IO1

Study about the requirements for an electric powertrain engineer

Co-funded by the
Erasmus+ Programme
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EXECUTIVE SUMMARY

This document is the **Intellectual Output 1 (IO1) of the ECEPE project**. The primary objective of IO1 is to gather the different viewpoints of stakeholders from (a) EU policy maker and EU commission perspective, (b) representatives of German and Austrian automotive industry, (c) industry researcher and developer perspective (including two diverse views of development engineers and production & management engineers) and (d) non-classical passenger vehicle perspective (including public transport and alternative highly fuel-efficient vehicles).

Within this work, we present the **different stakeholder viewpoints and implications for the development of training concepts** related to a smooth upskilling of engineers for the electronic powertrain engineering topics. The aim of this analysis is to establish a basis of skills required by those companies, which are developing electric powertrain solutions of the future and develop an adequate training for future electric powertrain engineers. The target audience for this type of training and the project in general is related to higher education of students participating in any automotive related courses program. Regarding the training mechanism, concept of work-based learning combined with online training is taken into account and skills definitions and training materials of the ECEPE project should reflect that.

The aim of the **industry survey** is to get a deeper knowledge on the topic from the view of different industry stakeholders. For the success of the ECEPE project, it is necessary to collect and evaluate different viewpoints on the topic of electric powertrains in order to present tailored solutions.

The acquisition of the stakeholders viewpoints were **either done via personal meetings and discussions** on the ePowertrain engineering topic and a brief presentation of the proposed structures of the course, followed by a discussion on the individual points of interest (for the development engineers view and non-passenger and commercial vehicle view).

Alternatively, the answers to the questions were collected online in an anonymous form to secure data privacy. The online questionnaires were tailored for the specific viewpoints and use different tools. As such, the questionnaire for the EU representatives[1], the automotive industry representatives[2], and the management and production view[3] used different approaches.

In general, the survey was divided into four parts, but then tailored for the specific stakeholder group.

[1] https://drives-survey.vsb.cz/
[2] https://www.1ka.si/a/243083
[3] http://umfrageonline.com

The **first part** focuses on the participants and their expertise in their job area. Including the industry in which they are working and how many years of expertise, they have.

The **second part** is considered the most relevant in the survey, providing first-hand information which topics are relevant within the respective domain. To get a better knowledge on which topics should play a more prominent role in designing the new course and how the course shall be structured. The second question includes in total 27 elements of the electric powertrain development course material. The participants were asked to provide their opinion based on a Likert scale from not important to very important for electric powertrain-development.

The **third part** of the survey focuses on different job roles and their linkage to the topics, which are necessary to fulfil the development of electric powertrains. The third question aims to assign different job roles to the related topics.

The **last section** of the questionnaire aims to collect missing topics, which should be part of the final curriculum. As such, two open questions regarding cross-domain- knowledge and sustainability, Corporate Social Responsibility (CSR) and financial issues in the field of electric powertrain engineering were also added.

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1. INTRODUCTION

1.1 OBJECTIVE AND SCOPE OF THE DOCUMENT

This document gives an overview of the different viewpoints of stakeholders from (a) EU policy maker and EU commission perspective, (b) representatives of German and Austrian automotive industry, (c) industry researcher and developer perspective (including two diverse views of development engineers and production & management engineers) and (d) non-classical passenger vehicle perspective (including public transport and alternative highly fuel-efficient vehicles).
The objective is to gather the different stakeholder viewpoints and distillate implications for the development of training concepts related to a smooth upskilling of engineers for the electronic powertrain engineering topics. The aim of this analysis is to establish a basis of skills required by those companies, which are developing electric powertrain solutions of the future and develop an adequate training for future electric powertrain engineers.

The aim of the industry survey is to get a deeper knowledge on the topic from the view of different industry stakeholders. For the success of the ECEPE project, it is necessary to collect and evaluate different viewpoints on the topic of electric powertrains in order to present tailored solutions.

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The following viewpoints are covered:

- **European Union and European Roadmaps**
  Based on results of DRIVES demand survey, the importance of training and education provision mechanisms clearly shows the need for work-based learning as a delivery approach of training and education.
- **Automotive System Architecture and Engineering View**
  Viewpoint of representatives of German and Austrian automotive industry, the SoQrates working party members, constituted by leading automotive suppliers (Robert BOSCH, ZF Friedrichshafen AG, Continental Automotive, Magna Powertrain, etc.) and OEMs (e.g. KTM) are surveyed.
- **Non-passenger and Commercial Vehicle View**
  Apart from passenger cars, electric powertrains have great prospects for development in the field of commercial vehicles (trucks, busses, and public transport) and motor sport.
- **Engineers View**

Universities have the potential to play a vital role in the way to equip Europe with the skills and competences necessary to succeed in a globalised, knowledge-based economy.
In order to overcome mismatches between graduate qualifications and the needs of the labour market and to enhance the employability of graduates.

