ISG is not only very noiseless but also much faster than with any conventional starter. In the generation phase, the ISG produces electric power for any kind of device in the car and even with a higher level of efficiency than its conventional predecessors. In the braking phase, kinetic energy is converted into electrical energy and stored in batteries. These supply the ISG in its function as a motor when it is needed to bring more power to the axles or to drive the vehicle electrically over short distances, as it is the case with BSGs. Any power surplus is used to charge the battery pack. The combustion engine is automatically turned off as long as the driver keeps the foot on the brake pedal while the vehicle is stationary. The ISG accelerates the crankshaft within fractions of a second to idle speed when the brake pedal is released. At the right time, while speeding up the crankshaft, fuel injection and ignition begins. An integrated powertrain management software controls the functions of the ISG. Therefore, the control system has to be able to communicate extremely quick to fully exploit all the advantages.[148]

4.3.3 Summary of starter-generators

The spider diagram in Fig. 4.5 is based on the experience of the company FEV Inc. and compares specific characteristics of the BSG and the ISG. The ISG is a more costly solution than the BSG, however it offers more possibilities for hybrid functionalities and provides a higher comfort than the BSG. The ISG enables to reduce vibration significantly because of tow-starting the ICE and start injection and ignition at the right moment (see also Fig. 4.13). Costs and complexity are two factors which are crucial for car manufacturers. A BSG just needs adaption of the belt-drive system whereas the ISG needs an adaption of the whole drivetrain. Start-stop systems will play an important role in the next years to fulfill the CO_2 target emissions.[149]

[146] Cf. Aschenbrenner (2002), www.siemens.com, date of access [06.10.2013].
[147] Cf. Timmann/Renz/Vollrath (2013), p. 47.
[148] Cf. Aschenbrenner (2002), www.siemens.com, date of access [06.10.2013].
[149] Cf. FEV GmbH (2011), www.theicct.org, date of access [28.01.2014], pp. 100-102.

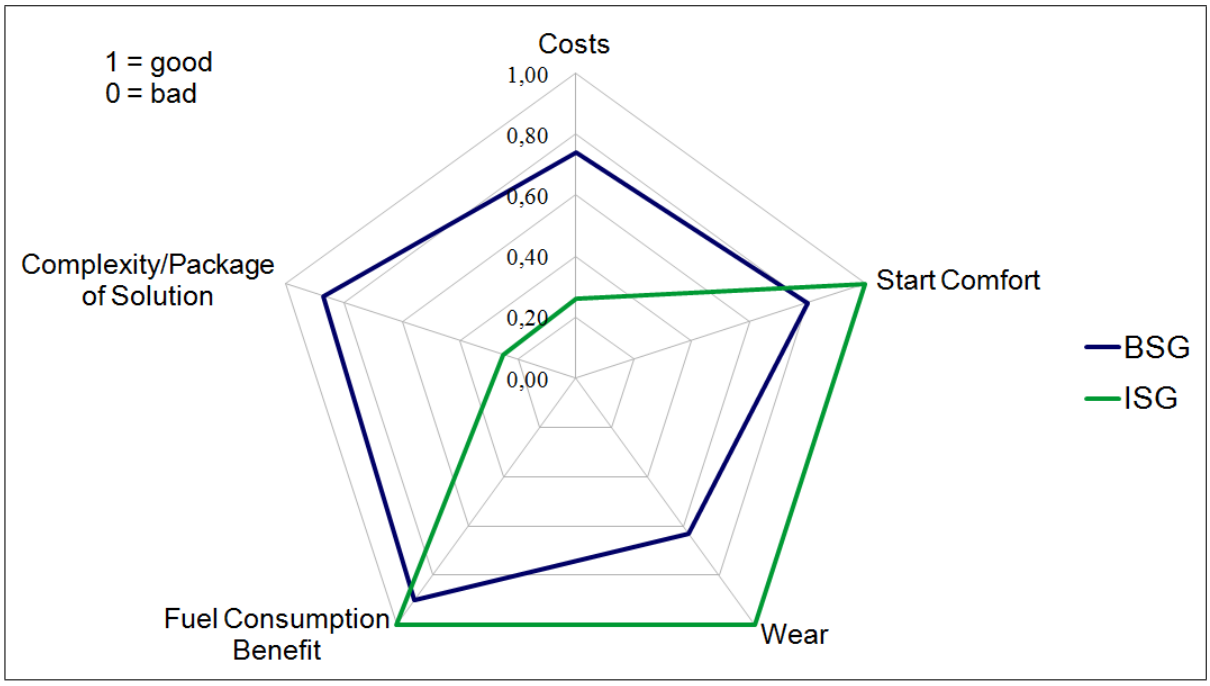

Figure 4.5: **Comparison of BSG and ISG.**[150]

4.4 SWOT analysis of the 48V-technology

The 48 V-technology will be discussed through a SWOT analysis to evaluate its potential.

4.4.1 Strengths

a) Higher Power (12 kW instead of 3 kW)

Due to the four times higher power of 12 kW many functions are more comfortable for the passengers compared to vehicles with lower power. Additionally, the power increase gains a reduction in CO_2 emissions. A higher heat output of 1.5 kW of the windscreen heater gains a clear view more quickly. Additionally, the power of the heating for the vehicle interior will be higher, which makes it more comfortable due to the fact that the desired temperature is reached earlier. Moreover, blower systems can be reduced which has a positive impact on the noises in the car. Also the full cool-down power for air conditions at idle speed can be used. Therefore, heating ventilation air condition (HVAC) is supplied with more power and provides passengers with a pleasant temperature. Even so called warm and cool welcomes, where heating up or cooling down the vehicle before entering it, are possible. Possibilities for more innovations like the electric steering stabilization are offered by the higher on-board supply.[151] Another innovation which can be suitable integrated are high-speed actuators which control the chassis ground clearance for better aerodynamics in order to save fuel.

[150] Cf. FEV GmbH (2011), www.theicct.org, date of access [28.01.2014], p. 100.
[151] Cf. Reiner (2013), lexikon.kfz.tu-berlin.de, date of access [26.08.2013], pp. 3-7.

Several other functions which are not viable by using only a 12 V on-board supply, can be suitable integrated by a 48 V on-board system. As a case in point, tensioning elements for a 48 V BSG, stability systems, roll stabilization and other innovations could be implemented.[152]

b) No contact protection

As shown in chapter 4.1 no protection against contact is mandatory below a voltage level of 60 V. Therefore, auto mechanics do not need a special high voltage education, which was another reason to stay below the shock protection voltage.[153] In contrast to high voltage systems, on-board power supplies with voltage levels below the 60 V-limit can be electrically grounded through the vehicle body. Therefore, elaborate galvanic isolations can be avoided.[154]

c) Low cost hybridization

Despite a highly competitive market and increasing requirements, costs should be kept low.[155] A possible improvement in propulsion efficiency is viable with inexpensive hybrid solutions.[156] Moreover, in many European countries, working with an on-board supply up to 30 V AC/60 V DC has to be differentiated to working with a higher voltage level.[157] Vehicles with voltage levels below the 60 V can be electrically grounded through the vehicle body and galvanic isolations are not required which saves extra costs.[158] Electronic designers need to implement an aligned battery management system for the combined voltage levels, a long battery life and safe operations which is as simple and inexpensive as possible.[159] This low voltage mild hybrid solution reduces carbon emission, without adding significant manufacturing cost or compromising performance.[160]

d) Fuel and CO_2-reduction

Due to increasing requirements, the 12 V on-board supply is operating at its limits, which was the reason to introduce a new voltage level of 48 V to supply all high load devices efficiently. Not only a higher comfort for passengers but also a reduction in fuel consumption and CO_2 emissions can be reached by this additional higher voltage level.[161]

ICEs have made a crucial step in reducing emissions over the last 15 years. The expected dominance of ICEs will be at least until 2020. Engine downsizing across all segments offers CO_2 savings and reduces weight and space.[162]

[152] Cf. Schaeffler AG (2014b), www.schaeffler.de, date of access [19.03.2014].
[153] Cf. Goppelt (2013), www.springerprofessional.de, date of access [17.03.2014].
[154] Cf. Gall et al. (2013), p. 459.
[155] Ibid.
[156] Cf. Auto.de (2013), www.auto.de, date of access [17.03.2014].
[157] Cf. Deutsche Gesetzliche Unfallversicherung (2013), publikationen.dguv.de, date of access [20.09.2013], pp. 40-41.
[158] Cf. Gall et al. (2013), p. 459.
[159] Cf. Hehn (2013), www.yudu.com, date of access [24.03.2014].
[160] Cf. Green Car Congress (2013a), www.greencarcongress.com, date of access [10.05.2014].
[161] Cf. Brünglinghaus (2013), www.springerprofessional.de, date of access [17.03.2014].
[162] Cf. Society of Motor Manufacturers and Traders (2013), www.smmt.co.uk, date of access [13.01.2013].

The CO_2 reduction potential of different functions of hybrid vehicles depends on some factors such as the used car, the driving cycle, etc. and can ,therefore, only be roughly estimated as shown in Fig. 4.6. The calculation is based on the functions start-stop, extended start-stop, coasting (only e-motor powers to keep constant speed) and recuperation.[163] The difference between the start-stop function and extended start-stop function is that the extended one switches the ICE already off while rolling to a stop, which also reduces the fuel consumption and the carbon dioxide emission.[164]

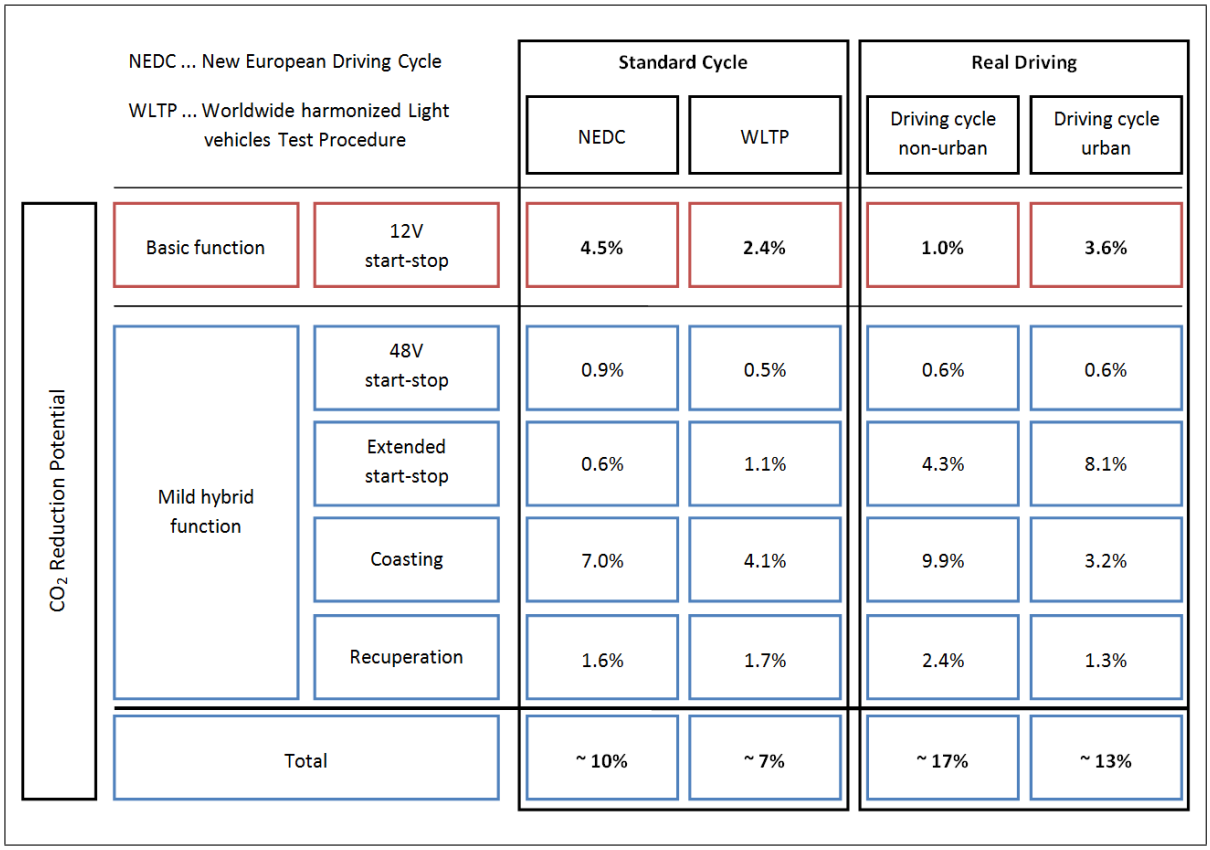

Figure 4.6: **CO_2 reduction potential (own illustration).**[165]

The reduction values vary in different driving cycles and routes such as the New European Driving Cycle (NEDC), the worldwide harmonized light vehicles test procedure (WLTP), a non-urban driving cycle and an urban cycle to compare CO_2 emissions on different conditions. The greatest savings were achieved by the function coasting which is very effective at higher speeds when the ICE can be switched off and the e-motor takes over.[166]

Compared to the result of the calculation in Fig. 4.6 Professor Gutzmer, CTO of the company Schaeffler AG, estimates a CO_2 emission and fuel reduction of up 15 % due to the very efficient

[163] Cf. Müller (2014), www.ihs.com, date of access [26.03.2014], p. 12.
[164] Cf. Porsche (2013), www.porsche.com, date of access [27.03.2013].
[165] Cf. Müller (2014), www.ihs.com, date of access [27.03.2014], p. 12.
[166] Ibid.

recuperation.[167] Dr. Bohr, chairman of the Bosch Automotive Group, also asserts that their so-called boost regeneration system (BRS) on vehicles with the additional 48 V on-board supply cuts CO_2 emission by 15 %.[168]

The so-called coasting technology switches off the engine in order to save fuel whenever the vehicle is in motion and no pedal is in use. Therefore, the vehicle can coast without an engine brake. Bosch states, that this function will give drivers a roughly 10 % fuel saving. Keeping the vehicle at a certain speed can be supported by an electric motor without using the ICE.[169]

Figure 4.7 shows the potential of the kinetic energy. An upper middle class vehicle (1900 kg, with 3.6 l V6 combustion engine) was accelerated to a speed of 100 km/h to let the car coast to a speed of 50 km/h. This experiment shows clearly an increased rolling distance with a decoupled engine, in comparison with an ICE in 6^{th} and 3^{rd} gear, until 50 km/h is reached. The rolling distance with the almost friction-less decoupled engine is more than twice as long as rolling as with the 6^{th} gear. Therefore, this experiment shows the wasted energy, which can now be used by the so-called function coasting.[170]

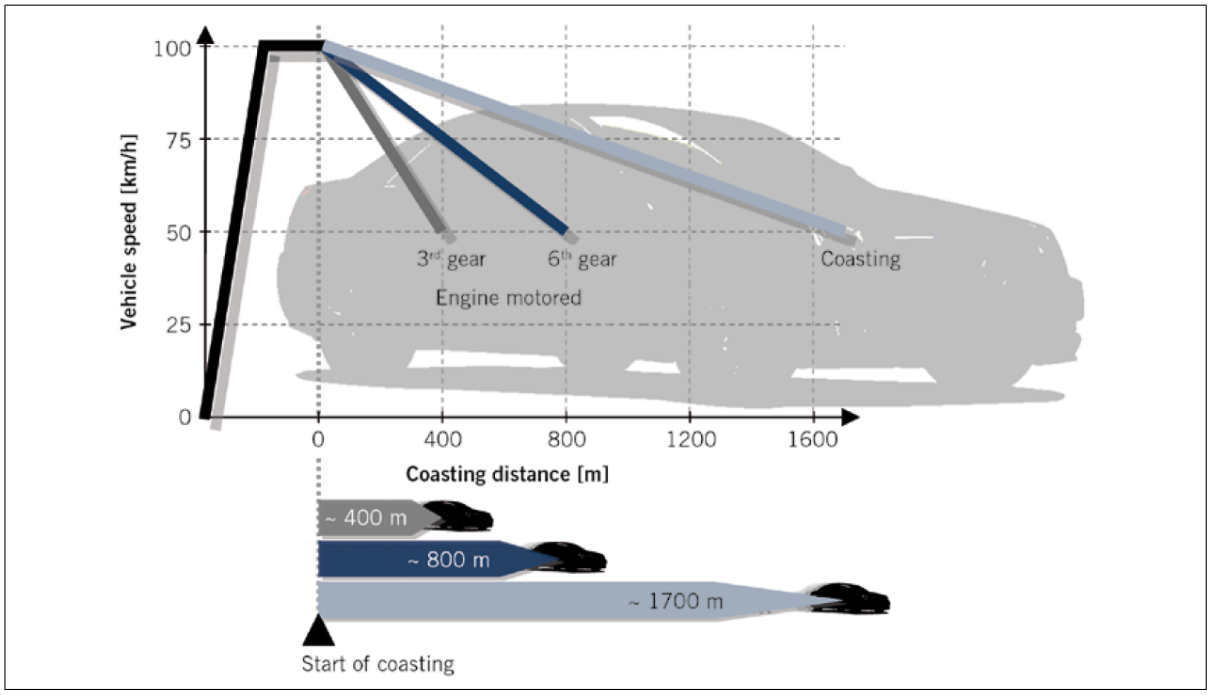

Figure 4.7: **Coasting compared to a motored engine in 6^{th} and 3^{rd} gear.**[171]

[167] Cf. Schaeffler AG (2014a), www.schaeffler.com, date of access [26.08.2013], pp. 26-27.
[168] Cf. Automotive Design & Production (2013), p. 10.
[169] Cf. Bosch AG (2014), www.bosch.com, date of access [28.03.2013].
[170] Cf. Müller/Strauss/Tumback (2011), pp. 15-16.
[171] Müller/Strauss/Tumback (2011), p. 16.

e) Efficient start-stop systems

The conventional start-stop functions reduce fuel consumption of about 0.5 l/100 km which cuts CO_2 by 12 g/km in the NEDC. This NEDC standardized driving sequence is used to have a practical relevant comparison of CO_2 emission and fuel consumption. The reason why the 48 V on-board supply is that efficient, is because most of the slowing-down processes are under the maximum of 12 kW. By using this switch-off-function in all phases in which the ICE does not propel the car or in which it is not generating energy, the reduction can gain up to 1 l/100 km in real driving cycles.[172] In stop-and-go-traffic, quiet residential areas, parking garages or other traffic situations it is possible that only the electric motor propels the vehicle which makes it more convenient for the vehicle occupants as well as for the environment.[173] If the pedals are released the vehicle usually rolls almost friction-less by decoupling the engine's mechanical connection which is called coasting whereas in braking at speeds around 20 km/h, the idling engine is completely switched off to save energy.[174] During the coasting phase the ICE can be completely switched off while only the electric motor supplies the vehicle with enough power to keep the same speed. It is called boosting when the electric motor supports the ICE with additional torque. This occurs when the vehicles move off from a stationary position or when the car needs extra power to overtake another vehicle.[175] Therefore, the ICE can be downsized to an appropriate size in order to save costs and weight.[176]

Fuel reduction by using the start-stop system can be improved by prolonging the switch-off time of the ICE. An optimized time to switch the combustion engine off is at the end of a braking phase in the transition to the idle-state which is in the 20 km/h to 30 km/h speed range. This measure could save approximately 0.27 l/km referring to the NEDC. Moreover, fuel savings are possible by switching the ICE off at every time when there is no requirement for torque.[177]

Coasting with a conventional on-board supply with only one battery, would be quite dangerous due to the fact that a failure of the battery would lead to a total power cut because the alternator is completely switched off. This is especially dangerous by night when there are suddenly no lights or in the rain when windshield wipers do not work anymore. Therefore, an on-board supply with two batteries reduce the risk tremendously.[178]

[172] Cf. Nalbach/Körner/Hoff (2013), p. 46.
[173] Cf. Schaeffler AG (2014b), www.schaeffler.de, date of access [19.03.2014].
[174] Cf. Nalbach/Körner/Hoff (2013), p. 46.
[175] Cf. Schaeffler AG (2014b), www.schaeffler.de, date of access [19.03.2014].
[176] Cf. Romain (2013), date of access [19.03.2014].
[177] Cf. Nalbach/Hoff/Körner (2013), p. 435.
[178] Cf. Nalbach/Hoff/Körner (2013), p. 436.

f) Effective Boosting and Recuperating

As illustrated in Fig. 4.8, regenerative braking captures the vehicle's kinetic energy when the driver presses the brake pedal. An electric motor can also function as a generator and therefore, convert torque into electric power. While the engine is switched off and decoupled an inverter converts the generated power to the appropriate voltage level in order to store the electric energy in a battery. In emergency braking situations, regenerative braking cannot provide the braking power which would be necessary.[179]

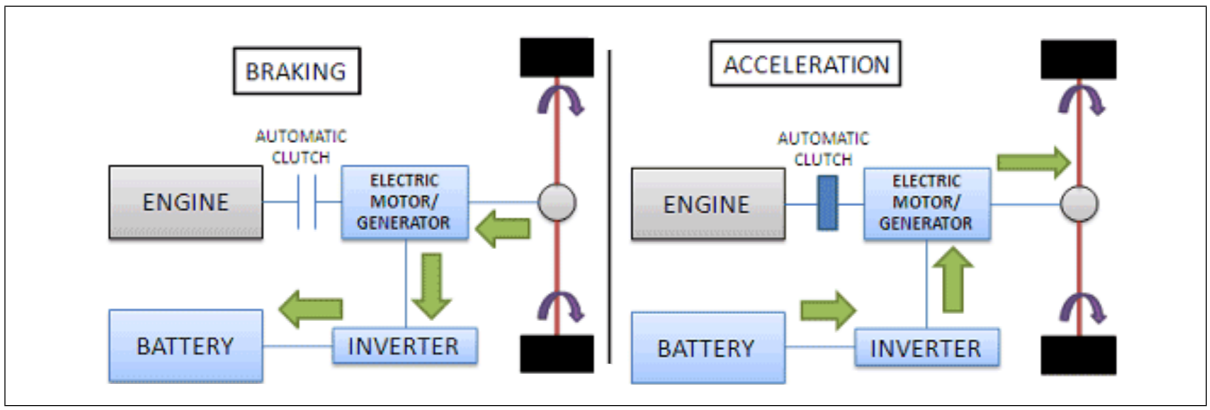

Figure 4.8: **Energy flow while recuperating and boosting.**[180]

The 48 V hybrid solution attains already different operating modes which were only possible with high voltage hybrid systems. Therefore, a remarkable recuperation can be achieved with a 48 V on-board system due to the fact that a major amount of the released kinetic energy can be recovered and stored in batteries instead of wasted heat energy from the brakes.[181]

This recuperated energy can then be used for different situations such as moving off, driving at low speeds or parking by using only an electric motor which can have a power of up to 12 kW.[182] The 48 V system offers a recuperation energy which is about four times higher compared to the 12 V technology.[183] The speed of the vehicle and the strength of the slow-down process is crucial for the converted kinetic to electrical energy. Fig. 4.9 shows that most slowing-down processes generate less than 12 kW which makes the 48 V system very effective.[184]

[179] Cf. CVEL - Automotive Electronic Systems (2014), www.cvel.clemson.edu, date of access [15.04.2014].
[180] CVEL - Automotive Electronic Systems (2014), www.cvel.clemson.edu, date of access [15.04.2014].
[181] Cf. Schaeffler AG (2014b), www.schaeffler.de, date of access [19.03.2014].
[182] Cf. Schaeffler AG (2014b), www.schaeffler.de, date of access [21.03.2014].
[183] Cf. Goppelt (2013), www.springerprofessional.de, date of access [17.03.2014].
[184] Cf. Schaeffler AG (2014a), www.schaeffler.com, date of access [26.08.2013], p. 29.

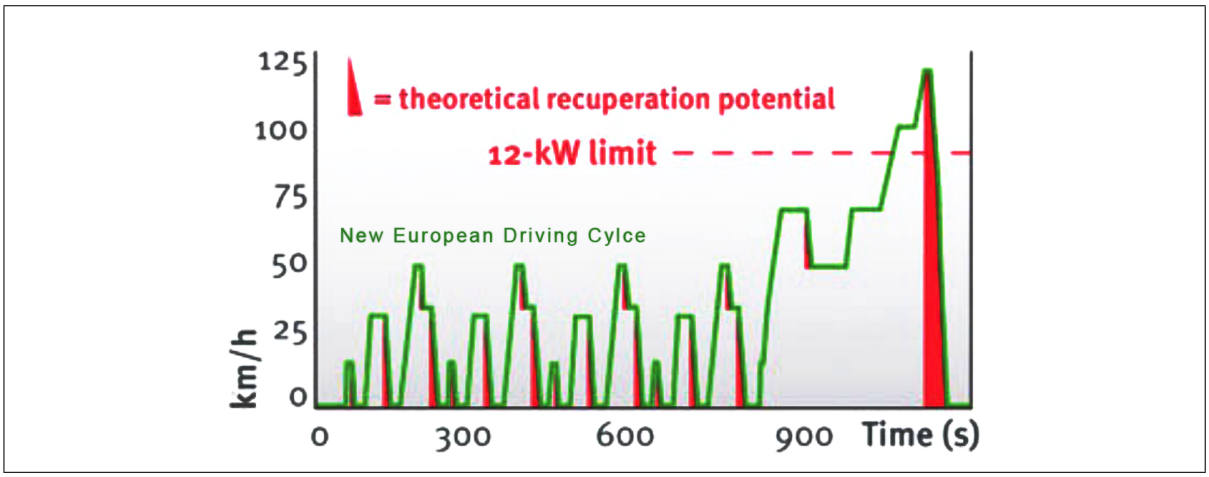

Figure 4.9: **Capture potential of recuperated energy.**[185]

The diagram in Fig. 4.10 shows roughly how drag losses influence the recuperation efficiency. The two horizontal dashed lines in Fig. 4.10 show the maximum recuperation power of the voltage levels 12 V and 48 V. The higher the ICE's number of cylinders, the higher are the drag losses, which reduce the potential of recuperating with a 48 V on-board supply. A three-cylinder motor has, therefore, little enough drag losses that there is basically no negative effect on the recuperation performance.[186]

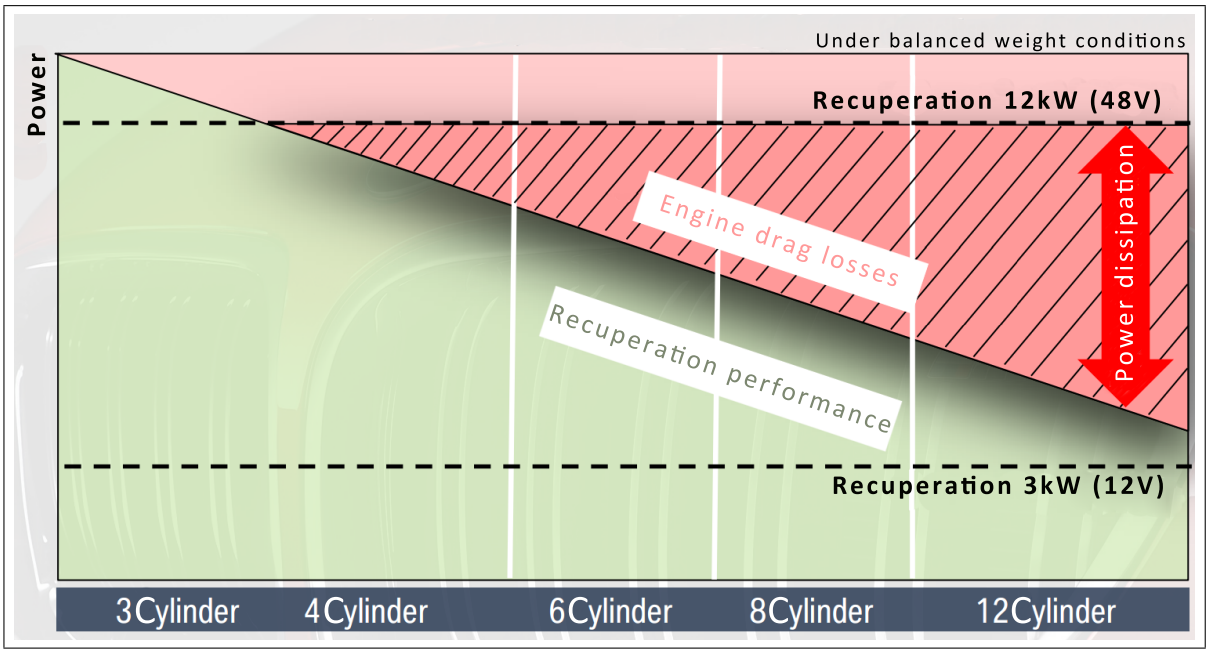

Figure 4.10: **Capture potential of recuperated energy.**[187]

[185] Cf. Schaeffler AG (2014a), www.schaeffler.com, date of access [28.12.2013], p. 29.
[186] Cf. Reiner (2013), lexikon.kfz.tu-berlin.de, date of access [23.03.2014], p. 21.
[187] Reiner (2013), lexikon.kfz.tu-berlin.de, date of access [27.12.2013], p. 21.

The mild hybrid concept Active Runabout (AR) involves a front-wheel drive which is powered by a 48 V lightweight BSG (Fig. 4.11). A 1.1-liter ICE with 100 kW has only 3 cylinders (with refers to Fig. 4.10) and is well-matched with the 10 kW BSG and the 0.25 kWh lithium-ion battery.[188]

Figure 4.11: **The 3-cylinder mild hybrid concept Active Runabout.**[189]

Despite effective recuperating, many hybrid vehicles waste energy when driving downhill. The energy management system, named Intelligent Hybrid, for hybrid vehicles from Mercedes-Benz, monitors and assesses the road ahead and takes it into account which is shown in Fig. 4.12.[190]

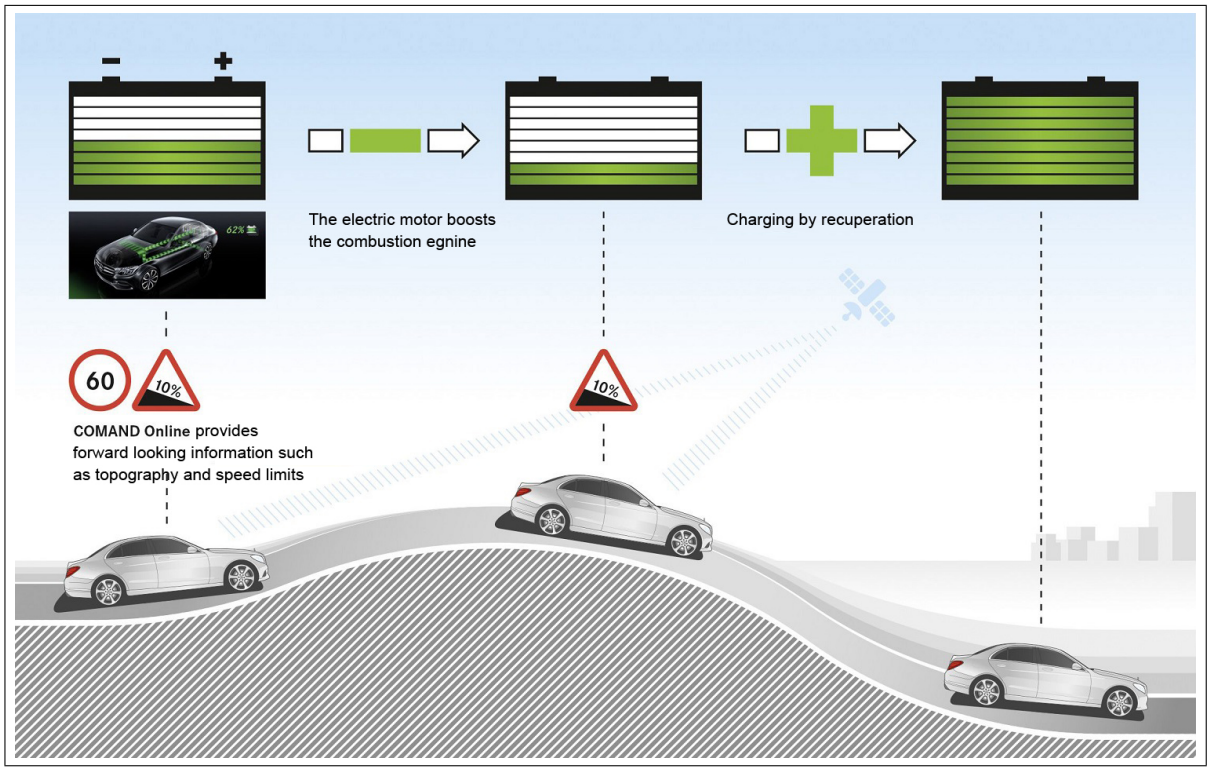

Figure 4.12: **Function of Intelligent Hybrid from Mercedes-Benz.**[191]

[188] Cf. Green Car Congress (2014d), www.greencarcongress.com, date of access [23.03.2014].
[189] Green Car Congress (2014d), www.greencarcongress.com, date of access [23.03.2014].
[190] Cf. Hybridcars.com (2014), www.hybridcars.com, date of access [12.05.2014].
[191] Hybridcars.com (2014), www.hybridcars.com, date of access [12.05.2014]

If the battery is charged to a certain level, the electric motor boosts automatically the ICE to offer storage to save recuperation energy. To use the potential of the road ahead, the navigation system Comand Online calculates the optimum use of energy from the car's battery. The system processes data such as speed limits and route profiles approximately seven kilometers in advance, which is based on a one-meter grid. Further adaptive control algorithms can even include the actual vehicle weight, the driving behavior and other data in the calculation for the forecasted recuperation potential. Predicting the topography can save a large amount of fuel due to the optimum allocation of using and recuperating the battery's energy. The more mountains on the driving route, the higher the fuel and CO_2 emission savings. When the navigation system does not know the destination, it calculates the probability of turning off depending on the road category which means for instance a car on a highway will most probably continue on it for the following seven kilometers.[192]

g) Safety and comfort

The higher voltage level of 48 V enables the ICE to tow-start during the start-up phase until right before idle speed is reached. Therefore, after passing the resonance frequency range of the engine and transmission, the combustion engine is triggered, which leads to a significant reduction of vibrations and start-up time in comparison to a conventional starter 4.13.[193]

Additional safety and comfort is provided by so called electric hill hold support.[194] Volkswagen calls this function Auto Hold and is an extension of the electronic parking brake system. It prevents rolling backwards when you are stationary on a hill. Therefore, there is no time when the car can roll backwards between releasing the braking pedal until the driver presses the accelerator. All the driver has to do is to press the accelerator when he or she wants to move forward, which improves drivers' comfort.[195]

[192] Cf. Hybridcars.com (2014), www.hybridcars.com, date of access [12.05.2014].
[193] Cf. Timmann/Renz/Vollrath (2013), p. 47.
[194] Cf. Mate (2013), www.artemis-ioe.eu, date of access [17.03.2014], p. 15.
[195] Cf. Volkswagen AG (2014), www.volkswagen.co.uk, date of access [17.03.2014].

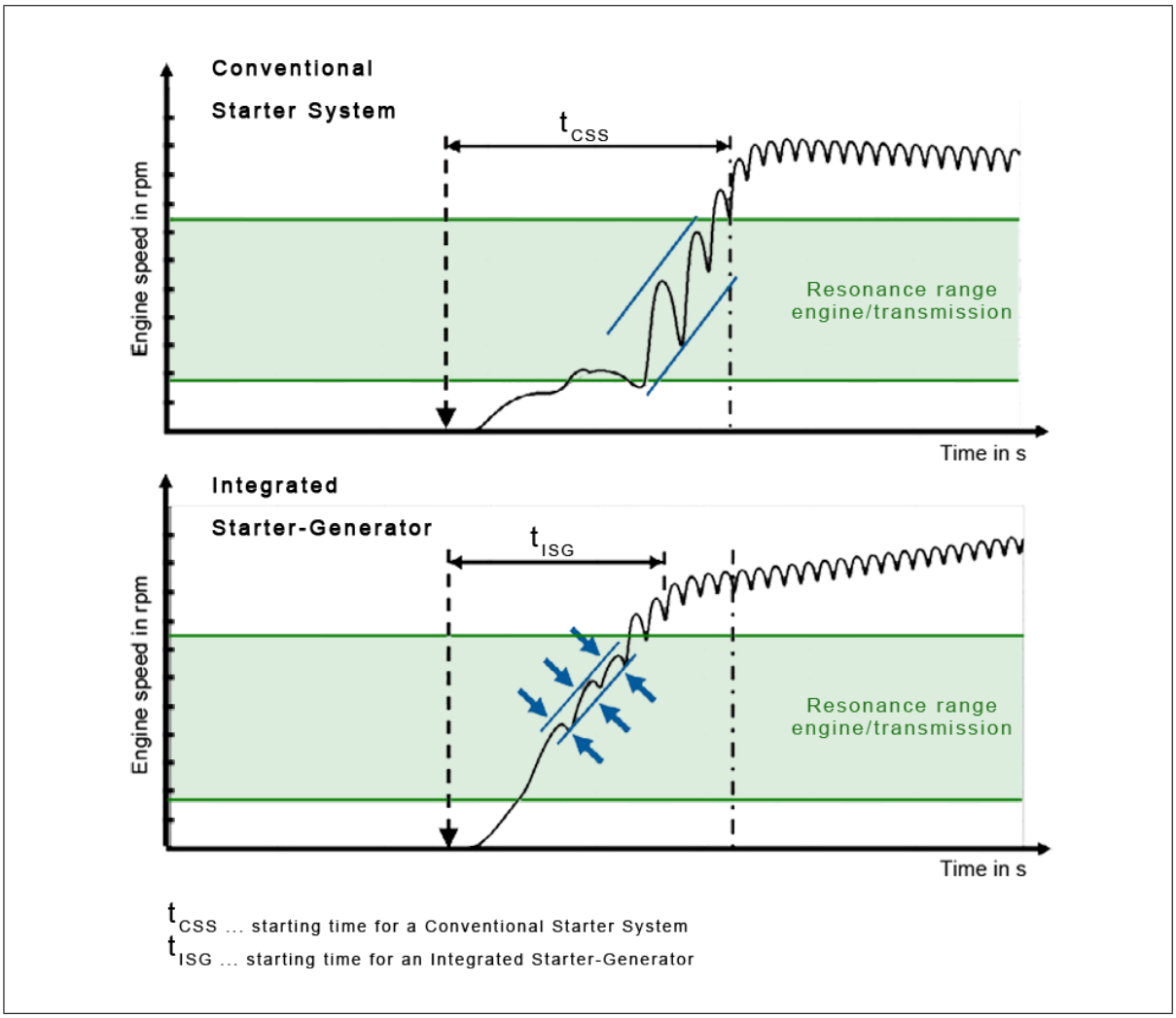

Figure 4.13: **Comparison of the engine speed of a conventional starting system and an ISG.**[196]

h) Noise reduction

The higher power that is provided by the 48 V system improves heating systems, which can, for instance, gain a clear view more quickly. Therefore, blower systems can be reduced that leads to a significant noise reduction in the interior. The stronger heating and cooling systems reduce the time of reaching appropriate temperatures for different applications, which raises safety and comfort.[197] However, the noise level in the car depends also on different factors from the outside of the interior such as the speed of the vehicle, the road conditions and even other noises that are produced by the environment.[198]

i) Weight and space savings

Additional batteries, inverters and motors gain the weight of the vehicle. However, the more inno-

[196] Timmann/Renz/Vollrath (2013), p. 47.
[197] Cf. Reiner (2013), lexikon.kfz.tu-berlin.de, date of access [26.08.2013], p. 7.
[198] Cf. PEP (Professional Engineering Publishers) (2002), pp. 177-178.

vations (e.g. electric steering system) are implemented in a car, the more the 48 V on-board supply pays off in terms of weight. Figure 4.14 shows the difference on weight between 12 V and 48 V on-board supply. The higher voltage offers a big leeway for further innovations.[199]

Due to the higher voltage of 48 V the current is much lower and the cable cross-sections can be reduced by 75 %.[200] Referring to Ohm's Law this means that the same power can be provided with only 25 % of the current.[201] As a result of this weight savings of five to ten kilograms of cable harness are expected.[202] Therefore, it is also a more convenient installation of the cable harnesses in the vehicle.[203]

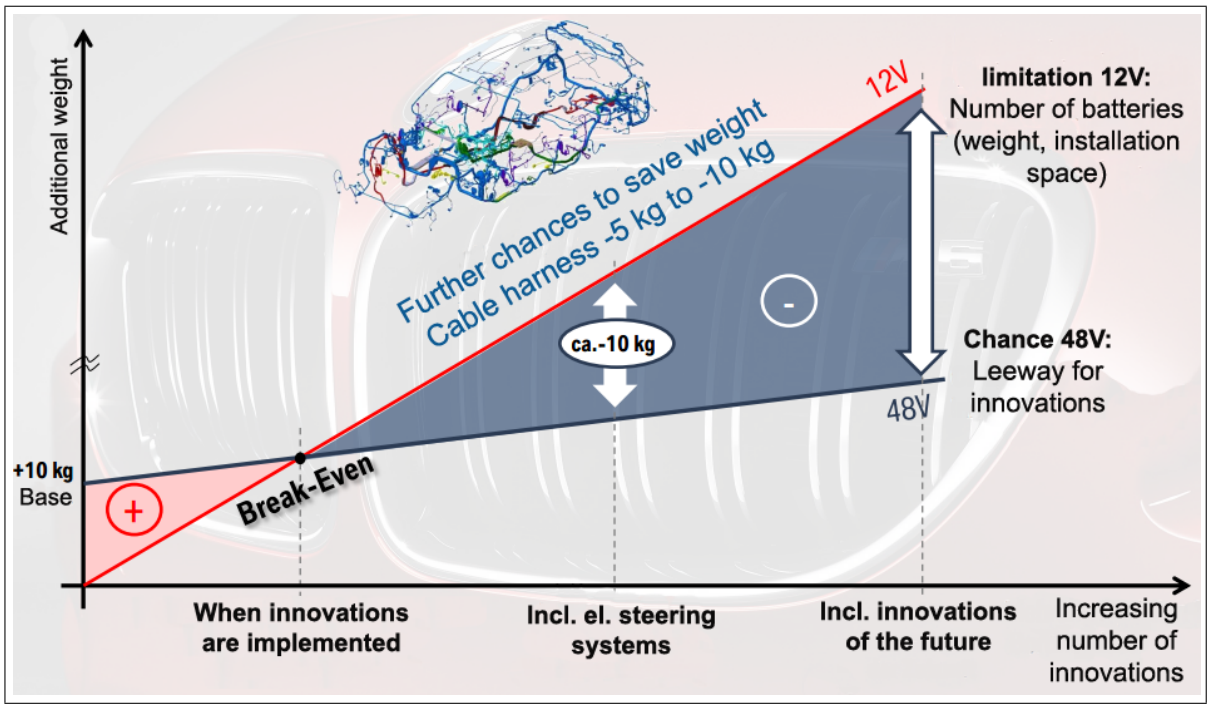

Figure 4.14: **Potentials for weight reduction.**[204]

4.4.2 Weaknesses

a) High level of complexity (two voltage levels, DC/DC-Conv. etc.)

As shown in chapter 4.2 two batteries and voltage levels are connected by a bidirectional DC/DC-converter which is a big challenge for engineers due to the fact that different components from different voltage levels work together.[205]

[199] Cf. Reiner (2013), lexikon.kfz.tu-berlin.de, date of access [26.08.2013], p. 6.
[200] Cf. Schaeffler AG, Frankfurt/Herzogenaurach (2013), www.fag.de, date of access [16.03.2014].
[201] Cf. Navigant Research (2014), www.navigantresearch.com, date of access [25.03.2014].
[202] Cf. Reiner (2013), lexikon.kfz.tu-berlin.de, date of access [17.03.2014], p. 6.
[203] Cf. Schaeffler AG (2014b), www.schaeffler.de, date of access [19.03.2014].
[204] Reiner (2013), lexikon.kfz.tu-berlin.de, date of access [27.12.2013], p. 6.
[205] Cf. Gall et al. (2013), p. 460.

b) Additional Costs (batteries, ICE, e-motor etc.)

Compared to conventional cars, micro-mild hybrid vehicles are more complex to build and utilize more components that result in higher costs; usually around 1.500 $ more than conventional cars.[206]

c) Wear of mechanical switches

The automotive industry found out that switching off 48 V DC in mechanical switches could cause contact erosion. When the user presses the button for the window lifter, current flows over the contacts of the mechanical switch. Releasing the switch let the contacts move apart and the contact surface becomes smaller which increases the current density. The high density can then melt and vaporize the surface which leads to a rapid wear of the switch. 48 V produces longer and hotter arcs and vaporizes more metal than with the conventional 12 V. Therefore, automakers upgraded the switches with expensive metals and other improvements like spring-loaded contacts which jump apart faster to reduce the arcing.[207]

4.4.3 Opportunities

a) Leeway for innovations

Fig. 4.14 shows that the more innovations (until a certain amount of power consumption) are put in a car, the more it pays off concerning weight savings. Therefore, leeway in terms of power can be provided for further innovations for the vehicle.[208]

b) Increasing raw material prices

It can be assumed that an unexpected increase of prices for raw material or fuel is rather an opportunity for hybrid cars due to the fact that the technology is not based on one technology such as electric vehicles or pure ICE vehicles.

c) Changing low-carbon policies

Car manufacturers are looking for methods to improve the efficiency of cars in order to meet future requirements and emission reduction goals. The 48 V-technology has a crucial influence of approximately 15 % on reduction of CO_2 emissions. Functions such as acceleration support and energy recuperation based on the voltage level of 48 V is a big step to fulfill emission goals which you can find in chapter 5.2.[209]

[206] Cf. Green Car Congress (2013a), www.greencarcongress.com, date of access [10.05.2014].
[207] Cf. Popular Mechanics (2009), www.popularmechanics.com, date of access [24.03.2014].
[208] Cf. Reiner (2013), lexikon.kfz.tu-berlin.de, date of access [26.08.2013], p. 4.
[209] Cf. Kuypers (2014), delphi.com, date of access [26.04.2014], p. 1.

4.4.4 Threats

a) Increasing electrification involves risks for a power interruption

Over the last six to seven years, electrification of powertrain technologies has been a significant trend. Therefore, start-stop systems, engine downsizing and turbocharging will play a major role in the future.[210] The higher voltage of 48 V as well as the two voltage levels result in a higher risk compared to conventional cars, based on 12 V, which is described in chapter 4.1 and 4.2.[211]

b) New market entrants

The entire automotive industry is affected by the increasing interest in electrification and alternative powertrain technologies. As a result of this, existing vehicle manufacturers include alternatively powered vehicles in their product portfolio. New market entrants try to use this opportunity to take place in the automotive industry which can be an unexpected threat for established companies.[212]

c) Patents of competitors

Newcomers who develop a new software can easily start almost without any budget which could cause problems for the big manufacturers. Patents can be a brake for innovations. Therefore, it would be reckless to assume that big firms will not need to deal with patents.[213]

e) Transitional solution

New technologies can turn out to be transitional solution due to the fact that full hybrid, plug-in hybrid and electric vehicle are already on the market. This further increase of electrification should reduce CO_2 emissions.[214]

e) Transitional solution

A purchase decision of a vehicle is more driven by pecuniary factors than the aspiration for environmental friendliness. Therefore, fuel efficiency is the most important purchase issue for the average consumer, whereas environmental friendliness is only ranked fourth as shown in figure 4.15. It is also remarkable, that the lifespan became distinctly more important from 2011 to 2013, which corroborates the most crucial buying factor cost.[215]

Financial, psychological and practical factors have to be considered when a new product will be introduced to the mass market due to the fact that consumers will not pay for benefits which do not bring a direct advantage for themselves. Therefore, a vehicle which has low CO_2 emissions may

[210] Cf. Frost & Sullivan (2011), s3.amazonaws.com, date of access [15.10.2013], p. 9.
[211] Cf. Kuypers (2014), delphi.com, date of access [26.04.2014], p. 1.
[212] Cf. Ernst & Young (2010), www.ey.com, date of access [26.04.2014], p. 1.
[213] Cf. Stevens (2014), www.lexology.com, date of access [26.04.2014].
[214] Cf. Continental AG (2013), www.continental-corporation.com, date of access [15.10.2013].
[215] Cf. KMPG International (2013), www.kpmg.com, date of access [02.09.2013], p. 6.

help to save the environment but if the price is higher than for conventional cars, most people will not buy these new products.[216]

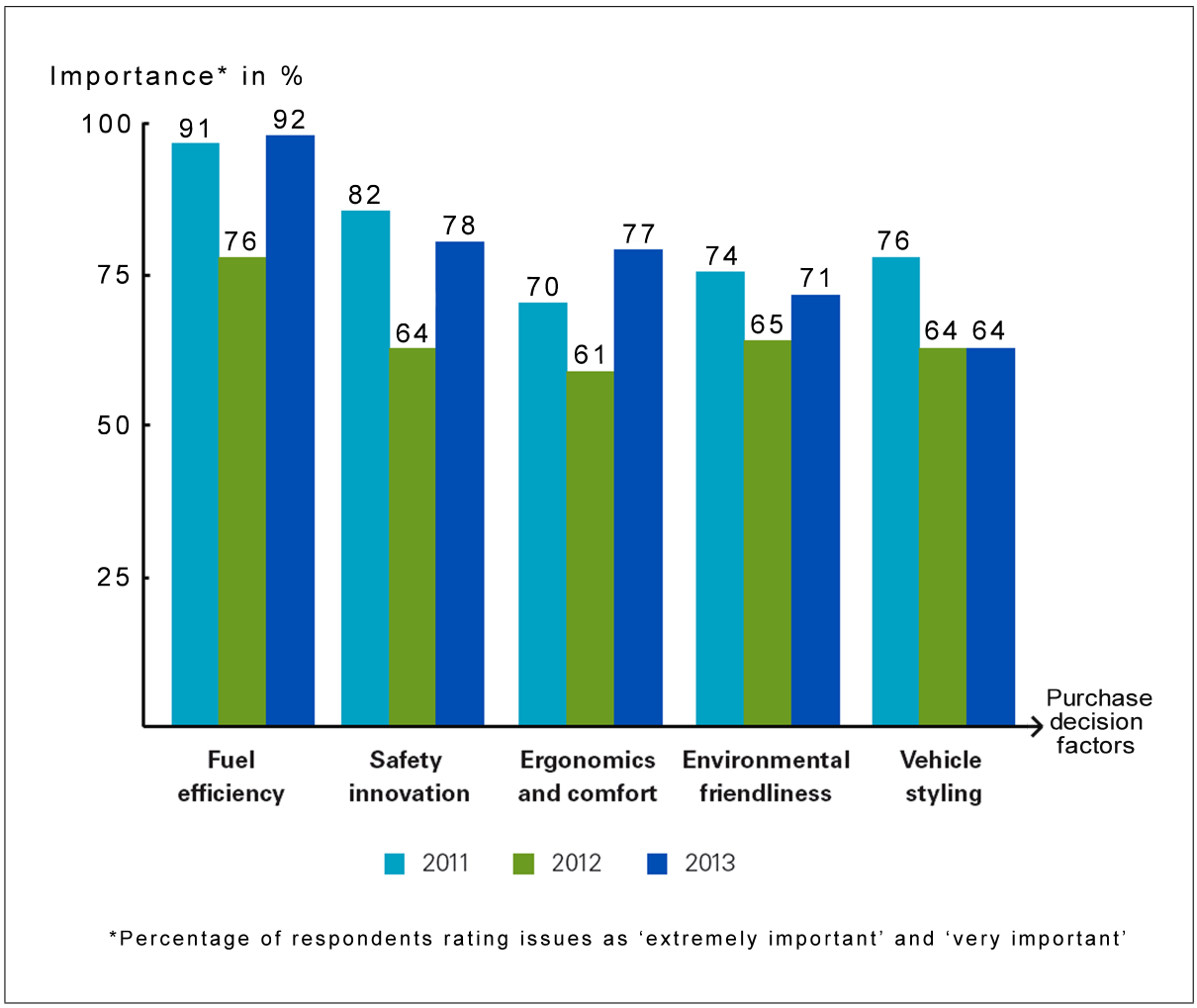

Figure 4.15: **Consumer purchase issues (own illustration).**[217]

Another survey shows that respondents expect a higher growth rate in the low-price segment which is about 52%. There is a predominant growth in the lowest and highest price segments expected as illustrated in Fig. 4.16.[218] However, the author expects, vehicles which are based on the 48 V-technology are rather in the mid-price segment. This could be a short transitional solution until full hybrid vehicles or electric vehicles will play a big part on the market.