- **Management and Production View**
  Different viewpoints collected for the management and production engineers view include the automotive industry, suppliers to the automotive industry, the agricultural machinery industry and the research environment. To get a full view on the topic, also the impact on agricultural machinery industry was evaluated.

1.2 STRUCTURE OF THE DELIVERABLE REPORT

The main body of this document contains a common introduction to the automotive domain and electric powertrain concepts. Next part contains a brief overview of the market and prospects of ePowertrains, as well as, the target audience for such training courses.

For each stakeholder viewpoint an abstract analysis, a tailored survey or questionnaire and an evaluation for implications for the ECPE project and the curricula of the envisioned training is done.

Based on the analysis implications deducted for the ECEPE trainings program are summarized in the final Summary & Conclusion section.

The intention with this structure is to keep the main body of this document limited in size and the reader can get a more complete overview of all activities by reading just this main parts.

1.3 OVERVIEW AND SPECIFICS OF THE AUTOMOTIVE DOMAIN

The automotive market is of a highly competitive nature and this is currently being reorganized on a very broad front by cyber-physical systems for powertrain electrification and connectivity approaches, which improve energy-efficiency and enable novel business fields. These systems demand such a rapid knowledge growth and high associated knowledge change that has never experienced before in the history of human activity. As a result, this significantly increases new opportunities for realizing innovative functionalities, but also requires lifelong learning approaches and upskilling of engineers.

It is estimated that over 1 billion cars travel our roads in Europe today and over 90 million new ones are produced annually. This high usage has turned the automotive domain and smart transportation into a key industrial sector for Europe with 13.8 million jobs, representing 6.1% of total EU employment, producing 21% of the vehicles worldwide and generating a yearly trade balance of over €99 billion. Almost 6.1 million of those motor vehicles were exported in 2018, generating a trade surplus of €84.4 billion for the European Union. Taxation on these vehicles is worth €428 billion per year in the EU15 countries (1).

At the same time, Europe's automotive industry remains committed to address tomorrow's challenges. The automotive sector has been Europe's key driver of knowledge and innovation for many years and worldwide the second biggest R&D sector. EU automakers and suppliers have increased their R&D investments by 6.7%, to reach an all-time high of €57.4 billion per year, representing Europe's largest private contributor to R&D. This makes the automotive sector Europe's number one investor in innovation, responsible for 28% of total EU spending on R&D. Compared to other regions worldwide, the EU auto sector leads the way in terms of R&D investment. Moreover, 8,700 automotive patents were granted by the European Patent Office last year (1).

Recent trends indicate an automotive revolution driven by the concept of a connected and automated cars, but the European automotive industry is also massively challenged by CO_2 reduction regulations (phased in from 2020 the EU fleet-wide average emission target for new cars will be 95 g CO_2/km; corresponding a fuel consumption of around 4.1 l/100 km of petrol or 3.6 l/100 km of diesel) (2). Thus, the entire industrial sector needs to evolve and adapt at a very fast pace to also stay ahead of global competition, while including all stakeholders and addressing societal needs. Within the last years electrified mobility has been given first priority in the US, Japan, China, Korea and EU. The move from conventional combustion based mobility to more electric or full electric mobility poses many questions with answers depending on a multitude of interdependent parameters.

1.3.1 Economic figures related to the European Automotive Sectors

As already outlined, the scope of the European automotive sector is enormous in terms of economic significance. The sector provides direct and indirect jobs to 13.8 million Europeans, representing 6.1% of total EU employment (1). Moreover, 11.4% of all EU manufacturing jobs are related to the automotive industry. Europe's automotive sector has been the key driver of knowledge and innovation for many years and responsible for €84.4 billion trade surplus. In addition, numbers employed in the sector have risen over the last years (see Figure 1) with a quarter of all cars produced worldwide are made in Europe.

Along with US and Asian countries, the European automotive industry is identified as mainly an innovation-driven economy (3).

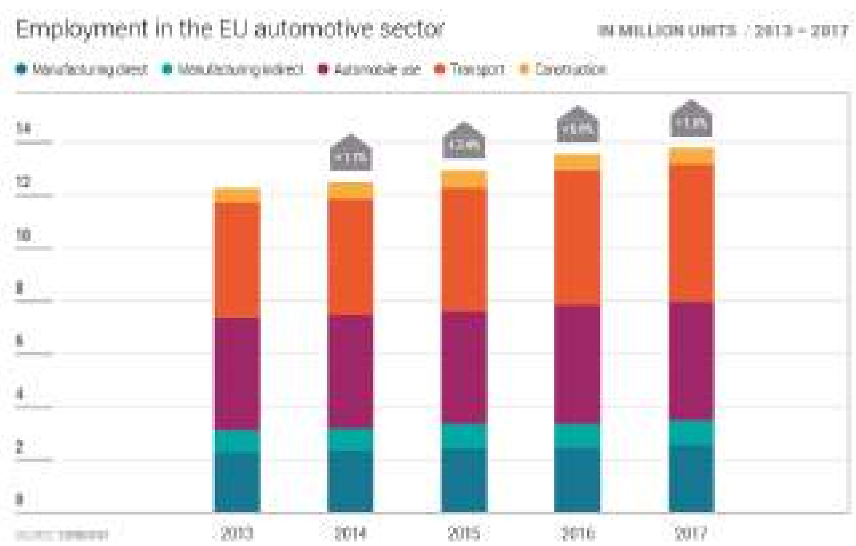

Figure 1 Employment in the EU automotive sector (1)