[216] Cf. International Energy Agency (2013), www.ieahev.org, date of access [26.04.2014], p. 2.
[217] Cf. KMPG International (2013), www.kpmg.com, date of access [02.09.2013], p. 10.
[218] Cf. Ernst and Young GmbH (2013), www.ey.com, date of access [07.10.2013].

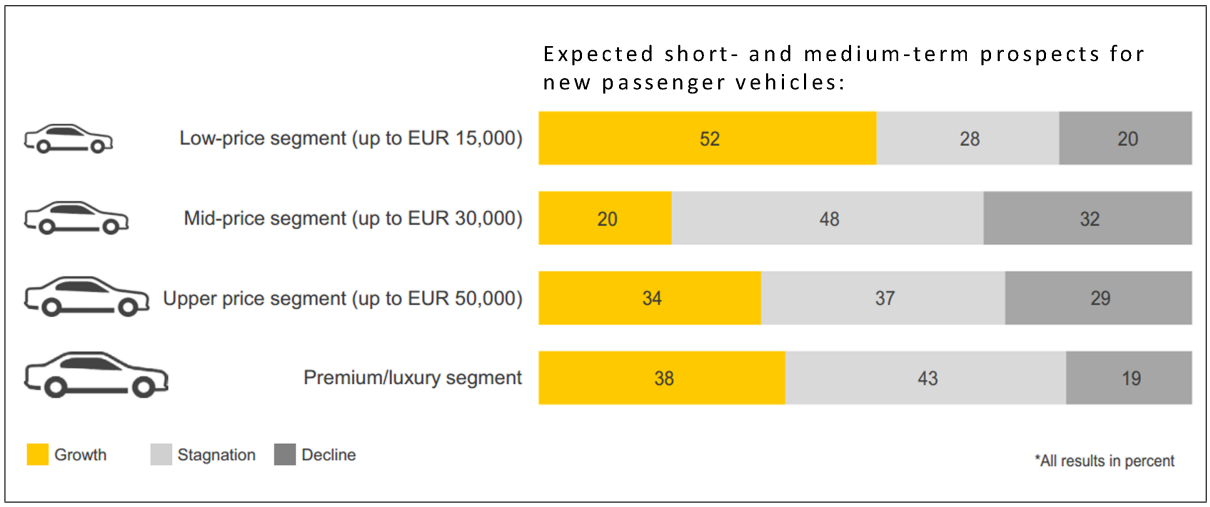

Figure 4.16: **Growth of different price segments.**[219]

4.4.5 Summary of the 48 V-technology

Finally, all strengths, weaknesses, opportunities and threats of the 48 V-technology are summarized in Fig. 4.17.

	Helpful	Harmful
Internal	**Strengths** a) Higher Power (12kW instead of 3kW) b) No contact protection c) Low-cost hybridization d) Fuel- and CO_2-reduction e) Efficient start-stop systems f) Effective Boosting and Recuperating g) Safety and comfort h) Noise reduction (ICE tow-started) i) Weight and space savings	**Weaknesses** a) Higher level of complexity (two voltage levels, DC/DC-Conv. etc.) b) Additional Costs (batteries, ICE, e-motor etc.) c) Wear of mechanical switches
External	**Opportunities** a) Leeway for innovations b) Increasing raw material prices c) Rising fuel prices d) Changing low-carbon policies	**Threats** a) Increasing electrification involves risk for a power interruption b) New market entrants c) Patents of competitors d) Changing customer needs e) Transitional solution

Figure 4.17: **SWOT-Analysis of the 48 V-technology.**[220]

[219] Ernst and Young GmbH (2013),www.ey.com, date of access [02.02.2014], p. 8.
[220] Own illustration.

4.5 Test systems

Testbeds are environments for experimentation of development projects. Replicable and reliable tests of technologies, scientific theories as well as other tools are possible and allows users to evaluate and improve their units under test (UUT).[221] Testbeds investigate new technologies or existing technologies which are combined in an untested modality.[222]

Designing controlled systems requires the integration of mechanical and control systems during the simulation phase which is fulfilled by different steps. At the beginning of the development, MiL (Model-in-the-loop) or SiL (Software-in-the-loop) and then HiL (Hardware-in-the-loop) is used.[223]

4.5.1 Model-in-the-loop

Model-in-the-loop simulation, also called system simulation, enables to map a real system to a representation that consists of equation or event sources. PCs or Workstations are usually the hardware of the development systems, which are typically not the actual hardware for the final implementation.[224] The main advantage is the early verification of the requirements and the algorithms of the final solution. However, it is difficult to determine required resources at this early stage.[225]

4.5.2 Software-in-the-loop

Software-in-the-loop simulation is processed with the real control algorithm, which replaced the model of the control software. For this reason, the control algorithm interacts with the model of the plant. Therefore the control algorithm, which is running on a developing hardware, interacts with the model of the plant.[226] The main advantage is that the most errors will be detected at this stage. Compiler and processor of the PC may have different behaviors than the final platform.[227]

4.5.3 Hardware-in-the-loop

It is called Hardware-in-the-loop simulation if the software is executed on the embedded platform, where the environment is replicated by the HiL simulator. The simulation can be done before the entire prototype hardware of the system is build.[228]

[221] Cf. Southeastern Universities Research Association (2010), www.sura.org, date of access [03.06.2014].
[222] Cf. Industrial Internet Consortium (2014), www.iiconsortium.org, date of access [04.06.2014].
[223] Cf. LMS International (2013), www.lmsintl.com, date of access [30.12.2013].
[224] Cf. Köhler (2011), p. 23.
[225] Cf. Kirner (2008), ti.tuwien.ac.at, date of access [04.06.2014], p. 6.
[226] Cf. Köhler (2011), pp. 23-24.
[227] Cf. Kirner (2008), ti.tuwien.ac.at, date of access [04.06.2014], p. 7.
[228] Cf. Kirner (2008), ti.tuwien.ac.at, date of access [04.06.2014], p. 9.

HiL simulation in the automotive industry means basically coupling of an Engine Control Unit (ECU) (powerful computer in cars) and a vehicle model.[229]

4.5.4 Emulators

It is called emulation if the functions of one system (original system) are duplicated by a second system which behaves like the original system. The exact reproduction of external behaviours are intended compared to other kinds of computer simulations. The hardware of an emulator limits the possibilities. Emulators can speed up simulation or even replace simulators.[230] As an example, realistic emulations are used to emulate the 48 V on-board system for the development of the electrified power train. Different voltages and currents can be emulated to supply and test electrical components for vehicles. This battery emulator can, therefore, replace most kinds of batteries.[231]

[229] Cf. Köhler (2011), p. 24.
[230] Cf. Köhler (2011), pp. 25-26.
[231] Cf. Scienlab electronic systems (2013), www.scienlab.de, date of access [03.01.2014].

5 48 V-MARKET

The rapidly-growing hybrid market is being driven by several factors including the increase of fuel prices, the pursuit of improved fuel efficiency, incentives and the appeal to consumers and automotive manufacturers of creating a 'green' image.[232] Tab. 5.1 shows the key players concerning the 48 V system in the automotive market which were determined by Navigant Research. It is recommended to monitor these companies accurately.[233]

Name	Country	Logo
ALABC	*USA*	
Audi	*Europe*	
BMW	*Europe*	
Bosch	*Europe*	
BYD	*Asia*	
Continental	*Europe*	
CPT	*Europe*	
Delphi	*Europe*	
Eberspaecher	*Europe*	
EIG	*Asia*	
FEV	*Europe*	

Name	Country	Logo
General Motors	*USA*	
Hella	*Europe*	
Infineon Technologies	*Europe*	
Johnson Controls, Inc.	*USA*	
Leyden Energy	*Europe*	
PowerGenix	*USA*	
Ricardo	*Europe*	
Schaeffler	*Europe*	
SK Continental E-motion	*Europe*	
Valeo	*Europe*	

Table 5.1: **Global key player for the 48 V-technology (own illustration).**[234]

5.1 Production and sales

The global light vehicle production was around 69.2 million units in 2007 and dropped down to 57.4 million in 2009. After that, the production increased permanently every year. However, the growth rate is expected to exceed 92 million in 2015 as shown in Fig. 5.1.[235]

[232] Cf. Murphy (2011), p. 11.
[233] Cf. Navigant Research (2013), www.navigantresearch.com, date of access [09.04.2014].
[234] Cf. Navigant Research (2013), www.navigantresearch.com, date of access [07.04.2014].
[235] Cf. Murphy (2011), p. 22.

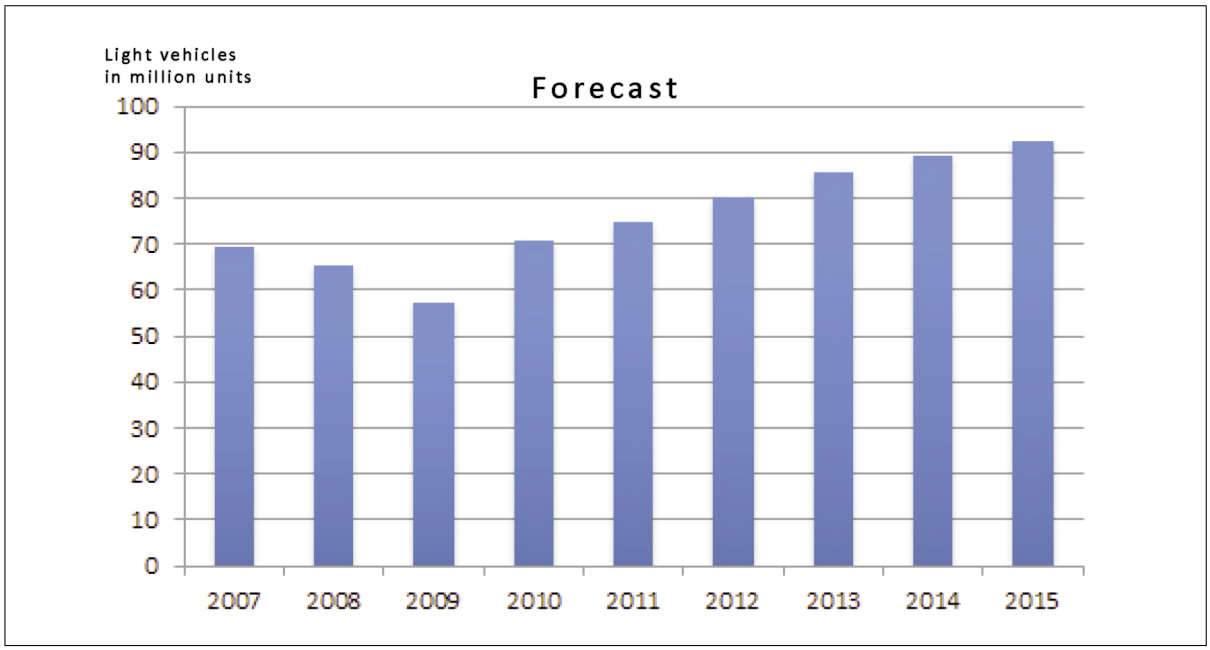

Figure 5.1: **Global light vehicle production in million units.**[236]

The company Continental has already received orders and announced its Eco Drive system production start in 2016 which performs as a low cost alternative to the full high-voltage hybrid drive. A fuel consumption cut of 13 % is expected. The comparable boost recuperation system (BRS) from Bosch offers a CO_2 emission reduction of up to 15 %. Continental and Bosch claim that extra savings in high-current applications such as the compressor, starter, heaters, etc. will be achievable. Continental expects that one third of all passenger vehicles will implement a 48 V on-board supply by 2025.[237]

The individual sales forecast for light vehicles in different markets, which is shown in Tab. 5.2, illustrates that China has the strongest forecasted increase in the following years. Only Japan has an expected slight decline until 2015.[238]

The expected global light vehicle production is over 100 million by 2015 whereas Asia is expected to clearly outpace other regions, despite Asian OEMs (Original Equipment Manufacturer) also increase output outside of Asia. The share of the Asian light vehicle production will grow from 48 % in 2011 up to 53 % by 2016. This means that 55.8 million light vehicles will be expected to be produced by 2016 in Asia whereas 23.4 million produced cars are forecasted for Europe and 17.3 million for North America.[240]

[236] Murphy (2011), p. 22.
[237] Cf. Ricardo Quarterly Review (2013), p. 5.
[238] Cf. Polk and Company (2012), www.polk.com, date of access [29.08.2013].
[239] Polk and Company (2012), www.polk.com, date of access [29.08.2013].
[240] Cf. Standard & Poors (2012), date of access [07.10.2013], p. 8.

Light vehicle sales forecast

	2012	2013	2014	2015	2016
Global	77.7	83.4	88.1	92.2	96.3
Europe	19.0	20.3	21.5	22.7	23.7
United States	13.7	14.9	15.6	16.0	16.3
Brazil	3.6	3.8	3.9	4.1	4.3
China	17.9	19.4	20.6	22.0	23.6
Japan	4.5	4.8	4.9	4.8	4.8

All numbers in million units per region

Table 5.2: **Light vehicle sales forecast in million units per region.**[239]

Fig. 5.2 shows a global scenario of production volumes of passenger vehicles. It is remarkable that there is a massive decline in pure ICE powertrains in the following years. Only a share of 13 % pure ICE vehicles of the global passenger vehicle production in 2025 is forecasted. An expected share of 56 % by 2025 shows clearly that start-stop systems have already become very relevant for car manufacturers. The estimated share of electrified powertrains in 2025 is over 30 % of passenger vehicles world wide whereas around 12 % are based on a voltage of 48 V. Other hybrid and electric vehicles can be based a voltage level of several hundreds of volts. In 2013, about 2.6 million electrified passenger vehicles were produced, whereas the production will be over 37 million in 2025.[241] Western Europe will be the leading market for the 48 V-technology over the following ten years.[242]

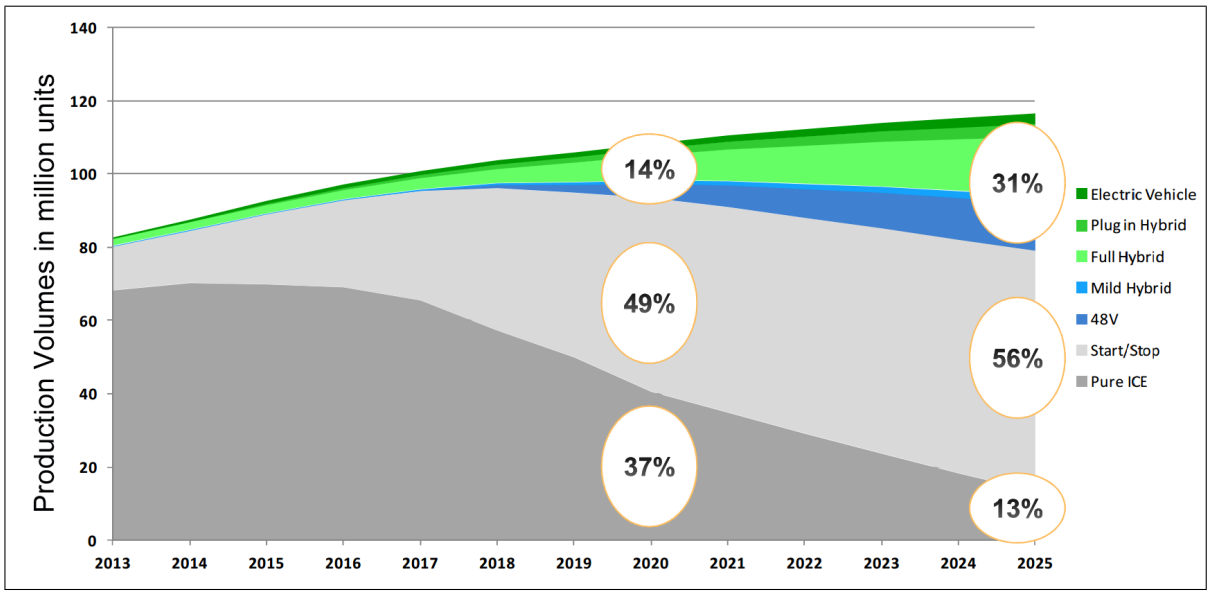

Figure 5.2: **Production forecast for powertrains in passenger vehicles.**[243]

[241] Cf. Mate (2013), www.artemis-ioe.eu, date of access [03.02.2014], pp. 5-6.
[242] Cf. Navigant Research (2014), www.navigantresearch.com, date of access [25.03.2014].
[243] Mate (2013), www.artemis-ioe.eu, date of access [10.04.2014], p. 5.

5.2 CO_2-savings

12 % of the total CO_2 emissions in the EU are caused by cars.[244] Average CO_2 emissions from new cars in Europe dropped from 132.3 g/km in 2012 down to 126.8 g/km in 2013. 15 of the top 20 car maker brands achieved an average CO_2 emission below 130 g/km in Europe. Manufacturers are very mindful of improving efficiency, CO_2 emissions and lower running costs for the customer with each new introduced model. The greatest improvement from 2012 to 2013 had Renault who reduced its average CO_2 emission significantly from 121.3 g/km to 110.1 g/km (Tab. 5.3). The new Clio and Captur are the main drivers for Renault's positive result. Peugeot retained its second place with an average CO_2 emission of 114.9 g/km which was the result of its models Peugeot 208 and Peugeot 2008. Toyota moved up one position to the third rank due to its hybrid versions of the Auris and Yaris while Citroën took fourth place, which was mainly achieved by its new 3-cylinder petrol engines in the C3 model. Fiat's new 7-seater named 500L MPV is the reason that Fiat lost its title of the lowest average CO_2 emissions in Europe after six years which were achieved by its models Panda and 500. A slight reduction of only 1.4 g/km let Fiat drop drown four ranks.[245]

Position	Brand	2013 Average CO_2 (g/km)	2012 Average CO_2 (g/km)	Difference in %	2012 Position
1	RENAULT	110.1	121.3	-11.2	3
2	PEUGEOT	114.9	121.1	-6.2	2
3	TOYOTA	115.9	121.7	-5.8	4
4	CITROEN	116.2	122.0	-5.8	5
5	FIAT	118.1	119.5	-1.4	1
6	SEAT	118.9	124.0	-5.1	6
7	FORD	122.1	129.3	-7.1	9
8	SKODA	125.3	132.6	-7.3	11
9	DACIA	127.1	137.9	-10.8	15
10	SUZUKI	127.3	130.5	-3.3	-
11	VOLKSWAGEN	127.8	133.5	-5.6	13
12	NISSAN	129.3	136.4	-7.2	14
13	MINI	129.5	128.6	0.9	7
14	KIA	129.5	128.9	0.6	8
15	HYUNDAI	129.7	132.3	-2.6	10
16	OPEL/VAUXHALL	132.0	132.8	-0.8	12
17	VOLVO	132.1	143.3	-11.1	19
18	AUDI	135.0	139.3	-4.3	16
19	BMW	135.7	140.8	-5.1	17
20	MERCEDES	139.5	147.6	-8.1	20

Table 5.3: **Top 20 car brands of average CO_2 emissions.**[246]

All analyzed 23 European countries achieved a CO_2 emission reduction from 2012 to 2013 (Tab. 5.4). However, the difference between the lowest and highest emission countries is increasing because of divergent economic conditions and politics initiatives. The highest CO_2 reduction of 9.7 g/km was

[244] Cf. European Commission (2014), www.ec.europa.eu, date of access [07.01.2014].
[245] Cf. Jato Dynamics (2014), www.jato.com, date of access [08.04.2014], pp. 1-3.
[246] Jato Dynamics (2014), www.jato.com, date of access [08.04.2014], p. 2.

recorded in the Netherlands with an average of 109.0 g/km in 2013. The reason for this massive reduction was driven by a tax regime which encouraged to buy lowest-CO_2-emission cars. Greece had the second most improved CO_2 reduction of 8.9 g/km and retains, therefore, the second place in Europe which is the result of an increased share of diesel cars in this long-time petrol-dominated market. Despite the low average CO_2 emissions of 111.6 g/km in Portugal, they were dropping down from the first to the third rank. 2013 is the first year that the average CO_2 emission value of cars is under 130 g/km.[247]

Country	2013 Average CO_2 (g/km)	2012 Average CO_2 (g/km)	Difference in %
Austria	130.5	134.7	-4.1
Belgium	123.7	127.6	-4.0
Croatia	125.4	132.9	-7.5
Czech Republic	135.4	140.6	-5.2
Denmark	113.5	117.4	-4.0
Finland	132.9	139.8	-6.9
France	117.0	124.0	-7.0
Germany	135.9	141.1	-5.2
Great Britain	128.2	132.8	-4.6
Greece	111.3	120.1	-8.9
Hungary	133.8	138.5	-4.8
Ireland	120.4	124.8	-4.4
Italy	120.7	126.1	-5.4
Netherlands	109.0	118.7	-9.7
Norway	123.3	130.5	-7.2
Poland	136.2	141.1	-5.0
Portugal	111.6	117.1	-5.5
Romania	129.2	137.5	-8.3
Slovakia	133.4	139.0	-5.7
Slovenia	125.3	132.7	-7.4
Spain	122.4	128.3	-5.8
Sweden	135.2	137.3	-2.1
Switzerland	144.7	151.3	-6.6
Total Market	**126.8**	**132.3**	**-5.5**

Table 5.4: **Average CO_2 emissions of European countries.**[248]

In 2007 new applications like start-stop systems, smaller combustion engines with a turbo charger, optimized aerodynamics and weight reduction were implemented in so called micro hybrid vehicles. All these mentioned applications became a standard to reduce fuel.[249] Therefore, there is a reduction of 18 % in 2015 and 40 % in 2020 expected compared to the year 2007, when the fleet average was 158.7 g/km. The fuel consumption targets are around equivalent to 5.6 liters per 100 km (l/100km) of petrol or 4.9 l/100 km of diesel in 2015 and 4.1 l/100km of petrol or 3.6 l/100km of diesel. The limits for emissions are set according to the fleet average and not to single cars, which means manufacturers are allowed to produce cars which exceed the limit. The average fleet limit of 130 grams of CO_2 per kilometer will be phased in between 2012 and 2015 which is also shown in Fig. 5.3.

[247] Cf. Jato Dynamics (2014), www.jato.com, date of access [08.04.2014], pp. 3-4.
[248] Jato Dynamics (2014), www.jato.com, date of access [08.04.2014], p. 4.
[249] Cf. Nalbach/Hoff/Körner (2013), p. 435.