1.3.2 Automotive supply chain characteristics

The automotive sector is amongst the largest, most competitive, and most internationalised of all industries, with high barriers to entry (4). It is also a classic example of a producer driven commodity chain. It is characterised by a pyramid structure where on top are the Original Equipment Manufacturer (OEMs) referred to as companies that make the final product for the consumer market (e.g. Audi, BMW, Daimler, VW) (5). Tier 1 companies are directly supplying OEMs with major vehicle systems (such as drive train, infotainment, motor units) and are themselves supported by Tier 2 companies (supplying components such as vehicle control units, battery management systems). Tier is a common terminology in the automotive industry and refers to

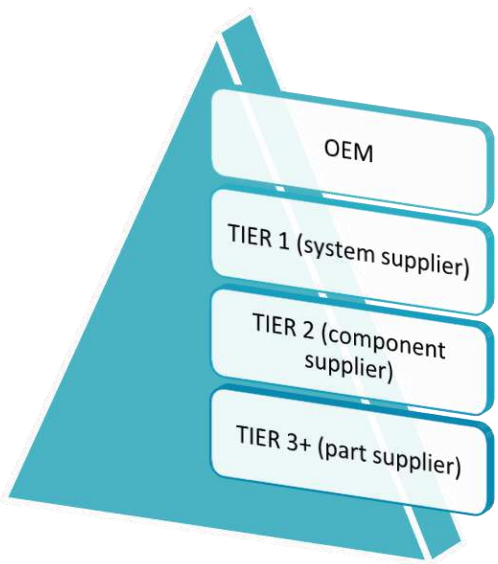

Figure 2 Automotive Supply Chain

major suppliers of parts. This structure is given due to the very complex end product and the multiple components and sub-assemblies it consists of key players and novel competitors.

The leading positions in the industry are still occupied by large global producers. Statista provides several 'top' lists in this regards, e.g. the largest 200 companies in the Automobiles & Automotive Parts sector ranked by revenue (6). In the Top10, ranking only three European automotive brands appeared Volkswagen (2nd), Mercedes (9th) and Renault (10th). Based on Statista calculations of market share values and rankings, global sales of 93.6 million units were achieved in 2018.

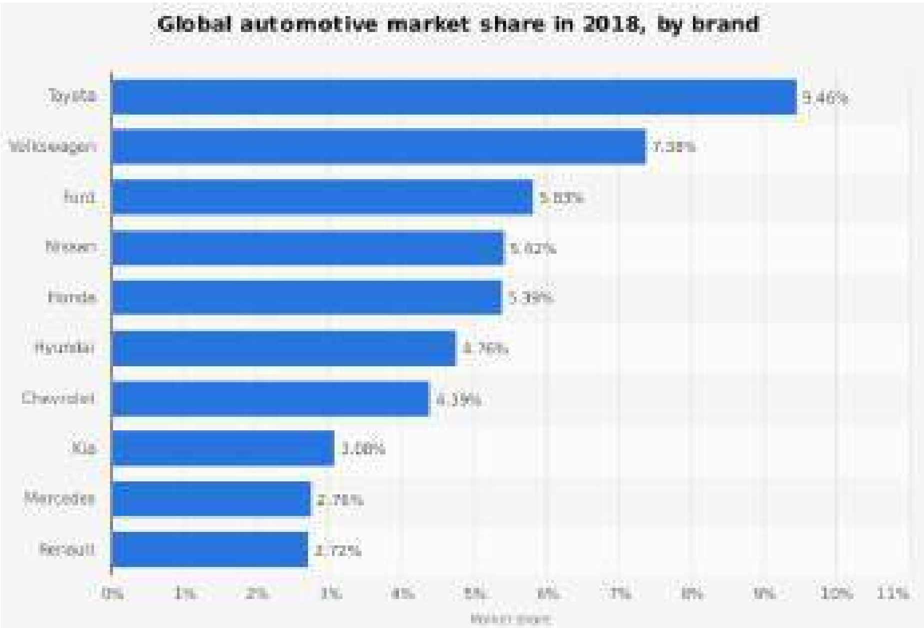

Figure 3 Global automotive market share in 2018 per brand by (6)

Traditional car manufacturers find themselves increasingly sidelined in a 'parasitic' relationship with tech titans such as Google, Apple and Baidu. Those novel players provide disruptive concepts and business models for basic car structures, technology (such as automated driving, voice-assistants like Siri, cloud-based solutions, cyber-protection, etc.) and infotainment systems.
As a counterpoint to these trends, Europe's automotive industry has a very high level of know-how, expertise, R&D, and highly skilled workers.