A manufacturer has to pay a fine for each registered car if its average fleet is higher than the limit of 130 grams of CO_2 per kilometer in any year from 2012. For the first exceeded g/km costs of 5 € are to pay, 15 € for the second g/km, 25 € for the third g/km, and 95 € for each additional g/km. In 2019, every single gram which exceeds the limit occasions costs of 95 €. The fleet average target for 2020 is set on 95 g/km.[250]

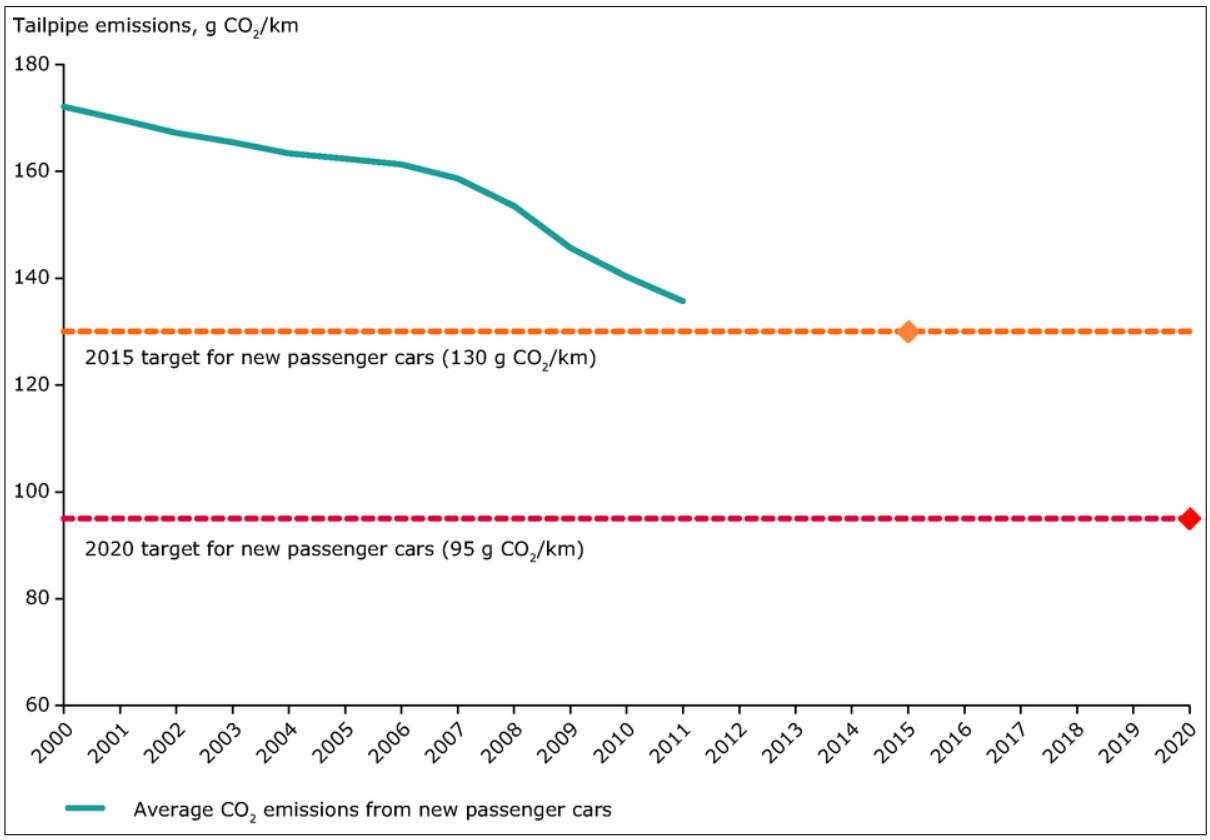

Figure 5.3: **Average CO_2 emissions of European countries.**[251]

However, there are also incentives for the car manufacturers if they produce cars with very less emission. Every car below 50 g/km will be counted as 3.5 vehicles in 2012 and 2013, 2.5 in 2014 and 1.5 vehicles in 2015 which supports the manufacturers to observe the average fleet emission limits. Exceptional cases must be applied for separately and will be decided by the European Commission.[252]

[250] Cf. European Commission (2014), www.ec.europa.eu, date of access [07.01.2014].
[251] European Environment Agency (2013), www.eea.europa.eu, date of access [08.01.2014].
[252] Cf. European Commission (2014), www.ec.europa.eu, date of access [07.01.2014].

5.3 48 V-related industries

A secondary research resulted applications and industries besides passenger vehicles which are based on 48 V which are shown in Tab. 5.5.

48V-related industries and applications
Air Conditioning
Audio industry
Automation
Bus systems
Electric personal vehicles
Electric Tools
Energy engineering
Forklift trucks
Golf carts
Light duty vehicles
Light industry
Marine industry
Medical technology
Pedelecs
Telecommunication industry
Uninterruptible Power Supplies
Wheelchairs

Table 5.5: **Industries and applications based on 48 V besides passenger vehicles.**[253]

Air conditioning

Several DC air conditioners are designed to work with 48 V from solar panels, wind power generated DC power source, telecom DC power source, battery or industrial DC power source.[254]

Natural smoke- and heat venting devices must also work reliable in the event of fire. Essmann GmbH offers control units which work with a power supply of 48 V. Domed roof lights are also in the product portfolio of Essman which also work with a voltage of 48 V.[255]

[253] Own illustration.
[254] Cf. Aislu Electric Co., Ltd (2013), www.aislu.com, date of access [30.09.2013].
[255] Cf. Essmann GmbH (2013), www.essmann.de, date of access [10.10.2013].

Audio technology

Phantom power is a standard power supply in the audio industry between 12 V and 48 V DC which is used to supply a capacitor microphone. Usually mixer consoles, audio interfaces or other external power supplies provide the phantom power which is connected to capacitor microphones via XLR-connectors. A DI-Box is also supplied by phantom power, which is basically used to convert a single-ended signal to a symmetric signal, thus a low noise transmission over long distances is possible.[256]

Automation

The KUKA LBR Robot (Fig. 5.4) works with 48 V and is perfectly made for positioning, picking-and-placing, inserting and assembling. Furthermore, its flexibility allows it to be a robot assistance system for medical engineering.[257]

Figure 5.4: **KUKA LBR Robot based on 48 V.**[258]

Bus systems

48 V for DC bus systems has established itself. DC/DC-converters enable to use other modern electronic devices which need different voltage levels like 24, 12, 5 or 3.3 V. The company VICOR describes itself as a specialist for 48 V bus systems.[259]

Electric personal vehicles

Some kinds of electric mopeds, scooters, segways, trikkes, autoscooters, yike bikes etc. are supplied by 48 V battery systems. The global players in personal transport such as Toyota, Honda, BMW, Nissan, Volkswagen, Suzuki and General Motors are all seeking secondary transport solutions which

[256] Cf. San Segundo (2009), www.megaaudio.de, date of access [27.09.2013].
[257] Cf. Industrie-Schweiz (2013), www.industrie-schweiz.ch, date of access [30.09.2013].
[258] Industrie-Schweiz (2013), www.industrie-schweiz.ch, date of access [27.09.2013].
[259] Cf. Hy-Line Power Components GmbH (2013), www.hy-line.de, date of access [30.09.2013].

can be kept inside a car trunk and carried on public transport. These solutions should bridge nodes on the transportation grid and get everyone to their destination as quick as possible (Fig. 5.5).[260] Therefore, the author assumes that the power supply will also be primarily 48 V for the batteries due to the fact that the same on-board supply level is used for 48 V HEVs and electric bicycles.

Figure 5.5: **Different kinds of personal mobility devices: (from left to right) "Motor Compo"(Honda), "Bik.e"(VW), "Townwalker"(Honda) and a man on a yike-bike.**[261]

Electric bikes mostly have one or two 48 V batteries with around 20 Ah and 10 kg. The electric motors of these bikes are around 500 W, the maximum speed is mostly between 30 km/h and 40 km/h and the range approximately 50 km.[262]

Electric Tools

Similar to batteries of wheel chairs are the batteries for lawn mowers and vacuum cleaners which are mostly 48 V lithium-ion batteries with a capacity of 50 Ah.[263]

Energy engineering

Solar systems are often based on 48 V. Several offers include an additional battery to save the energy for different applications, e.g. e-bikes, pumps etc.[264] Moreover, some wind generators also work on a nominal voltage of 48 V.[265]

Forklift truck

48 V-electric-forklift trucks are available in a three-wheel or four-wheel version which have lifting capacities from up to two tonnes. Companies like CAT or Atlet advertise especially the very low total cost of ownership which refers to a low-maintenance solution. Fig. 5.6 shows a three-wheel 48 V forklift truck.[266]

[260] Cf. Hanlon (2013), www.gizmag.com, date of access [10.10.2013].
[261] Hanlon (2013), www.gizmag.com, date of access [10.10.2013].
[262] Cf. Daymak (2011), www.daymak.com, date of access [20.03.2014].
[263] Cf. HECO New Energy Technology Co., Ltd. (2014), www.lexology.com, date of access [29.03.2014].
[264] Cf. Solar Bike (2010), www.solarbike.com.au, date of access [30.09.2013].
[265] Cf. Rulis Eléctrica Lda (2013), www.silentwindgenerator.com, date of access [30.09.2013].
[266] Cf. Cat Lift Truck (2014a), www.catliftpower.com, date of access [23.03.2014].

Figure 5.6: **3-wheel 48 V forklift truck.**[267]

A quick and safe battery replacement with an easy sideways exchange possibility makes it more comfortable.[268] The 48 V batteries in the forklift trucks have up to 750 Ah and lift motor of around 11 kW.[269] Even the company Toyota offers similar 48 V electric forklift trucks with speeds of up to 20 km/h and heights of up to 7.5 meters.[270]

Golf carts

Mostly six 8 V batteries or eight 6 V batteries are used to supply golf carts. A DC motor with around 5 HP is included. Fig. 5.7 shows an example of a 48 V-based golf cart.[271]

Figure 5.7: **A golf cart with a 48 V motor supplied by six batteries of 8 V.**[272]

[267] Cat Lift Truck (2014a), www.catliftpower.com, date of access [27.12.2013].
[268] Cf. Cat Lift Truck (2014b), www.catliftpower.com, date of access [23.03.2014].
[269] Cf. Atlet (2014), www.atlet.com, date of access [23.03.2014].
[270] Cf. Toyota Material Handling Europe S.A. (2014), www.toyota-forklifts.eu, date of access [23.03.2014].
[271] Cf. Cars-N-Cars (2014), www.carsncarts.com, date of access [25.05.2014].
[272] Shenzhen Marshell Green Power Co.Ltd. (2014), www.marshell.manufacturer.globalsources.com, date of access [03.01.2014].

Light duty trucks

Electric vehicles are perfectly made for the transport sector due to the fact that they are quiet, ideal for short distances and inexpensive. Moreover, electric vehicles do not emit local CO_2 emission in the operational area.[273] A secondary market research shows that trucks which are based on an on-board supply of 48 V have rarely been introduced to the market yet. Only a few single approaches such as the electric utility vehicle for passenger transportation are using 48 V batteries to propel the vehicle (Fig. 5.8).[274]

Figure 5.8: **48 V electric utility vehicle for passenger transportation.**[275]

The company Alke from Padova (Italy) develops several different electric utility vehicles, whereas some of them even use the recuperation technology. The battery pack consists mostly of four 12 V lead-acid batteries[276]

Electric tippers with 48 V batteries are already available since 2004 such as the vehicle G5-E from the company Goupil (Fig. 5.9).[277]

Figure 5.9: **Goupil G5-E Van & Tipper with a 48 V system voltage.**[278]

[273] Cf. AustriaTech (2013), www.eurosolar.at, date of access [14.02.2014], p. 2.
[274] Cf. Direct Industry (2014), date of access [12.04.2014].
[275] Direct Industry (2014), www.directindustry.com, date of access [12.04.2014].
[276] Cf. Alke (2014), www.alke.com, date of access [12.04.2014].
[277] Cf. Chancey (2012), www.evalbum.com, date of access [12.04.2014].

The company Yangzhou Dawn Import & Export Co., Ltd. sells electric bicycles, electric cars and electric trucks. However, only a pickup truck/van with a 48 V on-board supply and a 6 kW electric DC motor is available yet.[279]

Sales of light duty vehicles with a 48 V electrical subsystem are expected to be very low in the following years until 2020. However, a consistently steady increase is forecasted and from 2020 to 2023 sales figures are presumed to rocket. It is expected that in 2023 the light-duty vehicle sales will be around 13.5 million (Fig. 5.10).[280]

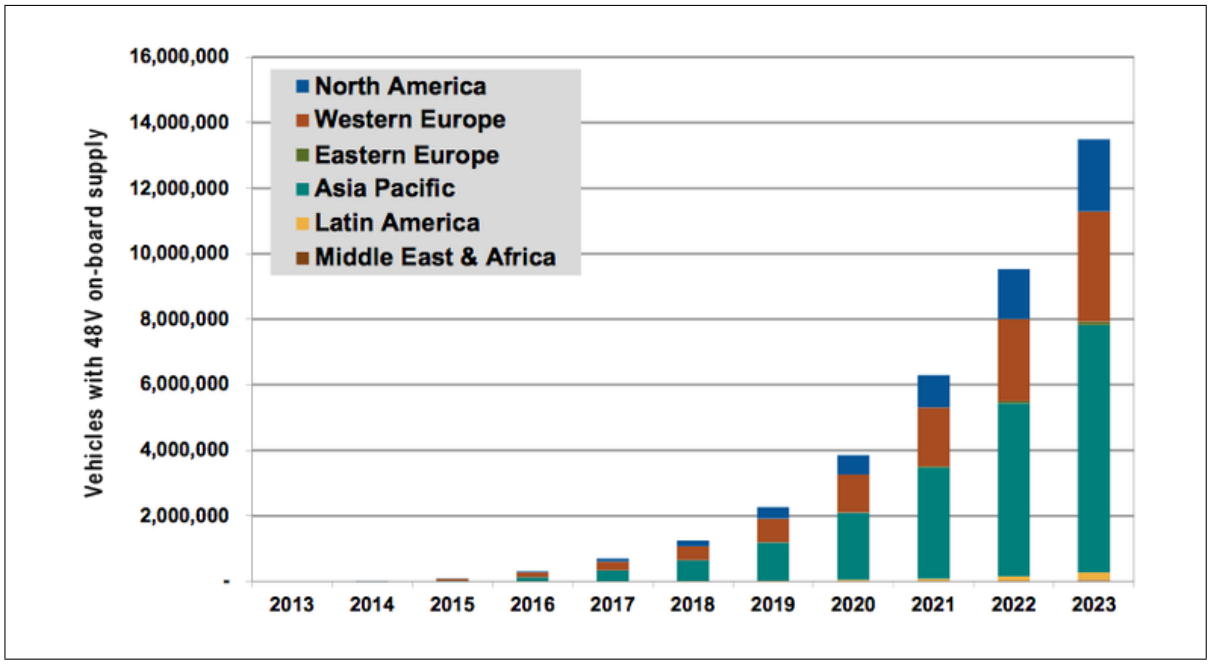

Figure 5.10: **Worldwide sales of light-duty vehicles with the 48 V-technology.**[281]

Light industry

Different kinds of lights like flashing beacons, strobe lights, headlights, spot lights and also lamps for electric scooters which are designed for 48 V DC are already available.[282]

Marine industry

The boat in Fig. 5.11 is named Acciona IMOCA 69 Eco Powered and is only powered with renewable energy. The boat includes 480 Ah/48 V lithium ion system from the company Mastervolt. Wind- and water generators as well as solar panels generate power and recharge the battery system.[283]

[278] Chancey (2012), www.evalbum.com, date of access [12.04.2014].
[279] Cf. Yangzhou Dawn Import & Export Co., Ltd. (2010), www.yzdawn.com, date of access [12.04.2014].
[280] Cf. Navigant Research (2014), www.navigantresearch.com, date of access [25.03.2014].
[281] Green Car Congress (2014e), www.greencarcongress.com, date of access [12.04.2014].
[282] Cf. BulbTown (2014), www.bulbtown.com, date of access [01.04.2014].
[283] Cf. Re Teh, Earth Friendly Energy Solutions (2012), date of access [20.11.2013].

Figure 5.11: **Acciona IMOCA 69 – a 48 V on-board supply powered boat.**[284]

Medical technology

In the medical technology industry numerous motors have a nominal voltage of 48 V, e.g. electric dermatomes, dental drills etc.[285] The KUKA LBR Robot is also used for different applications in the medical technology industry.[286]

Pedelecs

E-bikes which only assist human power instead of replacing it are called pedelecs which is the abbreviation for Pedal Electric Cycle. The European legislation says that above a speed of 25 km/h the electric motor must be automatically switched off.[287]

Telecommunications industry

In earlier days of telephone networks, the power supply of -48 V DC was found to make telephones work on long telephone lines and still low enough not to cause serious danger if somebody touches the telephone wires. After telephone central offices started using -48 V DC, the power supply became the standard. The main reason for the negative voltage on the line is to prevent electro-chemical reactions from destroying the copper cable quickly, if cables get wet.[288]

Uninterruptible power supplies

48 V uninterruptible power supplies (UPS) are power backup systems which have a big scope such as for telecom, medical devices, computer servers and desktop computers. Currently Li-ion batteries

[284] Re Teh, Earth Friendly Energy Solutions (2012), date of access [20.11.2013].
[285] Cf. Integra LifeSciences Corporation (2014), www.integralife.com, date of access [02.02.2014].
[286] Cf. Industrie-Schweiz (2013), www.industrie-schweiz.ch, date of access [30.09.2013].
[287] Cf. Go Pedelec (2014), www.gopedelec.eu, date of access [06.04.2014].
[288] Cf. Sinrace Power Supply Technology (2013), www.sinrace.com.cn, date of access [27.09.2013].

have a better energy and power density as well as reliability and lifetime than traditional battery types. A failure of this system could have terrible impacts, therefore, periodic self-imposed discharge measurement sequences along with detailed modeling and prediction algorithms provide the function with enough early warning to replace the battery. Since safe battery management solutions exist, those components are found in hybrid or battery electric vehicles.[289]

Wheelchairs

48 V lithium-ion batteries for wheel chairs, scooters, and other applications are offered by different suppliers, whose advertisements of lithium-ion batteries offer a five times higher lifetime compared to lead acid batteries and a capacity of 50 Ah.[290]

5.4 48 V test equipment suplliers

An online research and information from AVL have resulted in a list of some 48 V test equipment suppliers. Besides AVL, following suppliers should be monitored concerning test systems for 48 V:

Name	Country	Logo	Name	Country	Logo
Aerovironment	*USA*		ET System Electronic	*Europe*	
Arbin Instruments	*USA*		Genesis Test Integration Pte	*Asia*	
A&D Technology	*USA*		Kratzer Automation	*Europe*	
BaSyTec	*Europe*		Maccor	*USA*	
Benning	*Europe*		Magna Powertrain	*Europe*	
Bitrode	*USA*		NH Research	*USA*	
Chroma Systems Solutions	*USA*		PEC Corp.	*Europe*	
Digatron Power Electronics	*Europe*		Scienlab Electronic Systems	*Europe*	
Emerson Electric Co.	*USA*		Zenone Electronica s.r.l.	*Europe*	

Table 5.6: **Global test equipment suppliers for the 48 V-technology.**[291]

5.5 Summary

The global light vehicle production is estimated to exceed 92 million by 2015.[292] Moreover, the hybrid market is growing quickly which is driven by factors such as fuel prices, fuel efficiency, incentives etc.[293] A massive decline of pure ICE powertrains is forecasted from 2014. More than 50 % of the

[289] Cf. Pistoia, pp. 381-382.
[290] Cf. HECO New Energy Technology Co., Ltd. (2014), www.lexology.com, date of access [29.03.2014].
[291] Own illustration.
[292] Cf. Murphy (2011), p. 22.
[293] Cf. Murphy (2011), p. 11.

global production of passenger vehicles is expected to be ICE powertrains with start-stop systems by 2025 which shows very plainly the relevance of start-stop systems for car manufacturers. A share of 30 % of the global passenger vehicle production will be electrified powertrains by 2025.[294] The main market for the 48 V-technology will be Western Europe for the next approximately ten years.[295]

Some global players in personal transport also develop secondary transport solutions which are based on 48 V to bridge nodes on the transportation grid (Fig. 5.5).[296] Sales figures of light duty vehicles with a 48 V electrical subsystem are expected to increase significantly from 2020 to 2023.[297] Other applications such as wheelchairs, boats and robots also use 48 V batteries and could be an interesting market niche for AVL's test equipment.

[294] Cf. Mate (2013), www.artemis-ioe.eu, date of access [03.02.2014], pp. 5-6.
[295] Cf. Navigant Research (2014), www.navigantresearch.com, date of access [25.03.2014].
[296] Cf. Hanlon (2013), www.gizmag.com, date of access [10.10.2013].
[297] Cf. Navigant Research (2014), www.navigantresearch.com, date of access [25.03.2014].

6 PROCEDURE of the SURVEY

A primary research was carried out to assess AVL's customers' needs and to minimize the risk for investments in the 48 V-technology. Customers from AVL (OEMs, Tier-1s) were surveyed with an online questionnaire, which is in the appendix A. The progress of the survey, from the development of the questionnaire via improvements through to evaluating the results are shown in Fig. 6.1.

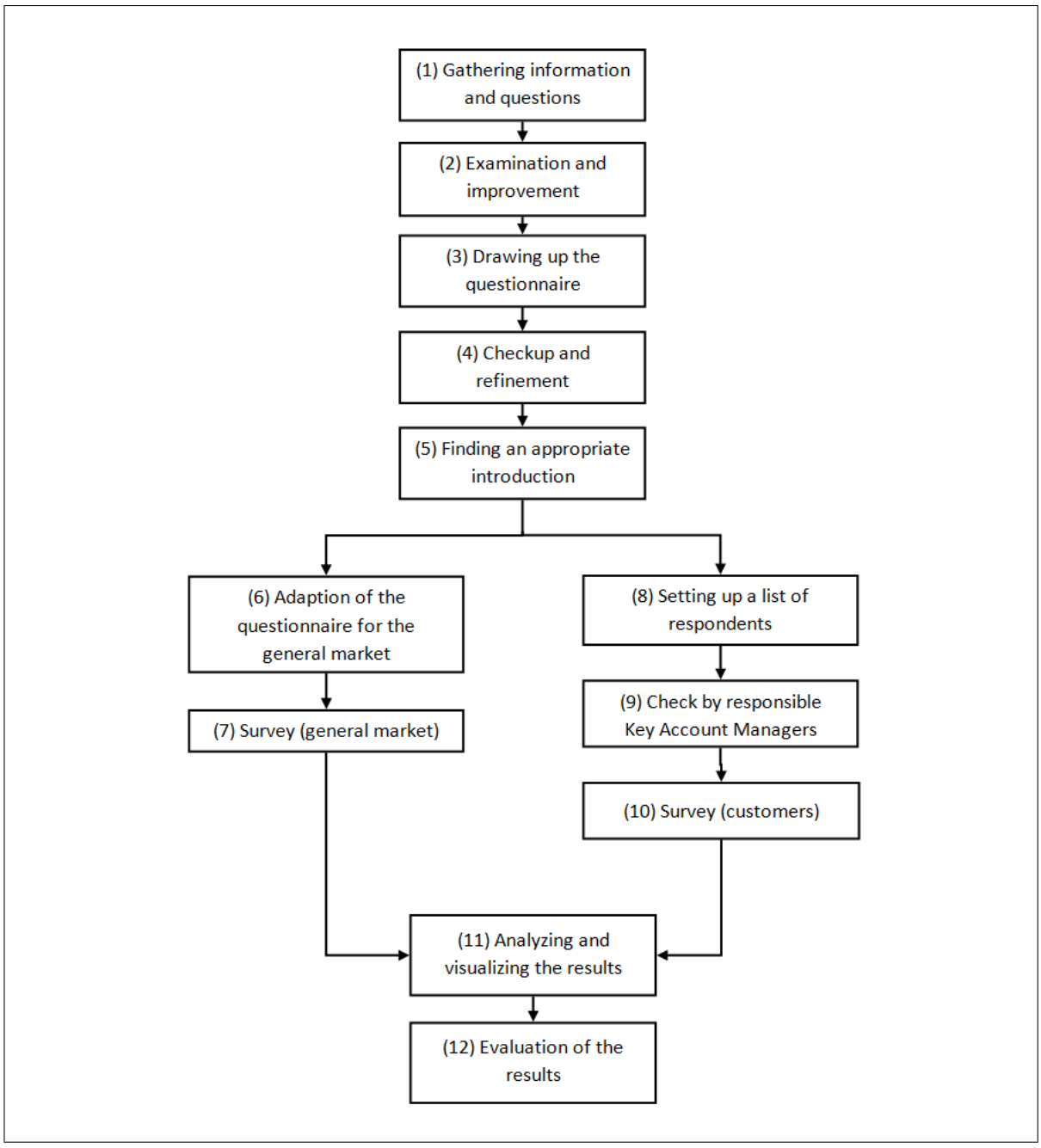

Figure 6.1: **Procedure of the survey.**[298]

[298] Own illustration based on Statistics Bureau (1996).

(1) Gathering information and questions

The questions in the questionnaire are developed by Donald Wright and by other employees of the department "Electrification and Racing Test Systems" in AVL as well as by the author of this thesis after going through current information and presentations of AVL. It is useful to bring in questions, which are suggested by employees from AVL due to the fact that they know what would be important to find out. Therefore, the result of this work step was a list of potential questions which could be asked to customers from AVL.

(2) Examination and improvement

The first basic examination of the predefined questions was done by Donald Wright. The check was basically about usefulness, order and possible answers. The result of this work step was a shortened list of questions which could be asked to AVL's customers.

(3) Drawing up the questionnaire

The questionnaire was made with the online software tool google forms. The general settings for the questionnaire were based on clarity and the least possible distortion of the result. Respondents had the chance to edit their questionnaire after finishing it which was allowed by activating the option "Allow responders to edit responses after submitting". The option "Publish and show a link to the results of this form to all respondents" to show interim results is deactivated due to the fact that only the overall result will be sent out to respondents if required. The result of this work step was a first draft of a questionnaire.

(4) Checkup and refinement

The difficulty, to find the most relevant questions for AVL, was solved by reviewing the defined questions from relevant employees of AVL. Therefore, the first version of the questionnaire was prechecked by six people of the business unit "Electrification and Racing Test Systems". Simplicity, importance of the question and effort to fill out were considered by choosing the final questions. All the improvement suggestions were discussed and adjusted in the questionnaire. The result of this work step was the finalized questionnaire.

(5) Finding an appropriate introduction

One crucial decision was the way how to ask respondents to fill out the questionnaire. Therefore, three scenarios have been discussed:

- Inquiry as a student
- Inquiry from AVL
- Combination

An inquiry from a student from Graz University of Technology to fill out the questionnaire is from a neutral position but respondents will probably recognize that this is most likely sponsored by a company around Graz which might have negative effects on relationships. Respondents would also wonder from where the sender got their e-mail addresses. A direct inquiry from AVL List GmbH Graz could lead to a competitive behavior which means that companies do not want to share their information with AVL or answers could even be given intentionally wrong. Therefore, a combination of both was the final solution for the introduction of the questionnaire. As discussed in chapter 2.2.2 the purpose of the questionnaire, the reason for the interviewer, incentives, contact details and the latest date for completing the questionnaire were included (appendix A). The same information is also in the header of the questionnaire to make facts clear even for respondents who receive a forwarded e-mail or message from their colleagues which only includes the link to the online-questionnaire.

(6) Adaption of the questionnaire for the general market

Before the questionnaire was sent out, an adapted variant of it was posted in expert groups on the social network LinkedIn as well as sent to the Institute of Automotive Engineering Graz and to contacts who work for different OEMs/Tier-1s. The questionnaire is shorter and the questions were basically asked from a car manufacter's point of view (see appendix B)

(7) Survey (general market)

The adapted online-questionnaire was sent out to following institutes/groups:

- TU Graz: Institute of Automotive Engineering
- Contacts: People from OEMs/Tier-1s
- LinkedIn: Electric Vehicles and Hybrid Electric vehicles test - EV/HEV test;

  Hybrid Vehicle;

  Hybrid, Electric, PEV, and PHEV Engineering Professional Group

The reason for this additional survey is to test the clarity and the comprehensibility of the questions. Moreover, an additional opinion can also help to understand the market needs.

(8) Setting up a list of respondents

At the same time the general market fills out the questionnaire, e-mail addresses of one employee per company (shown in Fig. 6.2) were found in the database of AVL. Due to the technically-oriented questionnaire, engineers were preferred as respondents.

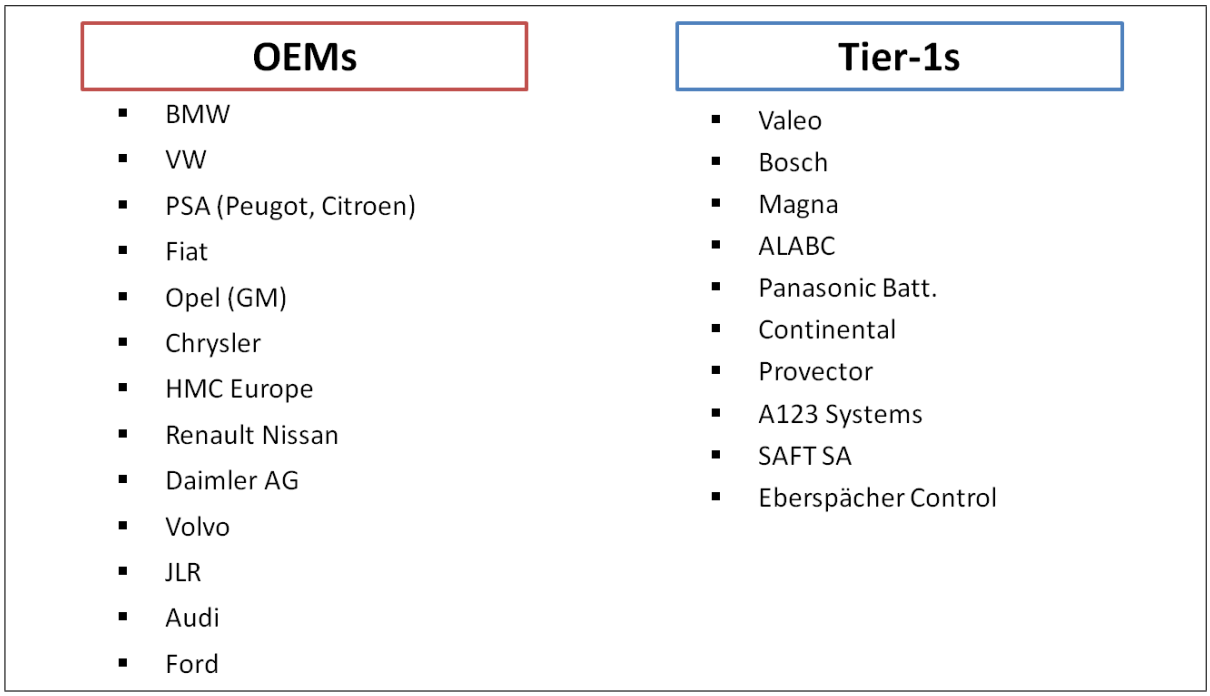

Figure 6.2: **AVL's customers which are relevant to the 48 V-technology.**[299]

[299] Own illustration.

(9) Check by responsible Key Account Managers

All Key Account Managers (KAMs) have been inquired for permission to ask respondents to fill out the questionnaire. This step avoids interviewing the wrong contact person.

(10) Survey (customers)

Questionnaires have been sent out per e-mail to all interviewees who were approved by AVL's KAMs. After nine days, a short reminder was sent out to the interviewees who have not replied as mentioned in chapter 2.2.2. Eight days later, another reminder was sent out.

(11) Analyzing and visualizing the results

All results and information, which were given by the respondents, were analyzed by merging them in lists, calculating medians and arithmetic averages. Furthermore, graphs were created to have a quick overview of the results.

(12) Evaluation of the results

The final visualized and interpreted results to the questionnaires are shown in chapter 7.

7 RESULTS

Responses from 12 different companies (5 OEMs and 7 Tier-1s) were received. 28 filled out questionnaires were received from the general market, which can be separated into 4 responses from the Institute of Automotive Engineering, 10 responses from contacts who work for OEMs/Tier-1s and 14 responses from LinkedIn groups. The number of responses of potential European customer's for 48 V systems are not sufficient to give statistically meaningful data and conclusion. However, rough assessments and tendencies can be derived from the survey results which are supported by supplementing literature research findings.

The questionnaire about requirements for test-systems was divided into four big parts: system questions, simulation and testing, targets and goals for 48 V and test system requirements. The goal of the questionnaire was to figure out future requirements of test equipment for passenger vehicles due to the fact that a big change concerning on-board supply in the automotive industry is expected. As described in chapter 4, a different on-board supply voltage affects almost all other components and offers new possibilities to electrify functions which were not electrified before.

7.1 System questions

System questions are basically used to receive information about the current situation of customers and what people would do in an OEM's position.

7.1.1 Energy storage

Fig. 7.1 shows the question of used energy storage methods for 12 V/48 V which is important to know for battery testbed designs. 15 predefined possible answers are selectable and a box to fill in further alternatives. Due to chapter 2.2.2 it is not recommendable to give too many choices, however, this is a multiple choice question which means you can choose as many as you prefer. Moreover, some answers about batteries are twice but with different voltages. Therefore, it is clear and easy to answer for interviewees. Fig. 7.1 shows that customers are mainly using the combination of a 48 V lithium-ion battery and a 12 V lead-acid battery. Moreover, lithium-ion batteries are even in use for 12 V systems. The general market would also use lithium-ion for the 48 V system and lead-acid for the 12 V supply above all else. Additionally, super capacitors and lead-acid batteries with 48 V are in high demand for the general market.

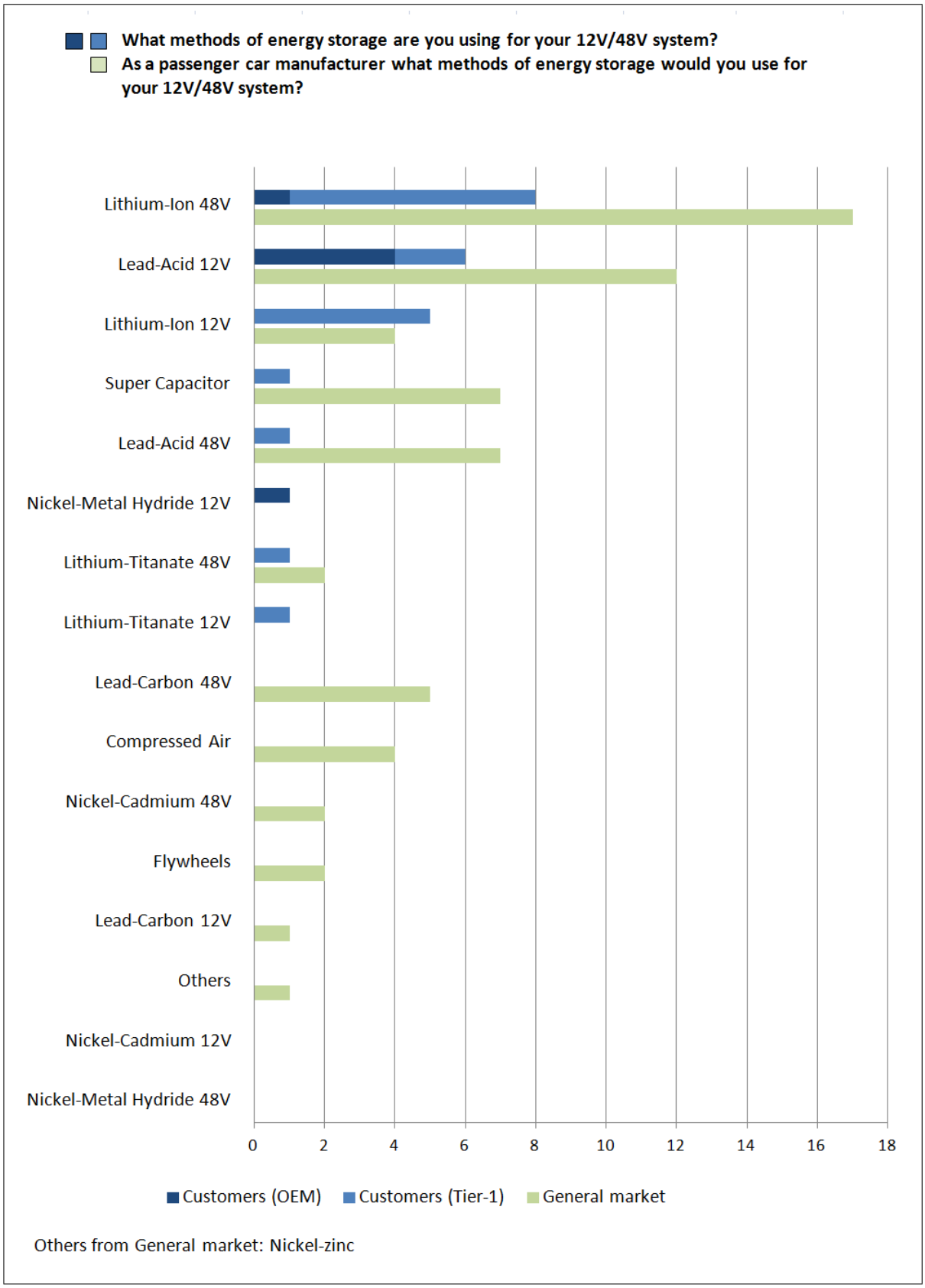

Figure 7.1: **Survey: Question 1 - Use of energy storage methods.**[300]

[300] Own illustration.

Lithium-ion batteries are in really high demand for car manufacturers. Therefore, Tesla has been planning to build its own factory - the so called "Gigafactory". The four states Nevada, Arizona, New Mexico and Texas have been shortlisted for the factory which will include solar and wind parks and will be in production by 2017. The Gigafactory will produce 35 GWh/yr in battery cells and 50 GWh/yr in cell packs. Finished battery packs will be delivered to the production factory in Fremont (CA). 30 % battery pack cost reduction until 2017 compared to now is expected. The production in 2020 will be bigger than the worldwide's total production in 2013 (Fig. 7.2). The total cost of the factory is estimated of up to $5 billion which will be paid by several partners and investors. The current supplier Panasonic is interested in investing $1 billion.[301]

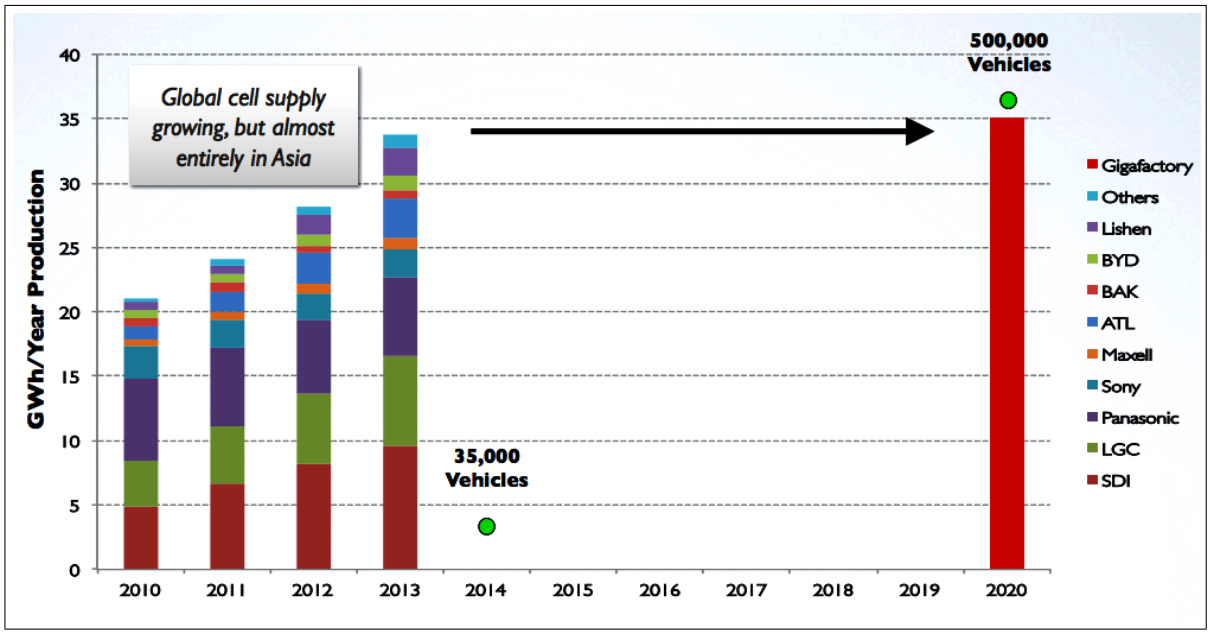

Figure 7.2: **Comparison of the global battery cell supply to Tesla's Gigafactory.**[302]

Bernd Bohr, chairman of the Bosch Automotive Group, states that Bosch plans to develop lithium-ion batteries that will offer double the range at half the cost per kilowatt hour to contribute to the growth of electric vehicles.[303]

Kia's European Research and Development centre developed a new hybrid system which uses a 48 V lead-carbon battery instead of an lithium-ion battery, which supplies a small electric motor. The reason for the battery choice was that lead-carbon batteries don't require active cooling and are easily recyclable at the end of the lifetime. Moreover, the efficiency of lead-carbon batteries are higher in sub-zero temperatures.[304]

[301] Cf. Howard (2014), www.extremetech.com, date of access [08.04.2014].
[302] Howard (2014), www.extremetech.com, date of access [07.04.2014]
[303] Cf. Automotive Design & Production (2013), p. 10.
[304] Cf. Green Car Congress (2014c), www.greencarcongress.com, date of access [23.03.2014].

7.1.2 Communication protocol

An ECU is the most powerful computer on most cars which gathers a huge amount of data from different sensors like coolant temperature or oxygen content in the exhaust. The data is calculated and used to control different actors around the ICE (spark timing, time of open fuel injector, etc.) to ensure the lowest emissions, best mileage.[305] A Transmission Control Unit (TCU) uses sensors from the vehicle and data from the ECU to control automatic transmissions. The data is used to calculate in real-time the optimum time to change gears in the vehicle.[306] Referring to the result in Fig. 7.3 Controller area network (CAN), local interconnect network (LIN) and also FlexRay are the most used communication protocols between different control units in a passenger car. Additionally, an employee of Infineon acknowledged that these three are the communications protocols which will be focused on by Infineon. Although this answer was expected, it could help to determine appropriate interfaces for the test equipment.

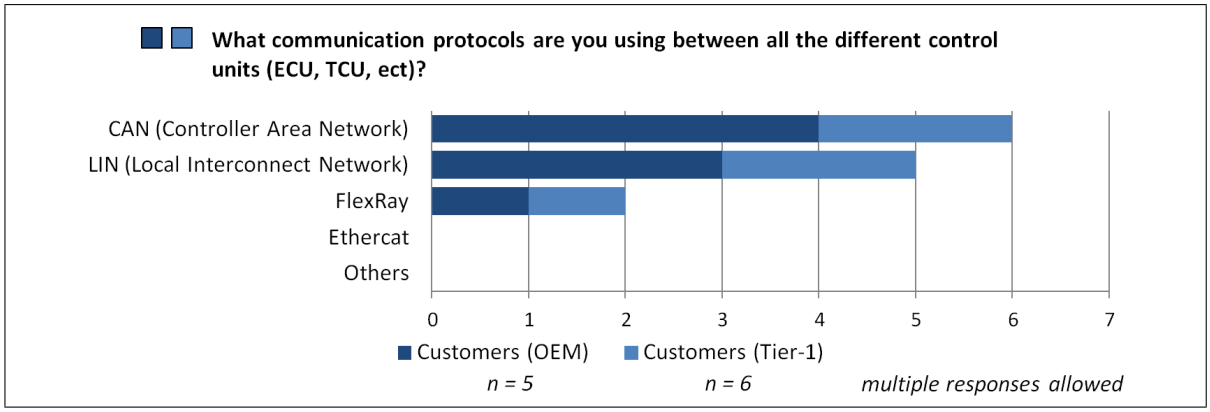

Figure 7.3: **Survey: Question 1 - Use of energy storage methods.**[307]

7.1.3 E-motor type

Fig. 7.4 shows the answers to the question about the use of the e-motor type. It is crucial for e-motor testbed systems to know about what kind of motor is in use by AVL's customers. The result shows clearly that both are used by AVL's customers, whereas twice as many responses were on ISG by the general market which shows a high acceptance of the integrated solution. Advantages and disadvantage (chapter 4.3.3) have to be considered for specific answers.

[305] Cf. Nice (2001), auto.howstuffworks.com, date of access [22.02.2014].
[306] Cf. Autotek Electronics (2012), www.autotekelectronics2012.blogspot.co.at, date of access [22.02.2014].
[307] Own illustration.

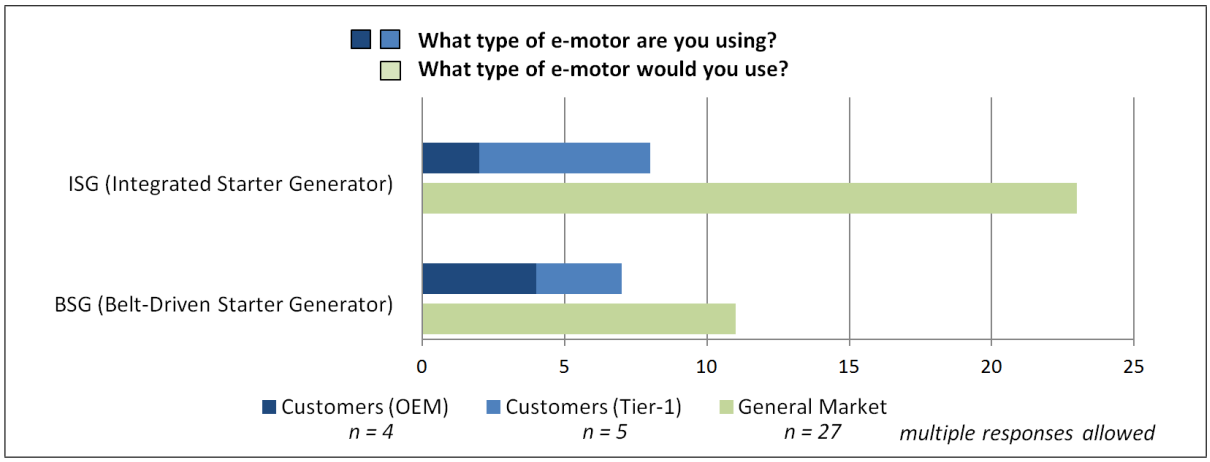

Figure 7.4: **Survey: Question 3 - Use of motor type.**[308]

7.2 Simulation and testing

Questions about simulation and testing are used to find out what potential customers are using and what the general market would use.

7.2.1 X-in-the-loop-development system

The answers to the question in Fig. 7.5 were totally different combined, however it shows that all three types of development tools are important for AVL's customers. HiL, SiL and MiL simulations (chapter 4.5) are, therefore, decisive steps for OEM's and Tier-1's development process.

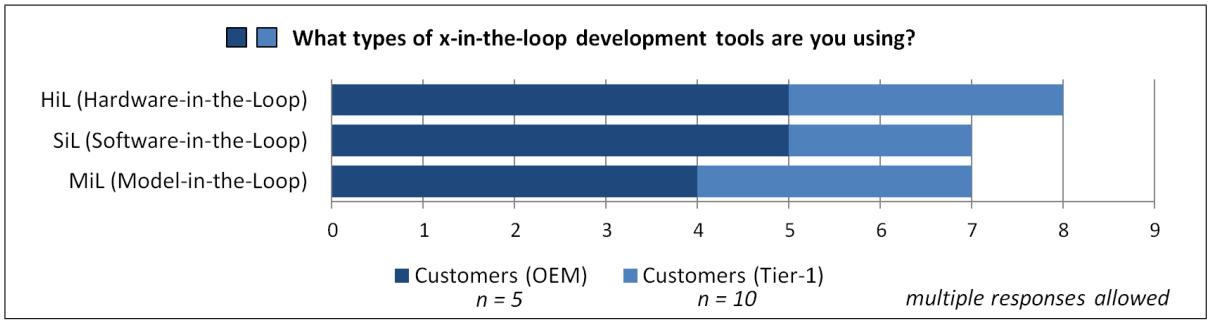

Figure 7.5: **Survey: Question 4 - Use of x-in-the-loop development tool.**[309]

[308] Own illustration.
[309] Own illustration.

7.2.2 Vehicle simulation platform on x-in-the-loop development systems

The result, illustrated in Fig. 7.6, shows that people use and would use a vehicle simulation platform on x-in-the-loop development systems. It can be expected that Tier-1 suppliers who develop single components do not use a vehicle simulation platform. The result was expected and is therefore a confirmation about the current situation of vehicle simulation platforms on x-in-the-loop development systems.

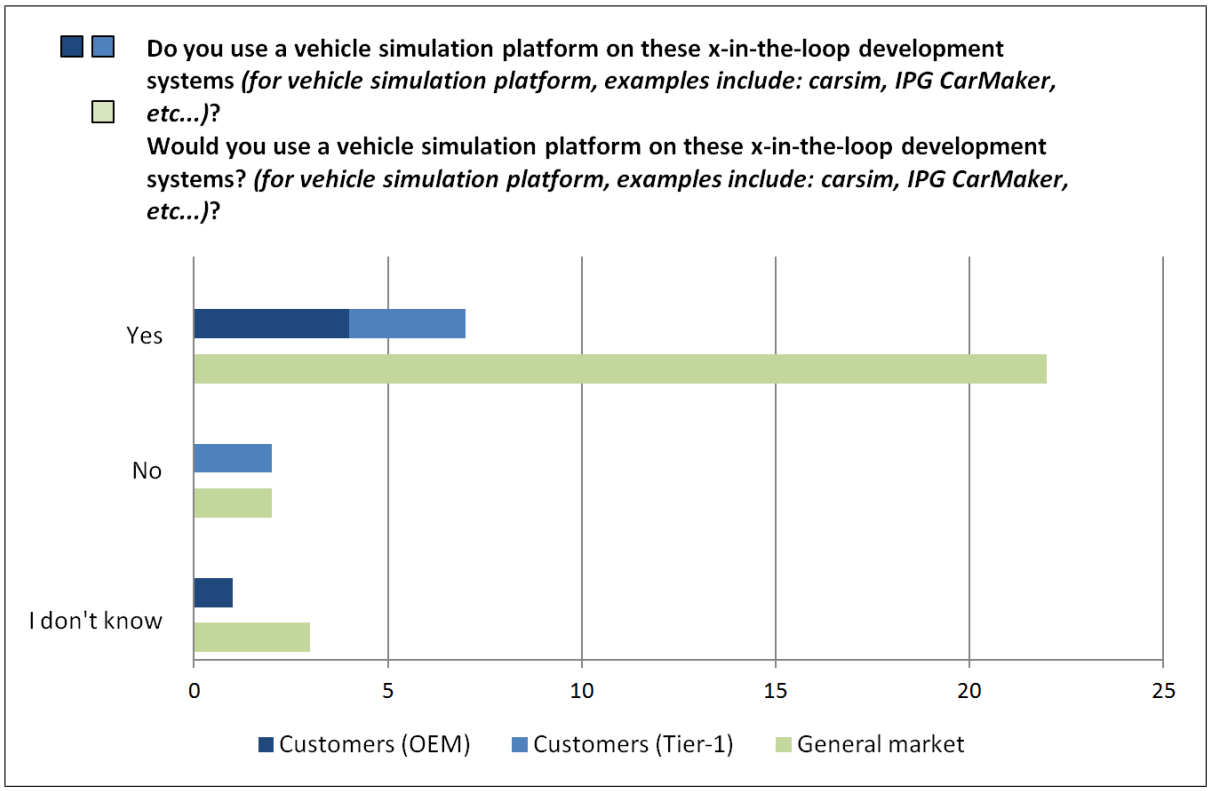

Figure 7.6: **Survey: Question 5 - Use of vehicle simulation platform on x-in-the-loop development systems.**[310]

[310] Own illustration.

7.2.3 Independent component test

Although, Fig. 7.7 does not show a clear result of what component is tested the most, it confirms that all listed components are tested independently, whereas engine, battery, inverter/power electronics and e-motor testbed are the most important ones. However, the general market would give battery test systems the highest priority for testing independently. Both, AVL's customers and the general market ranked transmission testbeds on the least important testbed to test components independently. Nevertheless, all listed components are important for AVL's customers and the general market to test independently before they are brought together.