Economic volatility drives the need for a reconfigured and transparent supply chain that will increasingly focus on issues such as the need to tackle climate change, environmental pollution, traffic congestion and safe travel. These factors are forcing automakers to rethink their product mix and business model – thus revamping their supply chain with new offerings. The major issue of sustainability has become highly relevant in the automotive industry in recent years.

1.3.3 Major trends for sustainability, mobility and market success of electric vehicle

Not only Europe’s environmental conscious societies are eagerly looking forward to the integration of clean mobility into their urban lives. The global trend for sustainability is obvious, and electro mobility is moving forward driven by a significant progress with attractive market oriented cars now providing enhanced drive dynamics, cruising capabilities and mileage overcoming the meagre car concepts of the past. The current vehicle generation on the market is based on improved energy efficiency and improved batteries, also becoming competitive to Japanese car manufacturers.
Nevertheless, the average customers reluctance to buy an electrical vehicle (FEV) is dropping and market success and penetration in all relevant car classes (e.g. Volkswagen E-Up, BMW i3 and in the luxury class: BMW i8 and Tesla S) is crucial to participate in the trend with leading solutions.

The key to reduce the emissions of the mobility sector is the increase the electrification to profit from the vastly improved energy efficiency of electrified powertrains. Fast chargers as well as wireless power transfer systems will directly support the transition from typical internal combustion based cars to electrified ones by drastically reducing today’s application barriers. By doing so an efficient energy management can be supported as well as a reduction in the overall energy consumption can be achieved.
Keeping in mind that the well-to-wheel efficiency of the electrical powertrain can be 25% to 27%, i.e. the consumption of primary energy for the chosen vehicle is between 400 and 480 Wh/km.

The overall target to bring more electrified cars on the road and also to change the ratio between combustion and electrified cars, which is forecasted in a ration 1:1 by 2030 and which is pivotal to Europe`s growth and prosperity. This will facilitate more green cars and fewer emissions. Furthermore, this will facilitate complexity reduction without compromising functionality and even with increased functionality with fewer resources and less materials. The society will benefit from the co-modal traffic, which is enabled by autonomous, semiautonomous and automated driving. With more efficiency, less weight and space without compromising drive dynamics and safety.

Electric vehicles will definitely have more “positive” impact on our lives. It is perceived that they are going to start changing the way we live and our mobility. Currently the main threshold to adoption are costs, range, infrastructure and convenience of electrical vehicles.

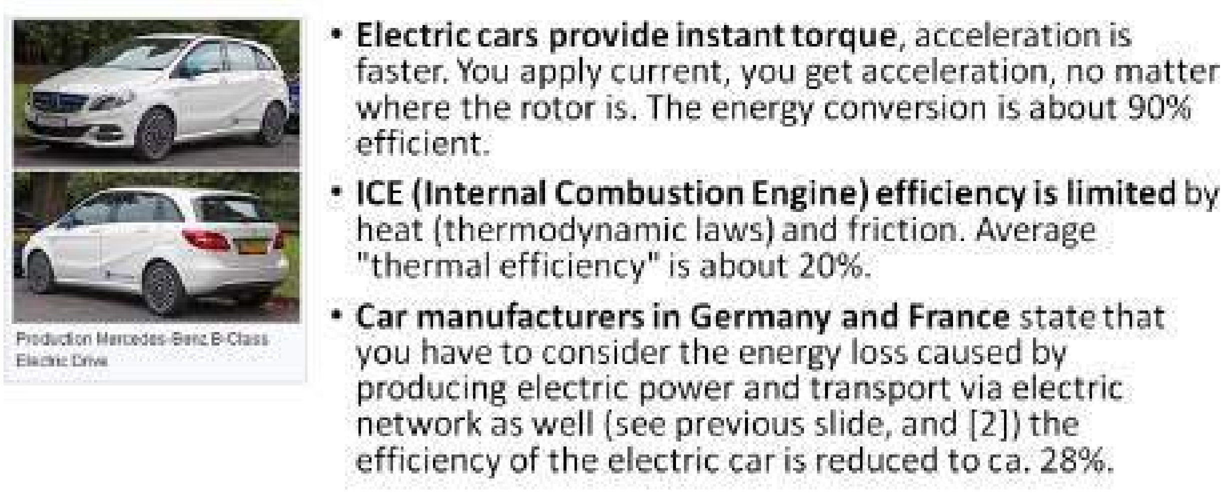

Figure 4 Advantages of Electric Car[4]

The energy efficiency is clearly much better in an electric car (see Figure 4)[5]. Even if the physical and mathematical energy efficiency of the electric motor is better[6], some still argue with the fact that electric energy production has the loss (see Figure 5). Therefore, in the EU there are additional strategy projects (e.g. EU Blueprint ALBATT[7]) that works on green electric energy concepts.