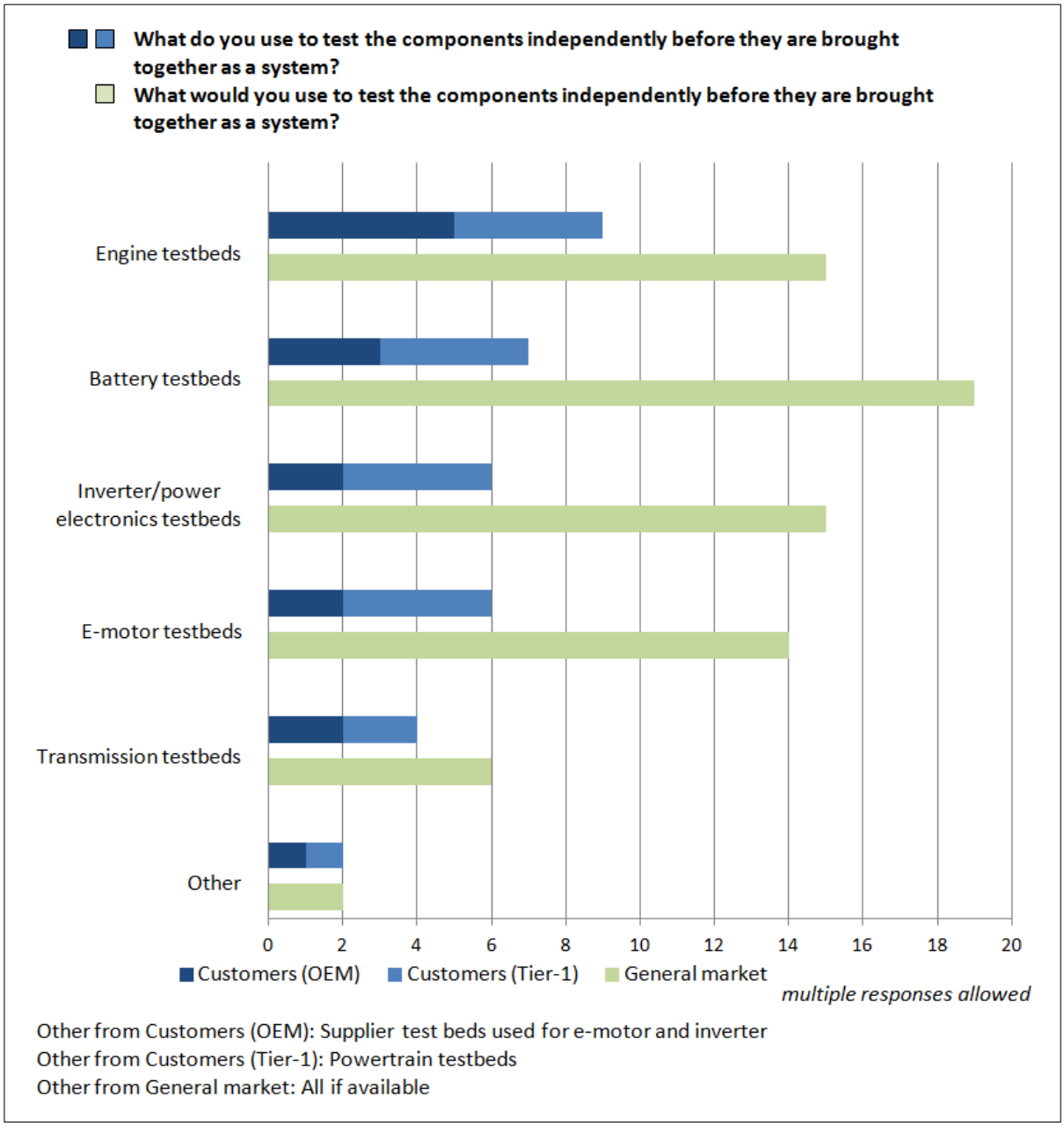

Figure 7.7: **Survey: Question 6 - Use of component test systems before brought together as a system.**[311]

7.2.4 Vehicle simulation on component testbeds

Fig. 7.8 shows clearly that customers use a vehicle simulation platform on their component testbeds. The general market agrees on that by stating that they would use a vehicle simulation platform on their component testbeds. Therefore, the demand for vehicle simulation platforms used on component testbeds is rather covered.

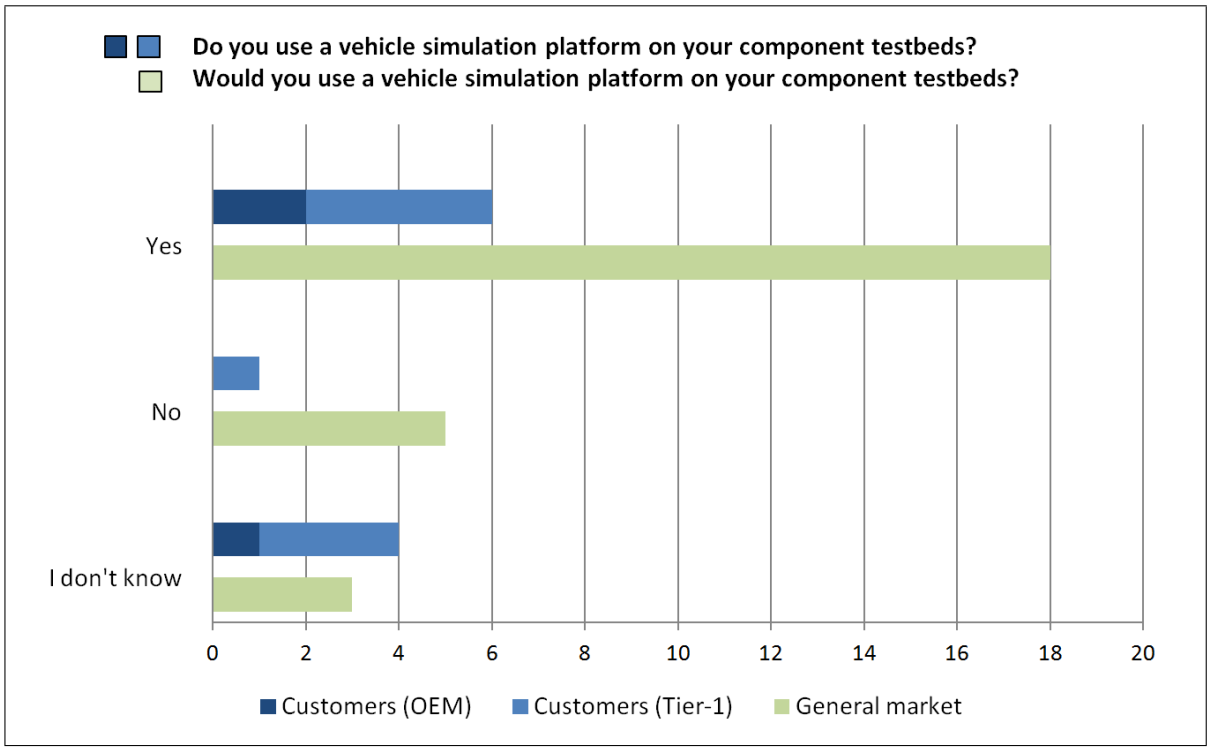

Figure 7.8: **Survey: Question 7 - Use of a vehicle simulation platform on component test systems.**[312]

[311] Own illustration.
[312] Own illustration.

7.2.5 System integration testbeds

Although the majority of the customers is already using system integration testbeds (Fig. 7.9), there are still OEMs and Tier-1s who don't use them. However, the general market would clearly use system integration testbeds.

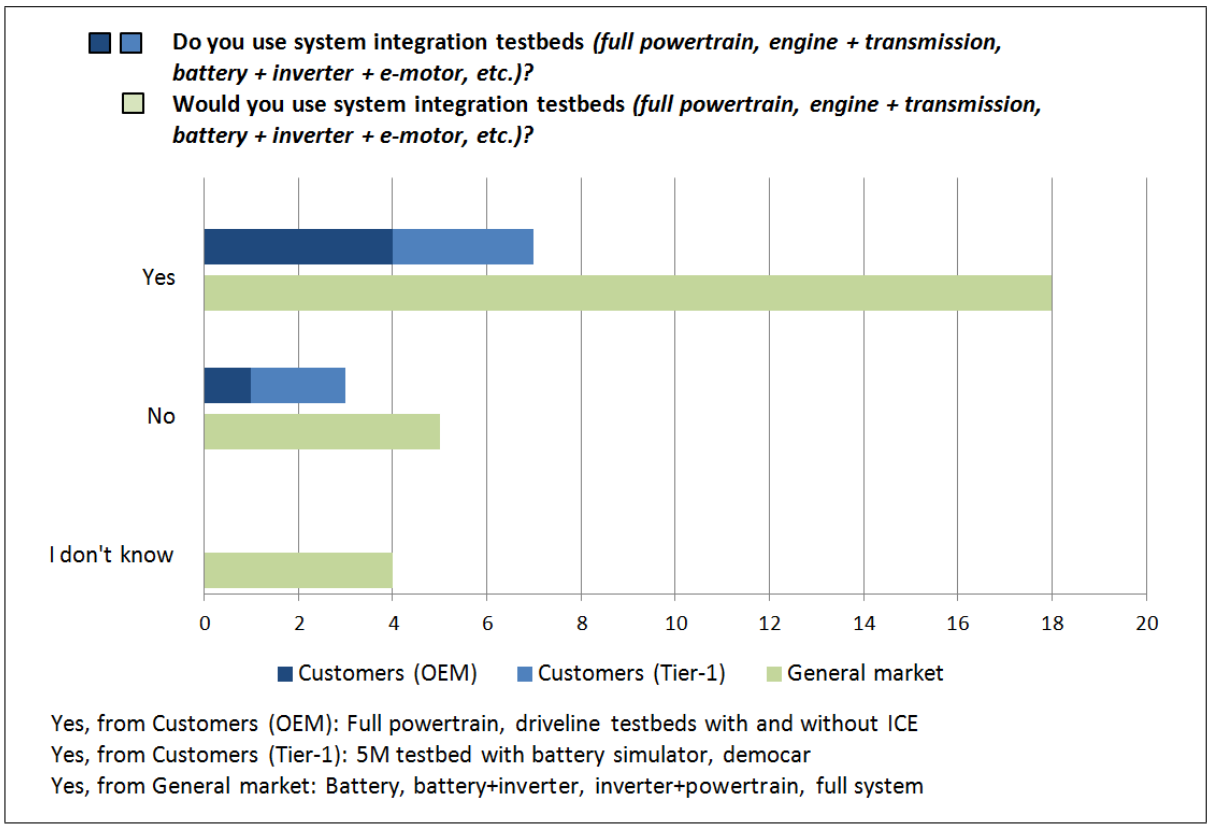

Figure 7.9: **Survey: Question 8a - Use of system integration testbeds.**[313]

The answers range from standard system integration testbeds to confidential treated in-house solutions. Therfore, of those who are using system integration testbeds, following types are used by customers or would be used by the general market (Fig. 7.10).

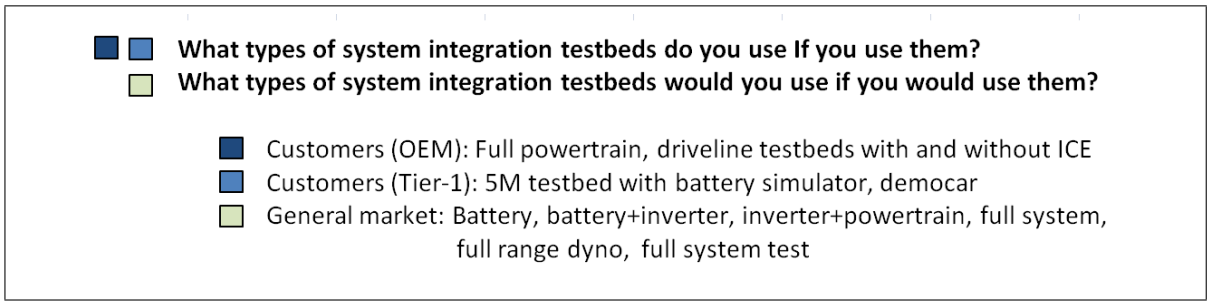

Figure 7.10: **Survey: Question 8b - Types of used system integration testbeds.**[314]

[313] Own illustration.
[314] Own illustration.

7.2.6 Vehicle simulation platform on system testbeds

Due to the result, which is illustrated in Fig. 7.11, most customers use a vehicle simulation platform on system testbeds. The general market would also rather use a vehicle simulation platform on system testbeds. Therefore, the demand for vehicle simulation platforms on system testbeds is rather covered.

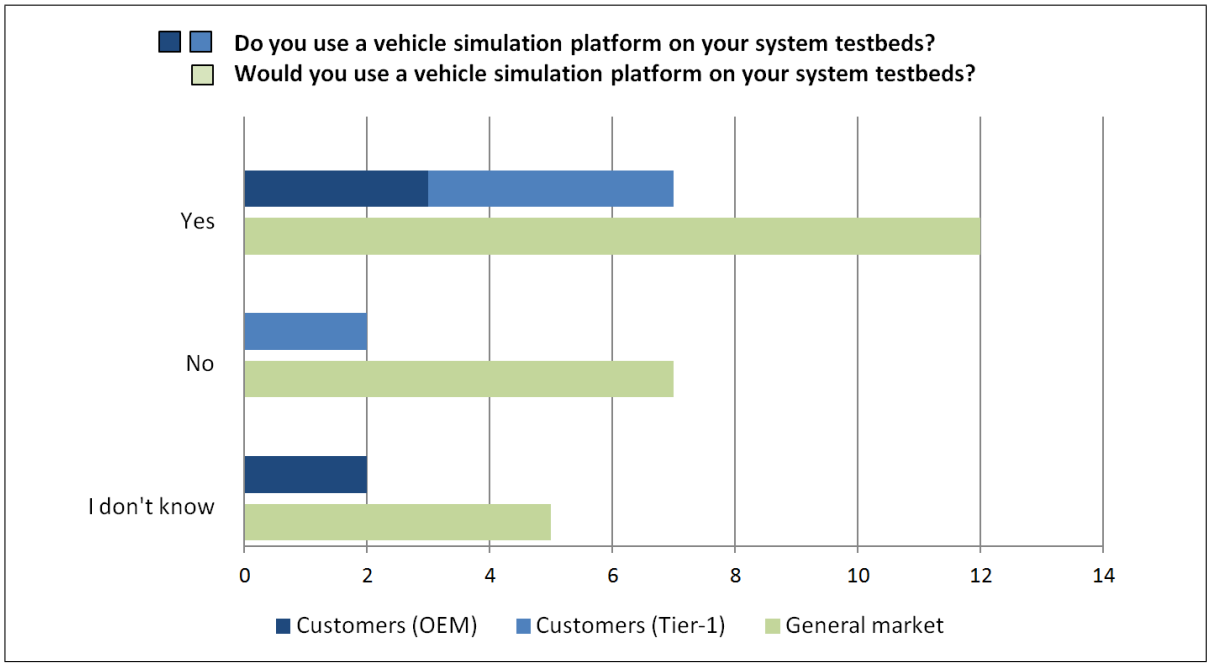

Figure 7.11: **Survey: Question 9 - Vehicle simulation platform on system testbeds.**[315]

[315] Own illustration.

7.2.7 Vehicle simulation platform for all three steps

Fig. 7.12 shows that customers of AVL do not use the same vehicle simulation platform for all three steps which include x-in-the-loop tests, component tests and system tests. However, the general market would use a vehicle simulation platform which covers all three steps of testing. This significant difference in the responses offers a big chance for AVL to close this gap. AVL's Integrated and

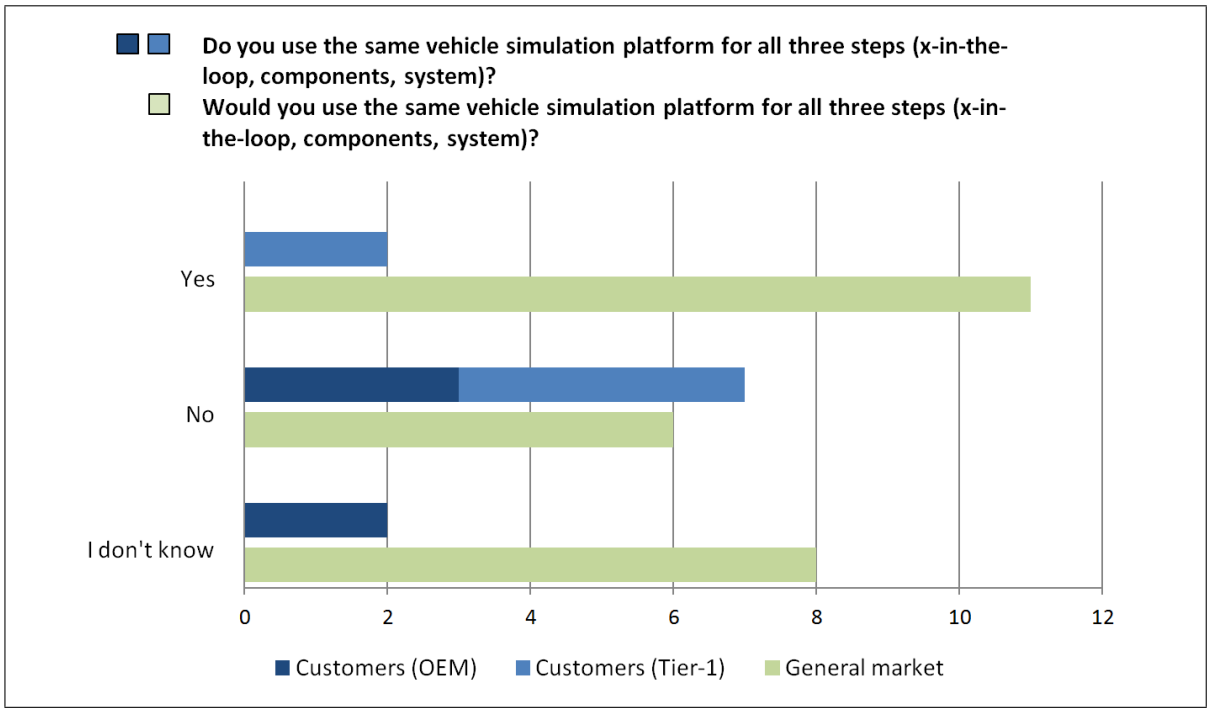

Figure 7.12: **Survey: Question 10 - Use of vehicle simulation platform for x-in-the-loop, component and system testbeds.**[316]

Open Development Platform (IODP) which is a consistent tool chain from the virtual world to the real world could be a chance to meet customer needs.[317] The author presumes, that this is a good opportunity to cover the whole development process by one vehicle simulation platform.

7.3 Targets and goals for 48 V

A crucial part of the survey is to find out the targets of potential customers for/with the 48 V technology. For this reason following answers could help to better assess future requirements:

[316] Own illustration.
[317] Cf. AVL List GmbH (2013), pp. 16-19.

7.3.1 Other target markets besides passenger vehicles

The survey results in Fig. 7.13 show that customers of AVL are targeting on light-duty trucks and sportcars, whereas Mr. Matthias Dank from AVL Racing department states, "There is no market for sportcars with a 48 V on-board supply".

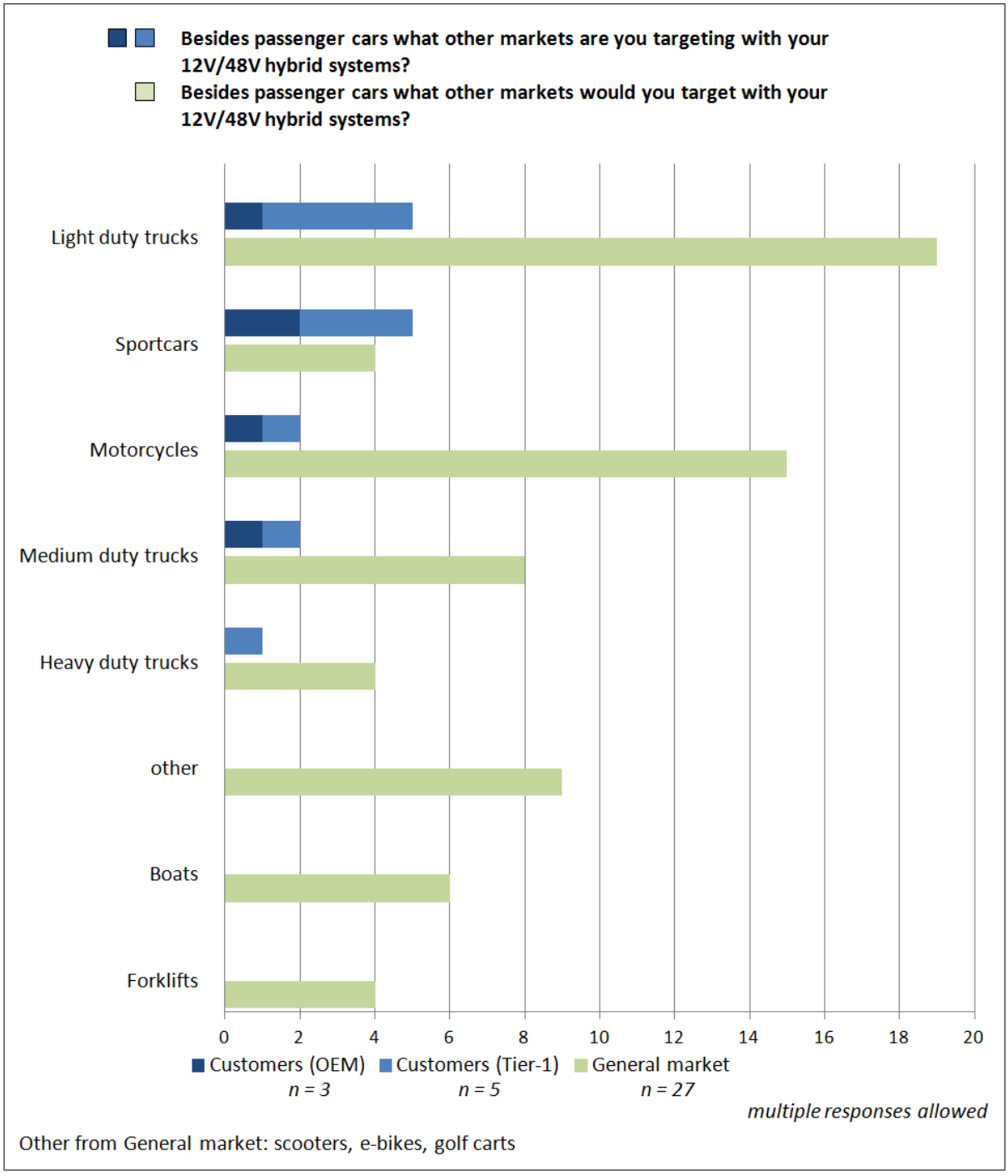

Figure 7.13: **Survey: Question 11 - Other target markets besides passenger cars.**[318]

[318] Own illustration.

The general market would mainly target light duty trucks and motorcycles which could be very interesting markets for AVL besides passenger vehicles. Additionally, smaller applications such as pedelecs, scooters and other bikes could be interesting for a 48 V battery supply. These so-called personal vehicles, which will be kept inside the trunk of a car, were already mentioned in chapter 5.3.

7.3.2 Potential of communication protocols

For customers and the general market, vehicle-to-x and vehicle-to-vehicle communication are attractive concepts to incorporate in the future as shown in Fig. 7.14. Fleet Telematics and Vehicle Tracking were not selected by customers and less often chosen by the general market. Therefore, AVL should focus on vehicle-to-x, vehicle-to-vehicle communication as well as GPS assisted callibration.