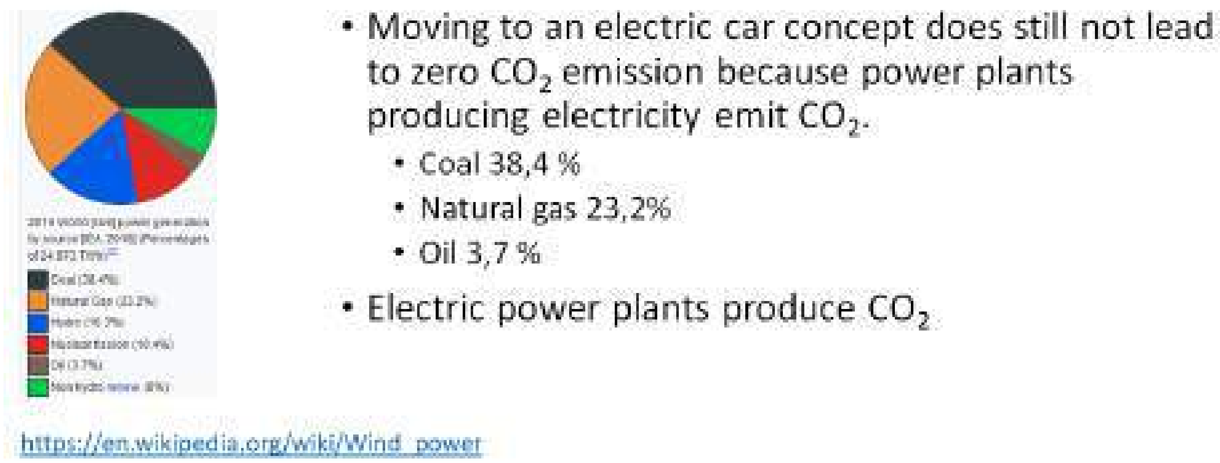

Figure 5 Zero emission requires change of energy cluster

[4] https://en.wikipedia.org/wiki/Mercedes-Benz_B-Class#B-Class_Electric_Drive
[5] https://en.wikipedia.org/wiki/Electric_car_energy_efficiency
[6] https://www.quora.com/Why-are-electric-motors-able-to-provide-instant-torque-though-internal-combustion-engines-cannot
[7] https://www.facebook.com/pages/category/Not-a-Business/Project-Albatts-104780274397590/

1.4 EPOWERTRAIN CONCEPTS

A variety of powertrain configurations exist, ranging from different hybrid (mainly combustion engine and electro motor) concepts to full electric vehicles (FEV) with one to four electric motor drives, with in-wheel or on-board installations, based on direct drive or including single- or multiple-speed transmission systems. These complex powertrain configurations (fundamental concept overview shown in Figure 6) aim at increasing energy and fuel efficiency.

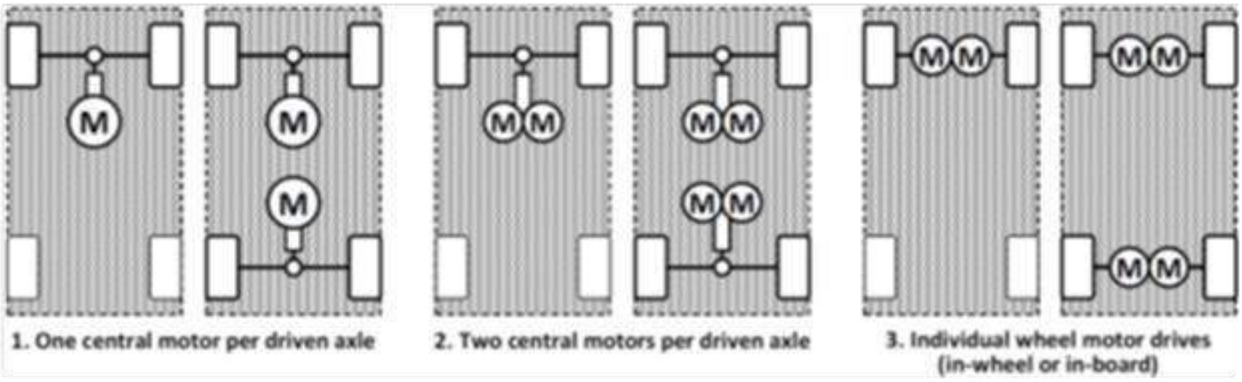

Figure 6 Fundamental concepts of hybrid powertrain configurations

Besides this, the variety of powertrain configuration options simultaneously increases the complexity of the powertrain itself as well as the required control systems (software functions and control units). Several different types of energy sources can only be utilized perfectly if the control systems are properly designed and perfectly configured. Current premium ICE driven and electric vehicles are characterized by several tens of distributed control units, with a complexity level of the E/E architecture significantly constraining vehicle performance improvements. To achieve further benefits of electro-mobility a further enhancement of the control functions and thus the re-design of the E/E architectures is required.

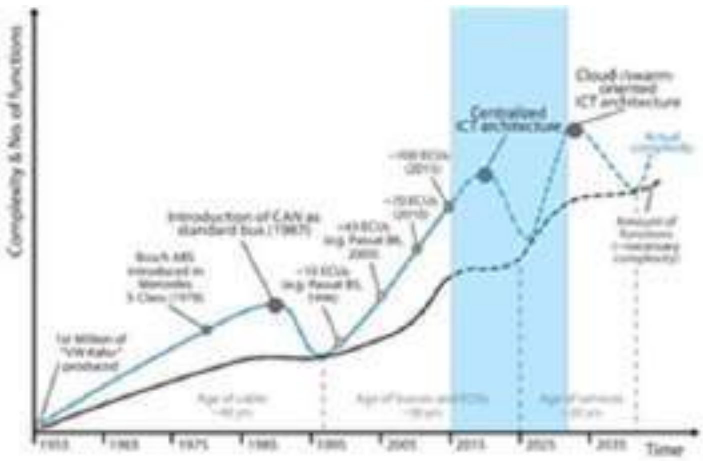

Figure 7 Evolution of complexity of automotive E/E architectures

After a few years of concept development, nearly all car manufacturers started to produce a similar concept, which is now multiplied many times.

Early phases 2008 - 2013:

- DC/DC motors are simple to control, you put more electric power in and you get higher speed, and you can do all with electronics and no Software. The major disadvantage was (remember your Merklin railway toy) for a powertrain, if you stop the torque it will continue to produce power for a delay time.
- 3 Phase asynchronous/synchronous motors are more complex, require inverter electronic and software, but can be controlled by software. If the software cuts the 3 phase currents, the motor does not produce torque any more.
- Then an e-car was designed with a single motor per wheel. However, any torque speed difference can the lead to steering in the car, which is rated as a highest safety critical event with potential death cases.

Mature phases 2014 - 2020:

- After these early phases, nearly all car makers decided for 3 or 6 phase motors, with inverter electronic and software and the motor being placed on an axle or two axles. This allows that both wheels will not turn differently.
- However, there are so-called torque vectoring systems, which allow adding additional torque to a wheel, this is different to the concept of a single motor per wheel.

This is the reason why the training focusses on the most common motor principle, which is used, the asynchronous or synchronous 3 phase current motor controlled by an inverter, and managing 3 magnetic fields in a sin phase wave.

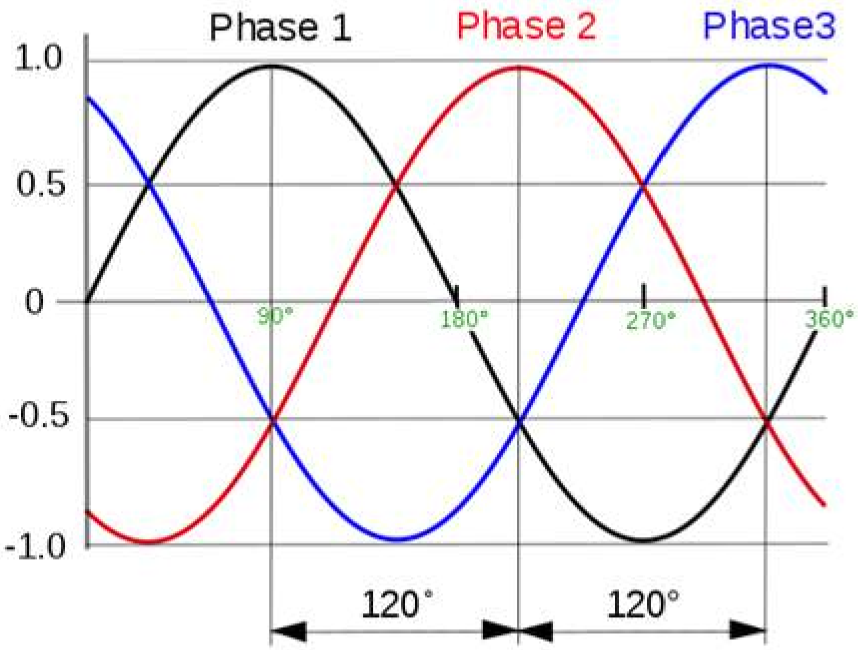

Figure 8 Managing 3 Phase Currents

This requires:

- Sin, cos functions – to program the controller with a 120 degree phase shift to actuate the three semiconductor elements that can switch the 3 phase currents I1,I2,I3
- The magnetic coils placed in a 120 degrees difference around the rotor
- Angle speed – to calculate the speed of the rotor

See also the system picture in chapter 3.