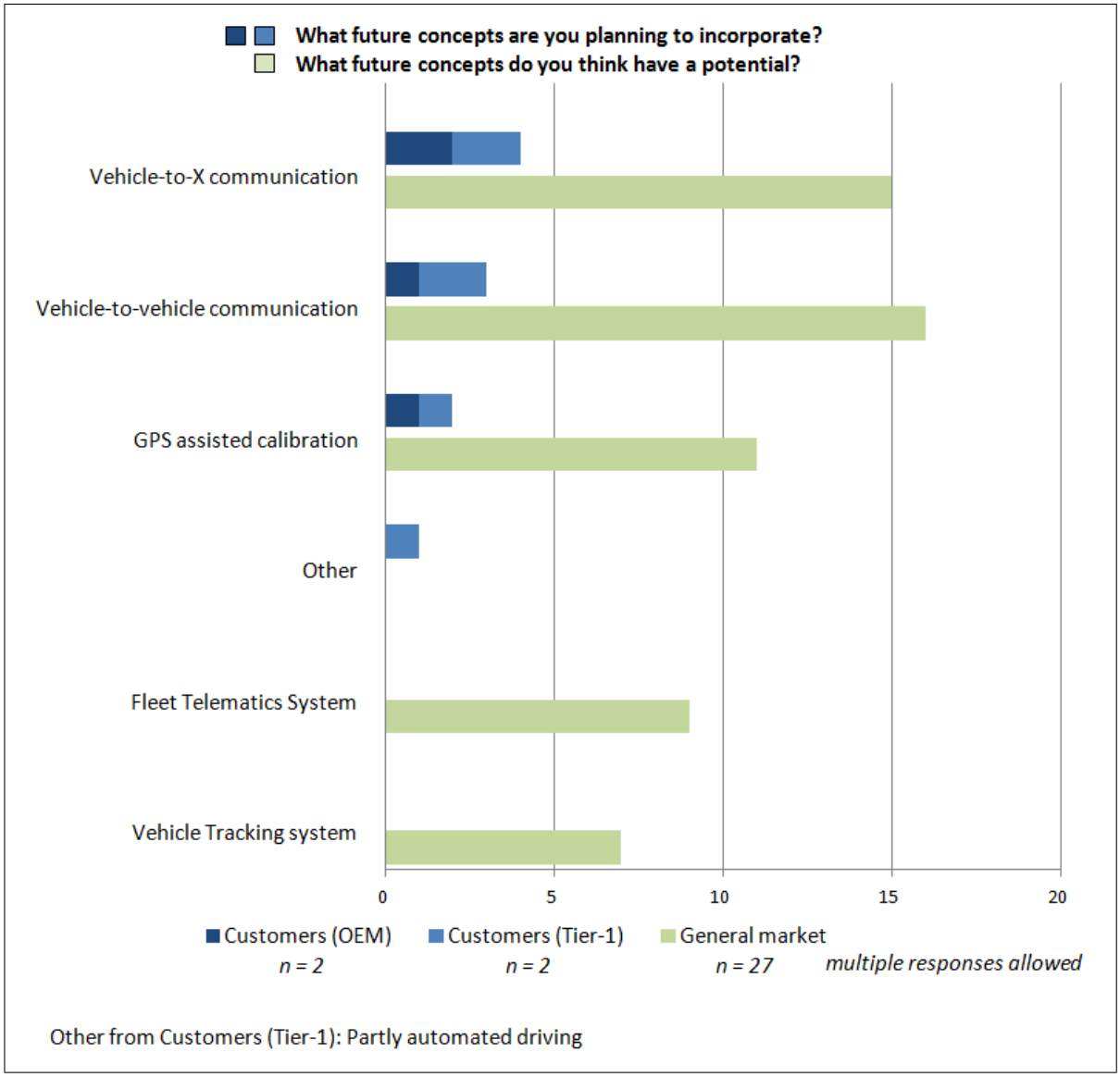

Figure 7.14: **Survey: Question 12 - Potential of communication protocols.**[319]

The answer "Partly automated driving" describes a technology when the system takes over control, while the driver should monitor the system and should be prepared to take over control again at any time to make further driving decisions.[320]

Numerous automakers are working on crash avoidance technologies, which are called vehicle-to-vehicle and vehicle-to-x communication systems. The technology relies on Wi-Fi Direct to allow devices like smartphones to communicate directly with each other instead of communicating through an access point. General Motors is working on a solution which makes it not only possible to anticipate dangers by communicating with other cars but also to receive information from traffic lights or detect pedestrians as well as cyclists as illustrated in Fig. 7.15.[321]

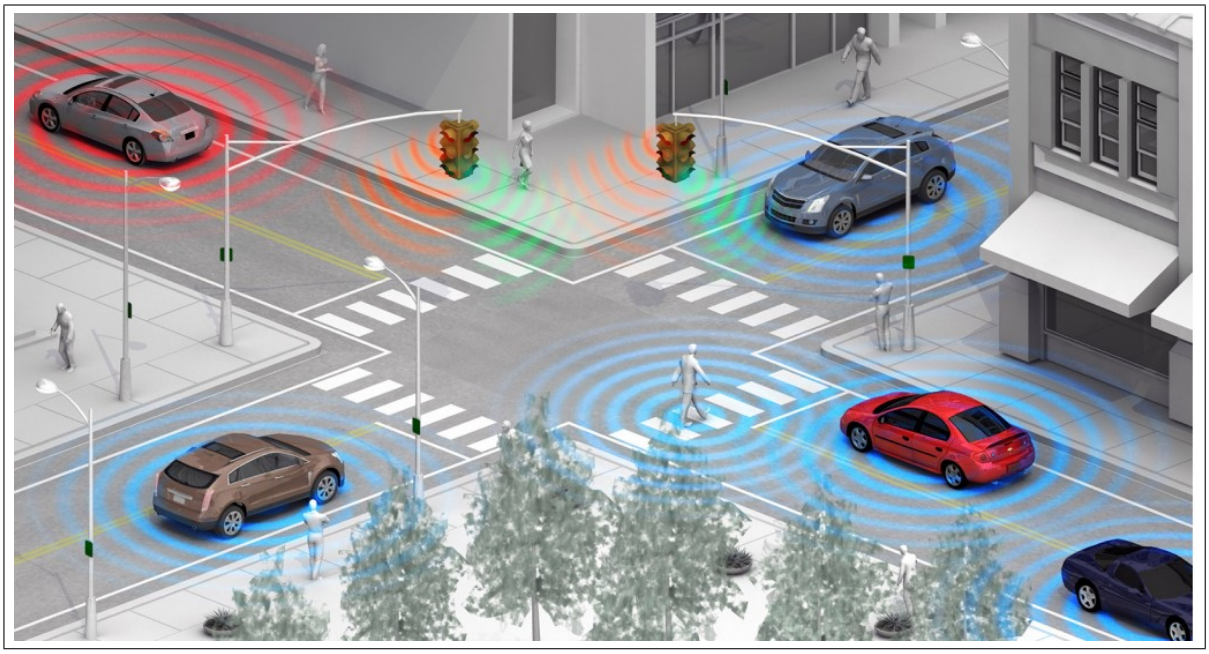

Figure 7.15: **Examples of application for vehicle-to-x-communication.**[322]

Global Positioning System (GPS) assisted calibration and fleet telematics are both based on the technology of global positioning to track vehicles. Fleet Telematics is a very fast growing technology to monitor the location, states, movements and behavior of a fleet of vehicles or a single one. Therefore, GPS and Global System for Mobile (GSM) are used to communicate with the user.[323]

[319] Own illustration.
[320] Cf. Etemad (2013), www.imobilitysupport.eu, date of access [07.05.2014], p. 6.
[321] Cf. Fleetmatics IRL (2014), www.fleetmatics.com, date of access [07.05.2014].
[322] Vijayenthiran (2012), www.motorauthority.com, date of access [06.05.2014].
[323] Cf. Fleetmatics IRL (2014), www.fleetmatics.com, date of access [07.05.2014].

7.3.3 CO_2 emission reduction goals

As shown in chapter 5.2 carbon dioxide emission reduction goals are crucial for automakers. Especially the defined CO_2 emission limits by the European Union are important to fulfill. Tab. 7.1 shows expected savings of CO_2 emissions. The answers are listed and divided into customer (OEM, Tier-1) and general market responses.

What are your CO_2 emission reduction goals for your 48V system (in % and by when)?
What do you think are realistic CO_2 emission reduction goals for your 48V system (in % and by when)?

Customers answers			General market answers	
Customers	**CO_2 reduction**	Duration	**CO_2 reduction**	Duration
Type	*in %*	*in number of years*	*in %*	*in number of years*
OEM	12	4	8	4
OEM	13	4	15	4
OEM	15	4	15	6
Tier-1	8	1	25	3
Tier-1	15	2	10	5
			15	6
			25	16
			18	6
			20	6
			15	1
			17	6
			20	6

Table 7.1: **Survey: Question 13 - Emission reduction goals.**[324]

Professor Gutzmer, CTO of the company Schaeffler AG, estimates a CO_2 emission and fuel reduction of up 15 % with a 12 V/48 V on-board supply due to the very efficient recuperation.[325]

[324] Own illustration.
[325] Cf. Schaeffler AG (2014a), www.schaeffler.com, date of access [26.08.2013], pp. 26-27.

7.3.4 Goals for fuel mileage savings

CO_2 emissions are proportional to fuel consumption, which means a 1 % increase in fuel consumption would lead to an increase of 1 % in CO_2 emissions.[326] Nevertheless, slightly different answers were given by the respondents. All responses from customers and the general market are shown in Tab. 7.2.

What are your goals for fuel mileage savings with your 48V system (in % and by when)?
What do you think are realistic goals for fuel mileage savings with your 48V system(in % and by when)?

Customers answers			General market answers	
Customers	**Fuel reduction**	Duration	**Fuel reduction**	Duration
Type	*in %*	*in number of years*	*in %*	*in number of years*
OEM	13	4	15	6
OEM	15	4	8	4
OEM	15	4	15	4
Tier-1	10	1	15	6
			25	5
			30	5
			20	6
			45	16
			15	6
			16	6
			10	1
			12	6
			15	6

Table 7.2: **Survey: Question 14 - Fuel reduction goals.**[327]

BOSCH is working on technologies that try to save fuel by influencing the driver instead of only focusing on technical parts. A start-stop system which is connected with the navigation system should coach the driver to release the accelerator when it is not necessary. BOSCH estimates that this can cut fuel of up to 15 % in real driving conditions.[328]

[326] Cf. United States Environmental Protection Agency (2008), date of access [07.05.2014].
[327] Own illustration.
[328] Cf. Automotive Design & Production (2013), p. 10.

7.3.5 Cost target for the complete 12 V/48 V system

Customers' estimations for the net cost for the complete 12 V/48 V system are between 610 € and 1250 €, whereas the general market estimations are between 500 € and 5.000 € (Tab. 7.3). The median has most likely a higher reliability than the arithmetic average due to the fact that the median neglects complete outliers. The median of customer's answers is 900 €, whereas the general market's median is 1.000 €. The median value of all answers is 1.000 €, which can be expected as a realistic value.

What is the net cost target for the complete 12V/48V systems (including batteries, integration, savings from a starter motor, etc. in €)?

What do you think is a realistic net cost target for the complete 12V/48V systems (including batteries, integration, savings from a starter motor, etc. in €)?

Customers answers			General market answers	
Customers Type	**Cost target** in €			**Cost target** in €
OEM	720,0			6000,0
OEM	1250,0			1000,0
Tier-1	1000,0			750,0
Tier-1	1080,0			700,0
Tier-1	800,0			3500,0
Tier-1	610,0			5000,0
				850,0
				500,0
				800,0
				1000,0
				1200,0
Arithm. Av.	910,0		Arithm. Av.	1936,4
Median	**900,0**		**Median**	**1000,0**

Table 7.3: **Survey: Question 15 - Cost target for the complete 12 V/48 V system.**[329]

[329] Own illustration.

7.3.6 Investment period for 48 V testing solutions

Fig. 7.16 shows the time when there is a need for 48 V testing solutions. It clearly shows that most of AVL's customers have already invested, however, some will invest in the following years. The responses from the general market also show a tendency that they would have already invested or would invest very soon. Literature and survey approve that an investment in 5 to 10 years would be too late.

Hybrid vehicles have already become a mass-market product and also plug-in hybrids and pure EVs are available.[330] For future work it is inevitable to pay attention to the development of standard technical solutions for the 48 V systems. Moreover, these solutions should be made for large series production and should also remain to be flexible for customer applications.[331]

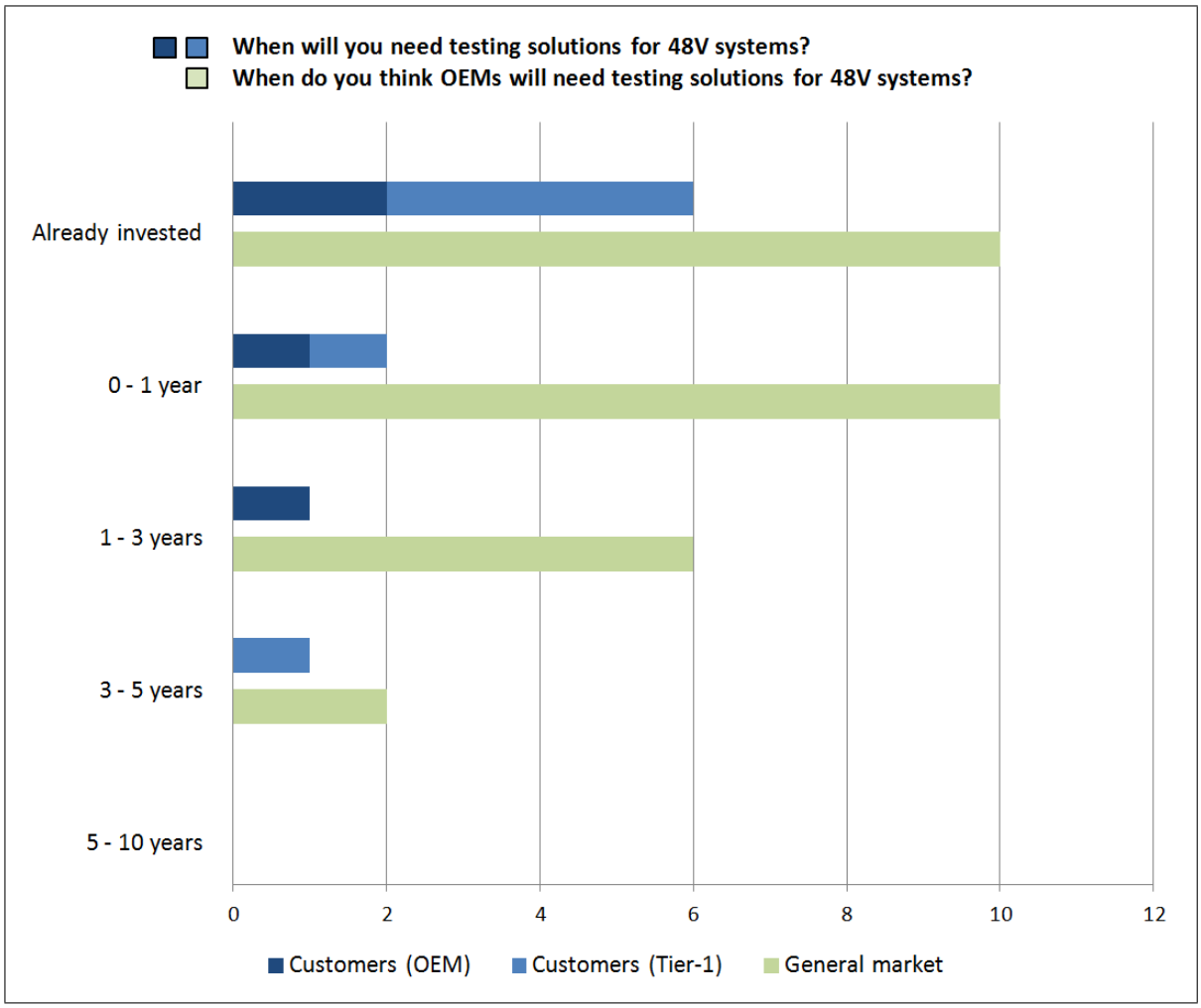

Figure 7.16: **Survey: Question 16 - Time to invest in testing solutions for 48 V.**[332]

[330] Cf. International Energy Agency (2013), www.ieahev.org, date of access [10.10.2013], p. 1.
[331] Cf. Mate (2013), www.artemis-ioe.eu, date of access [18.03.2014], p. 16.
[332] Own illustration.

7.4 Test system requirements

The part "Test system requirements" is about requirements from potential customers of 48 V test systems. Therefore, respondents were asked about specifications of test equipment.

7.4.1 Nominal power for 48 V battery test systems

As shown in Tab. 7.4 customer's answers of the required nominal power of the 48 V battery test systems vary from 1.5 kW to 25 kW, whereas OEMs tend to expect higher nominal power specifications than Tier-1 suppliers. The general market expects nominal powers between 1.5 kW and 100 kW. Thus, the general market's median as well as the arithmetic average are distinctly higher than the customer's answers. The median of all given answers to this question is exactly 20 kW. However, it can be expected that an appropriate value for the nominal power for testing 12 V/48 V batteries is between 15 kW and 20 kW.

For testing your 12V/48V batteries, a battery test system would need the following nominal power:
For testing your 12V/48V batteries, a battery test system would need the following nominal power:

Customers answers			General market answers	
Customers Type	**Nominal power** in kW			**Nominal power** in kW
OEM	25,0			3,0
OEM	10,0			20,0
OEM	20,0			100,0
Tier-1	1,5			4,0
Tier-1	1,5			100,0
Tier-1	20,0			55,0
				20,0
				5,0
				6,0
				20,0
				25,0
				15,0
				20,0
				15,0
				1,5
				40,0
				15,0
Arithm. Av.	13,0		Arithm. Av.	27,3
Median	**15,0**		**Median**	**20,0**

Table 7.4: **Survey: Question 17 - Required nominal power for battery test systems to test 12 V/48 V batteries.**[333]

[333] Own illustration.

7.4.2 Demand for ripple emulation

An unwanted AC component of a DC output voltage is called ripple, whereas in most cases, a pure DC output is required. An emulator can simulate this ripple function.[334] The absolute majority of surveyed customers require ripple emulation for the battery test (Fig. 7.17). Additionally, the general market also thinks that the inverter ripple emulation function is required. Consequently, it is recommendable for AVL to offer ripple emulation for battery testbed systems.

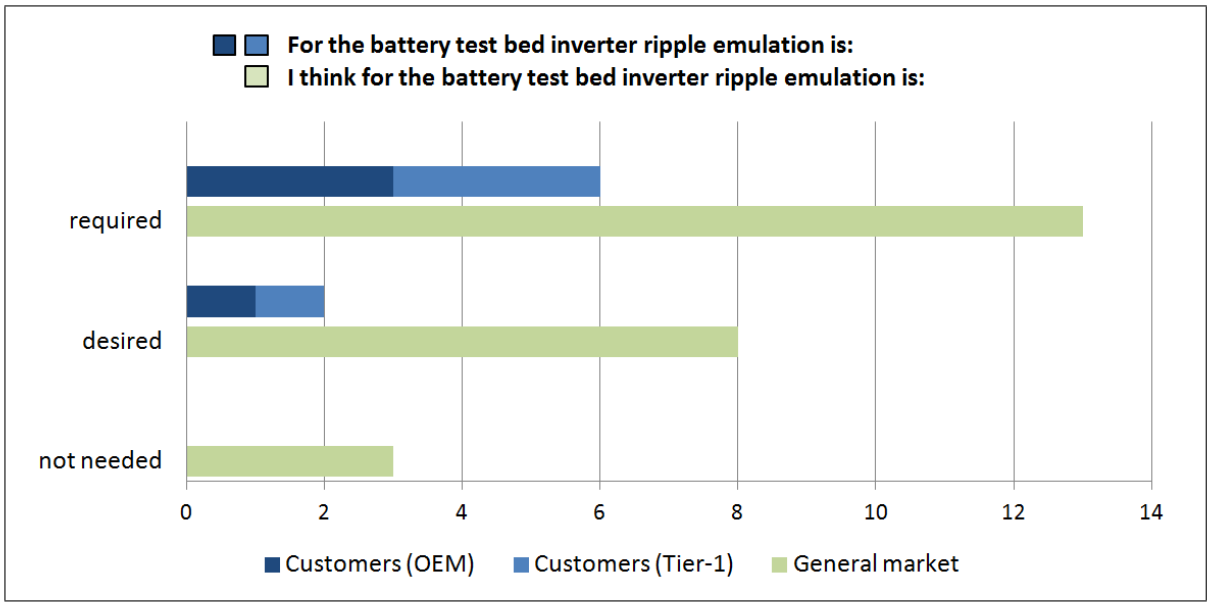

Figure 7.17: **Survey: Question 18 - Demand for inverter ripple emulation for battery tests.**[335]

[334] Cf. Rao (2012), pp. 15-16.
[335] Own illustration.

7.4.3 Nominal power for 48 V inverter test systems

All answers from AVL's customers for the required nominal power for inverter test systems is 20 kW except one Tier-1 supplier claimed a required power of 15 kW as shown in (Tab. 7.5). The answers from the general market vary from 1.5 kW to 150 kW, whereas the arithmetic average is 55 kW and therefore much higher than the arithmetic average from customer's answers. However, the median is 20 kW for customers and the general market. For this reason, an appropriate power for testing inverters for 12 V/48 V systems is 20 kW.

For testing inverters for your 12V/48V system, following power is required:
For testing inverters for your 12V/48V system, following power is required:

Customers answers			General market answers	
Customers Type	**Nominal power** in kW			**Nominal power** in kW
OEM	20,0			100,0
OEM	20,0			12,0
OEM	20,0			100,0
Tier-1	15,0			5,0
Tier-1	20,0			6,0
				12,0
				150,0
				20,0
				20,0
				100,0
				80,0
Arithm. Av.	19,0		Arithm. Av.	55,0
Median	**20,0**		**Median**	**20,0**

Table 7.5: **Survey: Question 19 - Required power for inverters for 12 V/48 V systems.**[336]

[336] Own illustration.

7.4.4 Nominal power for 48 V e-motor test systems

Tab. 7.6 shows that the customer's answers range from 8 kW to 200 kW. However, 200 kW is just one single unexpected high value which increases the arithmetic average significantly. Although, the general market's answers also vary between 5 kW and 150 kW the arithmetic average of 33.3 kW and the median of 17.5 kW are both lower than those from the customer answers. Therefore, an appropriate nominal power specification for e-motor test systems is expected to be approximately 20 kW. Additionally, the median of all given answers to this question is also 20 kW.

For an e-motor test system, following nominal power is required:
For an e-motor test system, following nominal power is required:

Customers answers			General market answers	
Customers	**Nominal power**			**Nominal power**
Type	in kW			in kW
OEM	25,0			20,0
OEM	200,0			100,0
OEM	20,0			150,0
OEM	20,0			5,0
Tier-1	8,0			6,0
Tier-1	15,0			20,0
				25,0
				12,0
				20,0
				15,0
				15,0
				12,0
Arithm. Av.	48,0		Arithm. Av.	33,3
Median	**20,0**		**Median**	**17,5**

Table 7.6: **Survey: Question 20 - Required power for e-motors for 12 V/48 V systems.**[337]

[337] Own illustration.

7.4.5 Power overload/max. speed for 48 V e-motor test systems

Due to the shortened questionnaire for the general market, only customer's answers were recorded for the required power overload and the speed for an e-motor test system. The answers to the required power overload range from 15 kW to 240 kW, whereas 240 kW is an unexpected single outlier. The related median of all answers from AVL's customers is 26 kW (Tab. 7.7). which is a good guide value for e-motors.

The answers from AVL's customers for maximum speed for an e-motor test system were between 8.000 rpm and 24.000 rpm. The arithmetic average and the median value are 16.000 rpm and 15.500 rpm, shown in Tab. 7.7. Therefore, the recommendation for an appropriate maximum speed for e-motors is expected to be around 16.000 rpm or higher.

For an e-motor test system, following power overload/max. speed is required:

Customers answers	
Customers	**Power overl.**
Type	in kW
OEM	30,0
OEM	40,0
OEM	22,0
OEM	20,0
Tier-1	15,0
Tier-1	240,0
Arithm. Av.	61,2
Median	**26,0**

Customers answers	
Customers	**Max. speed**
Type	in rpm
OEM	8000
OEM	18000
OEM	16000
OEM	24000
Tier-1	15000
Tier-1	15000
Arithm. Av.	16000
Median	**15500**

Table 7.7: **Survey: Question 21 - Required power overload/speed for e-motor testbeds for 12 V/48 V systems.**[338]

[338] Own illustration.

7.4.6 Nominal torque/ overload torque/ overload duration for 48 V e-motor test systems

Only a few answers were given on very specific questions. Some respondents stated that they don't have the expertise to fill out the questions which are shown in Fig. 7.18. Nevertheless, the median value of the requested nominal torque for e-motor test systems is 100 Nm, whereas the answers vary considerably. The median of the overload torque is 220 Nm, whereas the given answers also have a great variation due to the different requirements from customers. AVL's customer's required overload duration is between 5 s and 10 s which is a good guide value for 48 V e-motor test systems.

For an e-motor test system, following nominal torque/overload torque/ overload duration is required:

For an e-motor test system, following nominal torque/overload torque/ overload duration is required:

Customers answers	
Customers	**Nom. torque**
Type	in Nm
OEM	100,0
OEM	200,0
Tier-1	30,0
Arithm. Av.	110,0
Median	**100,0**

Customers answers	
Customers	**Overl. Torque**
Type	in Nm
OEM	220,0
OEM	400,0
Tier-1	55,0
Arithm. Av.	225,0
Median	**220,0**

Customers answers	
Customers	**Overl. Duration**
Type	in s
OEM	10,0
OEM	5,0
OEM	5,0
Tier-1	10,0
Arithm. Av.	7,5
Median	**7,5**

Figure 7.18: **Survey: Question 22 - Required nominal torque/ overload torque/ overload duration for e-motor testbeds for 12 V/48 V system.**[339]

[339] Own illustration.

7.4.7 Demand for engine pulse simulation

The absolute majority of AVL's customers require engine pulse simulation for e-motor testbeds for 12 V/48 V systems (Tab. 7.8). None of AVL's surveyed customers stated that engine pulse simulation is not needed. Moreover, the general market also requires clearly engine pulse simulation. Therefore, it can be assumed, that engine pulse simulation should be provided for 48 V e-motor testbed systems.

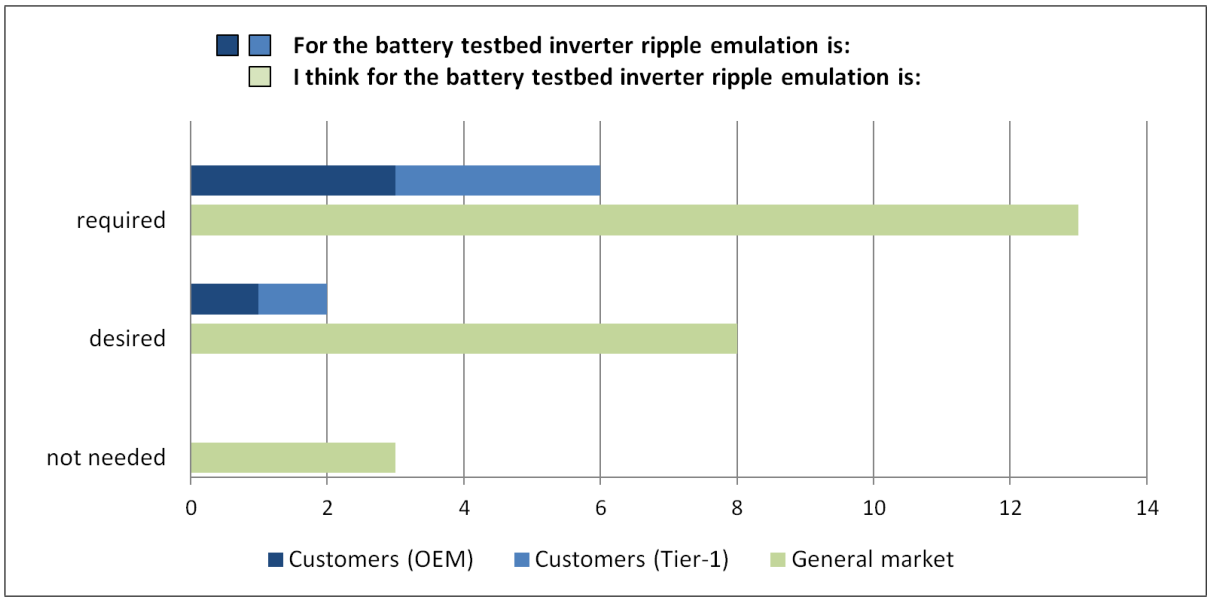

Table 7.8: **Survey: Question 23 - Demand for engine pulse simulation for e-motor testbeds for 12 V/48 V systems.**[340]

[340] Own illustration.

7.4.8 Belt drive simulation for BSG testing

The absolute majority of AVL's customers require belt drive simulation for e-motor testbeds with BSG testing. Additionally, Fig. 7.19 shows that the general market also approves clearly that belt drive simulation is required for 48 V e-motor testbeds. It is therefore absolutely recommended to provide belt drive simulation for 48 V e-motor test systems.

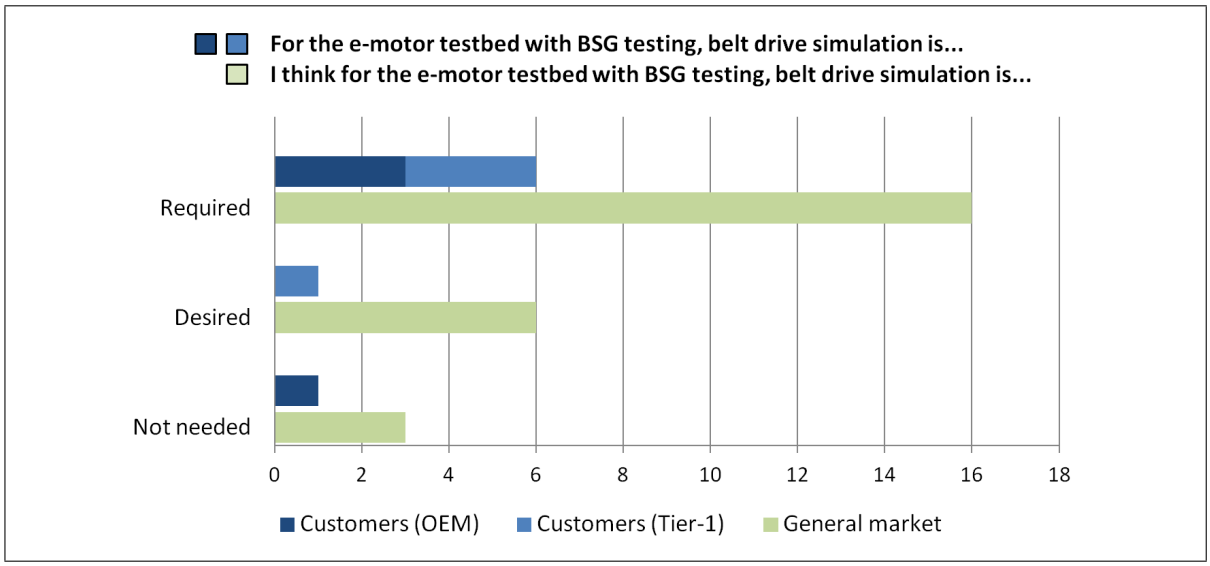

Figure 7.19: **Survey: Question 24 - Demand for belt drive simulation for e-motor testbeds with BSG testing for 12 V/48 V system.**[341]

[341] Own illustration.

8 SUMMARY AND CONCLUSION

The automotive industry pushes the electrification of vehicles ahead due to fulfill emission regularities, higher safety standards and comfort requirements. The increase of electronics in vehicles alone, would be not affordable with today's 12 V net that provides approximately 3 kW. For this reason, vehicle manufacturers introduced an additional 48 V on-board supply for hybrid vehicles, which supports loads of around 10 kW. Due to the change from 12 V to an on-board supply of 12 V/48 V, engineers are faced with new challenges.

For AVL List GmbH, it is important to reduce risk for further investments. Therefore, a comprehensive secondary research should clarify the potential of the 48 V-technology. In addition, a primary research should answer specific questions from AVL in order to meet their customers' needs.

Hybrid vehicles, based on an on-board power supply of 12 V/48 V, have a different topology that comprises generally a bidirectional inverter connected with two batteries. Especially, the communication between components over both voltage levels has a high risk for problems. The 48 V net can be grounded through the vehicle body, because the nominal voltage is below the 60 V touch protection voltage. This avoids expensive galvanic isolation and additional protection. Moreover, the higher voltage of 48 V instead of 12 V enables a reduction of cable cross sections and, for this reason, the weight of the cable harness. Additionally a power of up to approximately 12 kW offers a higher comfort and safety standard as well as leeway for further innovations. Recuperation with the 48 V-technology is very effective due to the fact that most breaking actions generate a power within the theoretical limit of 12 kW. For this reason, the 48 V-technology is a cost-efficient solution for hybrid cars. However, it is not advisable to use an internal combustion engine with more than 3 cylinders due to the fact that large drag losses would reduce the recuperation potential.

Starter-generators have to be well considered because integrated starter-generators have higher costs and are more complex than belt-driven starter-generators, but they are also associated with greater comfort and life expectancy as well as better rates of fuel consumption. Smart start-stop systems cut fuel consumption and reduce CO_2 emissions by switching off the combustion engine when it is not needed to power the vehicle. Estimations of CO_2 emission and fuel reduction are around 15 % with a 12 V/48 V on-board supply. Continental forecasts that around one third of all passenger vehicles are based on a 48 V on-board supply by 2025, whereas Western Europe will be the leading market over the following ten years.

Other markets which are based on 48 V are light duty trucks, sportcars, boats, motorcycles etc which could be interesting for AVL. Moreover, big car manufacturers try to integrate electric bikes into a

car's trunk, which can be used for short distances. Although vehicles that are based on 48 V reduce CO_2 emissions, costs are more important than the desire to drive environmentally friendly.

Lithium-ion is currently the most important storage technology for 48 V applications. Tesla will invest around five billion dollars in the so-called Gigafactory, which will reduce battery pack costs of approximately 30 % until 2017.

The survey results have shown that most companies have already invested in 48 V-testing solutions or will do this most likely in the following year. Therefore, it is important to pay attention on the development of 48 V standard solutions for series production but also on close tailoring to end user requirements. The complete system's net cost target, which includes batteries, integration, savings from the starter-motor etc. is approximately 1.000 €. Vehicle-to-x and vehicle-to-vehicle communication have a great potential to be implemented in the future and should be considered by AVL.

Customers of AVL do not use the same vehicle simulation platform for all three steps (x-in-the-loop tests, component tests and system tests). However, there is a need to cover all three steps by one platform. The author presumes that this could be an opportunity for AVL and recommends to focus on closing this gap with AVL's Integrated and Open Development Platform.

Furthermore, the nominal power for 48 V battery test systems should be around 20 kW and ripple emulation should be available. The nominal power for 48 V inverter test systems as well as e-motors is also recommended to be close to 20 kW. A maximum speed of 16.000 rpm or higher should be provided by AVL's e-motor test systems. The author absolutely recommends to provide engine pulse simulation for 48 V e-motor testbed systems due to the clear survey results. Additionally, belt drive simulation is required for AVL's customers and should therefore be included in e-motor testbeds with BSG testing.

Due to all researched data, the author presumes that the 48 V-technology is not a short-term solution, which never achieves a breakthrough. Nevertheless it is pointed out that AVL should be on time on the market due to the fact that many companies have already invested in this technology.

9 OUTLOOK AND INNOVATIONS

The approach of plug-in hybrids becomes more interesting due to the fact that public infrastructure increases. Therefore, the number of electric vehicle charging stations will reach 1.1 million units worldwide by the end of 2014. Additionally, automotive manufacturers will produce electric vehicles with batteries of about 40 kWh capacity in 2014 due to the fact that a price war between LG Chem and Panasonic let the prices of lithium-ion batteries decrease. As a result of this, a distance of approximately 240 km can be reached. Moreover, can be expected that incentives and legislative changes of electric vehicles will occur in some regions in 2014.[342]

Different innovations in the automotive industry arise quickly. For example, Fiat Chrysler will launch a new line of small gasoline engines by 2015 but will also focus on electrification whereas plug-in-hybrid minivans and crossover utility vehicles (CUV) are favored. Additionally, Fiat Chrysler will begin a market penetration with 48 V mild hybrid vehicles in 2016.[343] PSA Peugeot Citroën plans to introduce a 48 V mild-hybrid system for gasoline and diesel engines by 2017 which will reduce fuel consumption of up to 15 %. A 48 V lithium-ion battery will supply a 10 kW e-motor which cannot only support the internal combustion engine with additional power but also propel the vehicle alone at speeds of less than 20 km/h for parking or leaving a car park.[344] Bosch has presented a new start-stop system that uses coasting and cuts, therefore, up to 10 % fuel consumption. It is expected that suppliers and OEMs will present more new energy- and fuel-saving technologies in 2014.[345]

For instance, Ford has demonstrated its C-MAX solar energi concept in 2014 which is a solar powered plug-in hybrid vehicle. Ford has developed a solar canopy which functions like a magnifying glass (fresnal lense) to concentrate the rays of sunlight to the solar panels on the rooftop. Sensors and a software will autonomously control the car's position under the canopy and let the vehicle move a few meters forward or backward to receive as much sunlight as possible (Fig. 9.1).[346]

The average car is about 95 % of its lifetime in a parking position. On a really hot summer day the inside temperature of a car can reach up to 70 °C, which worsens batteries sharply. A proprietary passive cooling material from the company AllCell absorbs heat and protects battery cells from overheating for hours which is important for safety and performance of the batteries. AllCell's lithium-ion battery was exhibited the first time in September 2013 at the Battery Show in Michigan.

[342] Cf. Green Car Congress (2014a), www.greencarcongress.com, date of access [26.03.2014].
[343] Cf. Zoia (2014), www.wardsauto.com, date of access [26.03.2014].
[344] Cf. Green Car Congress (2013b), www.greencarcongress.com, date of access [26.03.2014].
[345] Cf. Green Car Congress (2014a), www.greencarcongress.com, date of access [26.03.2014].
[346] Cf. Settle (2014), www.yourenergyblog.com, date of access [26.03.2014].
[347] Ford (2014), ww4.hdnux.com, date of access [26.03.2014]

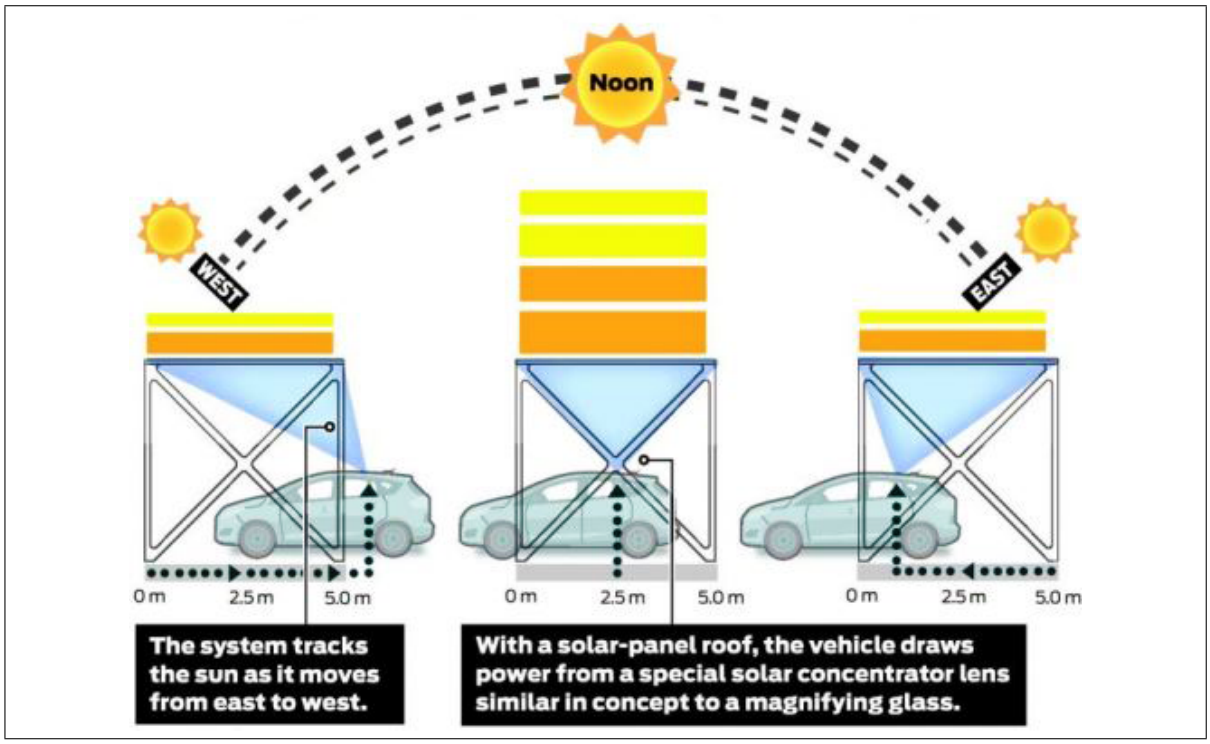

Figure 9.1: **Ford's new C-MAX Solar Energi Concept.**[347]

The so called phase change material (PCM) which consists of graphite materials and inexpensive wax absorbs and gives off heat regardless if the car is turned on or off. Therefore, no moving parts or active cooling systems are required. This composite PCM combines the effects of absorbing heat and limiting the maximum temperature which extends the battery life crucially.[348] This thermal management system is completely passive and limits the battery temperature even in hot environments to 40 °C. Furthermore, AllCell's 48 V lithium-ion battery has a weight of 10 kg and a volume of 10 liters. The capacity of this micro-hybrid battery of 15 Ah, a discharge power of 16 kW and a charge power of up to 19 kW are decisive improvements and, therefore, big steps forward compared to lead-acid batteries.[349] Wireless charging of vehicle batteries and catenaries for trucks are already in the development phase.[350]

[348] Cf. Probert (2013), www.bestmag.co.uk, date of access [23.03.2014].
[349] Cf. Space Mart (2013), date of access [23.03.2014].
[350] Cf. International Energy Agency (2013), www.ieahev.org, date of access [23.03.2014], p. 1.

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LIST OF ABBREVIATIONS

AC	Alternating Current
AR	Active Runabout
BEV	Battery-Hybrid-Electric-Vehicle
BRS	Boost Recuperation System
BRS	Boost Regeneration System
BSG	Belt-driven Starter-Generator
CAN	Controller Area Network
CUV	Crossover Utility Vehicle
DC	Direct Current
ECU	Engine Control Unit
ESC	Electronic Stability Control
EV	Electric Vehicle
GPS	Global Positioning System
GSM	Global System for Mobile
HEV	Hybrid-Electric-Vehicle
HiL	Hardware-in-the-loop
HVAC	Heating Ventilation Air Condition
ICE	Internal Combustion Engine
IODP	Integrated Open Development Platform
ISG	Integrated Starter-Generator
KAM	Key Account Manager
LIN	Local Interconnect Network
MiL	Model-in-the-loop
NEDC	New European Driving Cycle
OEM	Original Equipment Manufacturer
PCM	Phase Change Material
PHEV	Plug-in-Hybrid-Electric-Vehicle
SiL	Software-in-the-loop
SWOT	Strengths-Weaknesses-Opportunities-Threats
TCU	Transmission Control Unit
UPS	Uninterruptible Power Supplies
UUT	Unit Under Test
WLTP	Worldwide harmonized Light vehicles Test Procedure

A Appendix - questionnaire to AVL's customers

Requirements for Test-Systems

Dear Sir/Madam

I am studying at Graz University of Technology and I am doing a market review for micro hybrid passenger vehicles and related test equipment for my diploma thesis sponsored by Institute of Industrial Management and Innovation Research (TU Graz), Institute of Automotive Engineering (TU Graz) and AVL Graz.
Not every single field has to be completed, but please try to fill in as much as you can.

The questionnaire is anonymous.
IF YOU FILL OUT THIS QUESTIONNAIRE YOU WILL GET THE COMPLETE OVERALL RESULT!

Estimated Duration: 5 to 10 min

Latest date for completing the questionnaire: 28.03 2014

If you encounter any problems please contact the following email address:
christoph.schoeggler@student.tugraz.at

Please consider that this questionnaire relates to passenger vehicles.

System questions

What methods of energy storage are you using for your 12V/48V system?

- [ ] Lead-Acid 12V
- [ ] Lead-Acid 48V
- [ ] Lead-Carbon 12V
- [ ] Lead-Carbon 48V
- [ ] Lithium-Ion 12V
- [ ] Lithium-Ion 48V
- [ ] Lithium-Titanate 12V
- [ ] Lithium-Titanate 48V
- [ ] Nickel-Metal Hydride 12V
- [ ] Nickel-Metal Hydride 48V
- [ ] Super Capacitor
- [ ] Flywheels
- [ ] Nickel-Cadmium 12V
- [ ] Nickel-Cadmium 48V
- [ ] Compressed Air
- [ ] Other:

What communication protocols are you using between all the different control units (ECU,

TCU, BCU, ect)?

- [ ] CAN (Controller Area Network)
- [ ] FlexRay
- [ ] Ethercat
- [ ] LIN (Local Interconnect Network)
- [ ] Other:

What type of e-motor are you using?

- [ ] BSG (Belt-Driven Starter Generator)
- [ ] ISG (Integrated Starter Generator)
- [ ] Other:

Simulation & Testing

What types of x-in-the-loop development tools are you using?

- [ ] MiL (Model-in-the-Loop)
- [ ] SiL (Software-in-the-Loop)
- [ ] HiL (Hardware-in-the-Loop)

Do you use a vehicle simulation platform on these x-in-the-loop development systems?
(for vehicle simulation platform, examples include: carsim, IPG CarMaker, etc...)

- ( ) Yes
- ( ) No
- ( ) I don't know

What do you use to test the components independently before they are brought together as a system?

- [ ] E-motor testbeds
- [ ] Battery testbeds
- [ ] Inverter/power electronics testbeds
- [ ] Engine testbeds
- [ ] Transmission testbeds
- [ ] Other:

Do you use a vehicle simulation platform on your component test beds?

- ( ) Yes
- ( ) No
- ( ) I don't know

Do you use system integration testbeds (full powertrain, engine + transmission, battery + inverter + e-motor, etc.)

- ○ Yes
- ○ No
- ○ I don't know

If yes, what types?

Do you use a vehicle simulation platform on your system test beds?

- ○ Yes
- ○ No
- ○ I don't know

Do you use the same vehicle simulation platform for all three steps (x-in-the-loop, components, system)?

- ○ Yes
- ○ No
- ○ I don't know

Targets and goals for 48V

Besides passenger cars what other markets are you targeting with your 12V/48V micro hybrid systems?

- ☐ Light-duty trucks
- ☐ Medium-duty trucks
- ☐ Heavy-duty trucks
- ☐ Sportcars
- ☐ Motorcycles
- ☐ Forklifts
- ☐ Boats
- ☐ Other:

What future concepts are you planning to incorporate?

- ☐ GPS assisted calibration
- ☐ Vehicle-to-vehicle communication
- ☐ Vehicle-to-X communication
- ☐ Vehicle Tracking system
- ☐ Fleet Telematics System (FTS)
- ☐ Other:

What are your CO2 emission reduction goals for your 48V system (in % and by when)?

Fill in rough estimations/planned values.

What are your goals for fuel mileage savings (in % and by when)?
Fill in rough estimations/planned values.

What is the net cost target for the complete 12V/48V systems (including batteries, integration, savings from a starter motor, etc. in €)?
Fill in rough estimations/planned values.

Test system requirements for 12V/48V systems

When will you need testing solutions for 48V systems?

- ○ Already invested
- ○ 0 - 1 year
- ○ 1 - 3 years
- ○ 3 - 5 years
- ○ 5 - 10 years

For testing your 12V/48V batteries, a battery test system would need the following specifications:

Nominal power: (in kW)

For the battery test bed inverter ripple Emulation is:

- ☐ required
- ☐ desired
- ☐ not needed

For testing inverters for your 12V/48V system, following input and output specifications are required:

Power: (in kW)

For e-motor test system, following specifications are required:

Power (nominal): (in kW)

Power (overload): (in kW)

Max. Speed: (in rpm)

Torque (nominal): (in Nm)

Torque (overload): (in Nm)

Overload duration: (in seconds)

For the e-motor test bed, engine pulse simulation is...

- Required
- Desired
- Not needed

For the e-motor test bed with BSG testing, belt drive simulation is...

- Required
- Desired
- Not needed

If you have any comments for me please let me know in the following text box.

B Appendix - questionnaire to the general market

Requirements for Test-Systems

Dear Sir/Madam

I am studying at Graz University of Technology and I am doing a market review for micro hybrid passenger vehicles and related test equipment for my diploma thesis.
I would appreciate very much and thank you in advance if you can take the time to answer the following questionnaire.

Estimated Duration: 5 min

If you encounter any problems please contact the following email address:
christoph.schoeggler@student.tugraz.at

Please consider that this questionnaire relates to passenger vehicles.

System questions

As a passenger car manufacturer what methods of energy storage would you use for your 12V/48V system?

- ☐ Lead-Acid 12V
- ☐ Lead-Acid 48V
- ☐ Lead-Carbon 12V
- ☐ Lead-Carbon 48V
- ☐ Lithium-Ion 12V
- ☐ Lithium-Ion 48V
- ☐ Lithium-Titanate 12V
- ☐ Lithium-Titanate 48V
- ☐ Nickel-Metal Hydride 12V
- ☐ Nickel-Metal Hydride 48V
- ☐ Super Capacitor
- ☐ Flywheels
- ☐ Nickel-Cadmium 12V
- ☐ Nickel-Cadmium 48V
- ☐ Compressed Air
- ☐ Other:

What type of e-motor would you use?

- ☐ BSG (Belt-Driven Starter Generator)
- ☐ ISG (Integrated Starter Generator)
- ☐ Other:

Simulation & Testing

Would you use a vehicle simulation platform on these x-in-the-loop development systems?
(for vehicle simulation platform, examples include: carsim, IPG CarMaker, etc...)

- ○ Yes
- ○ No
- ○ I don't know

What would you use to test the components independently before they are brought together as a system?

- ☐ E-motor testbeds
- ☐ Battery testbeds
- ☐ Inverter/power electronics testbeds
- ☐ Engine testbeds
- ☐ Transmission testbeds
- ☐ Other:

Would you use a vehicle simulation platform on your component test beds?

- ○ Yes
- ○ No
- ○ I don't know

Would you use system integration testbeds (full powertrain, engine + transmission, battery + inverter + e-motor, etc.)

- ○ Yes
- ○ No
- ○ I don't know

If yes, what types?

Would you use a vehicle simulation platform on your system test beds?

- ○ Yes
- ○ No
- ○ I don't know

Would you use the same vehicle simulation platform for all three steps (x-in-the-loop, components, system)?

- ○ Yes
- ○ No
- ○ I don't know

Targets and goals for 48V

Besides passenger cars what other markets would you target with your 12V/48V micro hybrid systems?

- [ ] Light-duty trucks
- [ ] Medium-duty trucks
- [ ] Heavy-duty trucks
- [ ] Sportcars
- [ ] Motorcycles
- [ ] Forklifts
- [ ] Boats
- [ ] Other:

What future concepts do you think have a potential?

- [ ] GPS assisted calibration
- [ ] Vehicle-to-vehicle communication
- [ ] Vehicle-to-X communication
- [ ] Vehicle Tracking system
- [ ] Fleet Telematics System (FTS)
- [ ] Other:

What do you think are realistic CO2 emission reduction goals for your 48V system (in % and by when)?

Just give a rough Estimation. You can also leave this field blank.

What do you think are realistic goals for fuel mileage savings (in % and by when)?

Just give a rough Estimation. You can also leave this field blank.

What do you think is a realistic net cost target for the complete 12V/48V systems (including batteries, integration, savings from a starter motor, etc. in €)?

Just give a rough Estimation. You can also leave this field blank.

Test system requirements for 12V/48V systems

When do you think OEMs will need testing solutions for 48V systems?

- ( ) Already invested
- ( ) 0 - 1 year
- ( ) 1 - 3 years
- ( ) 3 - 5 years

- 5 - 10 years

For testing your 12V/48V batteries, a battery test system would need the following specifications: (Please fill in estimated numbers)

Nominal power:

I think for the battery test bed inverter ripple Emulation is:

- required
- desired
- not needed

For testing inverters for your 12V/48V system, following input and output specifications are required: (Please fill in estimated numbers)

Power:

For e-motor test system, following specifications are required: (Please fill in estimated numbers)

Power (nominal):

I think for the e-motor test bed, engine pulse simulation is...

- Required
- Desired
- Not needed

I think for the e-motor test bed with BSG testing, belt drive simulation is...

- Required
- Desired
- Not needed

If you have any comments for me please let me know in the following text box.