1.5 MARKET OVERVIEW AND PROSPECTS OF EPOWERTRAINS (HSD)

The field of ePowertrains is a heavily researched field. In the recent years, the topic of ePowertrains became more and more important for future mobility concepts. To get an overview of the state of the art of the market of ePowertrains, we considered the amount of newly registered cars with ePowertrains (hybrid & fully electrical). Additionally, we looked into the expected amount of newly registered cars with ePowertrains until 2030. Moreover, to give a full overview of the topic, we considered a study on the distribution of ePowertrains in the different vehicle classes. To sum the topic up we calculated the total amount of universities in Europe who are possible clients for the course and considered their market potential.

In 2019, the amount of new registered cars with ePowertrains in Germany was round about 300,000[8,9]. In general, 3.61 million cars were newly registered in 2019 in Germany[10]. According to the study, nearly 8 percent of the newly registered cars in 2019 contained an ePowertrain. In comparison to the year 2015, 3.21 million cars were newly registered of which only 46,000 were powered by ePowertrains[8,9,10]. This equates to 1.4 percent of the total amount. As can be seen the percentage of cars containing ePowertrains nearly multiplied by 6 during this time. In 2023 researchers expect that 1.5 Mio. registered cars on German streets will contain ePowertrains[11]. The number of cars containing ePowertrains will increase heavily in the next few years. This is the case, because in the future every new car concept contains batteries, fuel cells or at least a hybrid system. The amount of combustion engines will plummet in the next years due to heavy environmental impacts and regulations. At the moment, every car manufacturer worldwide has some concept of ePowertrain development ongoing. In conclusion, ePowertrains will be the stars in future automotive engineering while combustion engines will be something like the cows in a BCG portfolio matrix.

Besides the number of registered cars containing ePowertrains, the market potential of the course is highly relevant. The numbers from the section before show a high potential of ePowertrains in the future automotive market. Several engineering study programs can be considered as suitable for the course project. Students in Europe of the subjects electrical engineering, software engineering, system engineering, industrial engineering and automotive engineering are relevant to be taught in the course. The market potential in general is the sum of all engineering classes from above in Europe with the aim of getting a bachelor’s degree (ISCED level 6). Unfortunately, no current number of the different engineering related universities/study programmes in Europe is provided by the EU. At the University of Applied Sciences Düsseldorf, the newly training course could address at least students out of 10 different subjects in the current bachelors program. As a result, the training course will address many students in every country of the European Union. At least nearly, every engineer is a potential employee in the automotive industry. For example, a general mechanical engineer is also sufficiently educated for working in the automotive industry. This means that engineers in general should be able to take part in the course. In Germany, every year approximately 72.000 students finish with the bachelor’s degree[12]. This makes out nearly 30 percent from the approximately 247.000

[8] Statista, Anzahl der Neuzulassungen von Elektrofahrzeugen in Deutschland von 2003-2020, 2020
[9] Statista, Anzahl der Neuzulassungen von Hybridfahrzeugen von 2005-2020, 2019
[10] Statista, Anzahl der Neuzulassungen von PKW in Deutschland gesamt von 1955-2019, 2019
[11] Ecomento, Studie, Deutsche Elektroautomillion wird 2022 realisiert, 2018
[12] Statista, Anzahl der Absolventen in der Fächergruppe Ingenieurwissenschaften an Hochschulen in Deutschland in den Prüfungsjahren von 2005-2018, 2019

graduates in all subjects[13]. This means that 30 percent of all students in Europe are potential participants for the course.

Most of the graduates from tertiary school are mid aged in average 24 years[14]. The course should be suited for people in that age and consider learning types of that age group.
The Aim of the European Union is to increase the number of graduates to 40% of all people in that age. This target was set to achieve in 2020 but was already achieved in 2018[15]. This means that the target group will grow above average in the next years.

Putting the broad range of the training course and the exponentially increasing field of ePowertrains for the automotive market together, the course has a high market potential from now onwards. A possible application for the course are also other mobility concepts (e.g. Trains of agriculture), which are currently not included but could easily be included. This would even increase the current market potential by a high factor.

1.6 BRIEF OVERVIEW OF EXISTING COURSES AND THE GOAL

Since the ePowertrain, knowledge need is growing rapidly and the need for reskilling the workforce to a new technology is already there, many courses appeared during the last years. Most of the courses are dedicated to the re-skilling and are very expensive VET courses, like the following not exhaustive list:

https://www.ifptraining.com/course/hybrid-electric-powertrains.html#objectifs

https://www.udemy.com/courses/search/?q=electric+powertrain

https://www.sae.org/learn/content/acad06/

https://www.diyguru.org/class/automotive/page/2/

https://hssmi.org/evpss/#contact-us

Regarding the university teaching, each university is doing its own programme, more or less adjusted to the needs in the specific region/s. Comparison of such a courses based on “just” a learning outcomes is therefore difficult and it is hard to say how these courses reflects latest state of the art, how much detailed is the content and what real knowledge the students will get, etc. Our proposed pan-European approach with clearly stated detailed skill-card as a basis for certification should overcome this difficulty and allow to compare the outcomes and level of detail given by the course. By providing the

[13] Statista, Studienabschlüsse: Bachelor und Masterabschlüsse in Deutschland bis 2018, 2019
[14] Statista, Durchschnittsalter von Hochschulabsolventen in Deutschland bis 2018, 2019
[15] Eurostat, regional yearbook, p. 63, 2019

reference skill card, it will be possible to compare the relevant content not just in the project partner universities, but also for others that can join the job role development in the future.

The contend of the proposed course to be develop by the project is dedicated to the high education students and also by its nature for possible re-skilling of the workforce and will have a real level of detail needed by the development engineers to work on such a e-concepts. Envisioned content based on the pre-defined skill card will be following all necessary standards and procedures that has to be followed in automotive (ASPICE, Functional Safety, Cybersecurity,..) and graduates will be ready to work in the automotive sector development and come up with new ideas and concepts afterwards. The course will contain the theoretical, practical and self-learning parts where appropriate and needed. Since the modular structure following the EQAVET rules will be applied, the course can be integrated to the teaching as whole or specific parts can be integrated to the current subject, still as a whole defining the whole final concept of being certified ePowertrain engineer.

1.7 TARGET AUDIENCE

Global automotive drivers of change, like climate change due to CO_2 emission and related future innovative developments (electric powertrain, new infrastructures to support electric drive, e-mobility concepts) have led to an agenda by the automotive manufacturers and actions under the new skills agenda for Europe until 2030. One of the analysed key job roles to support future developments in automotive industry is to train/upskill knowledge, in particular a skill set for an electric powertrain engineers.

The target audience for this report and the project in general is related to higher education of students participating in any automotive related courses program in Europe. At a further level, the (automotive) industry is targeted as well, as they are profiting from skilled students when looking for their future employees. These programs may vary in type and focus, but are in cooperation with industry partners and subject to the strategic partnership to enforce the automotive domain with skilled personal.

Each consortium member expert will train students in their respective universities. Since all participating students are regular students of their university, no special arrangement is necessary. Another advantage is that this English-speaking course program can be easily integrated into several subjects, such as Software Engineering, Automotive Management, Information Systems etc. One of the main benefits is that all the universities will share and teach the same content and the quality will be granted by the common exercise arrangements certified following the ECQA rules. The electric powertrain related skills requirements will be analysed together with those companies, which are developing such electric powertrain solutions in the future.

The proposed transnational learning, teaching and training activities include the following tasks:

1. Train-the-Trainer: Essentially those trainers collaborate in pilot trainings, and exchange their individual views and expertise on the subjects of the ECEPE program.
2. Student classroom and on-line teaching events: Each consortium member expert will also train students in their respective universities/engineering schools.
3. Plan to implement the new curriculum long term: including new lectures in existing university curricula, which is often a very difficult and time-consuming task due to administrative and legal constraints.

2. EUROPEAN UNION FUTURE AND ELECTRIC POWERTRAIN ENGINEERING

"The European Green Deal is our roadmap for making the EU's economy sustainable. This will happen by turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all" (7). To reach the EU goal to be climate neutral in 2050, one of the main actions to be taken is "rolling out cleaner, cheaper and healthier forms of private and public transport". This also includes and highly influences the move from current widespread form of power transition (e.g. combustion engine etc.) to CO neutral way of powering the private and public transport vehicles.

However, a European green deal strategy is not the only driving force of the changes. As stated in A New Industrial Strategy for Europe (8), "Europe needs an industry that becomes greener and more digital while remaining competitive on the global stage".

There are three main challenges:

- A globally competitive and world-leading industry
  - Conditions to turn ideas into actions for companies of all sizes to thrive and grow
  - Be able to leverage the impact, the size and the integration of single market to set global standards
  - Uphold, update and upgrade the world trading system so it is fit to address today's challenges and tomorrow's realities
- An industry that paves the way to climate-neutrality
  - EU green deal – clean technologies
- An industry shaping Europe's digital future
  - Scalability is the key in a digital technology

Therefore, the fundamentals of Europe's industrial transformations are:

- Creating certainty for industry: A deeper and more digital single market
- Upholding a global level playing field
- Supporting industry towards climate neutrality
- Building amore circular economy
- Embedding a spirit of industrial innovation
- Skilling and reskilling
- Investing and financing the transition

Regarding all of that, the Europe must react and prepare a sustainable approach to overcome these challenges. E-powertrain is also part of it for some time (9)

All of that is also visible in EU strategic Sector Skill Alliance project DRIVES, led by VSB-TU Ostrava, which is the Blueprint for strategic cooperation on skills in automotive sector. DRIVES is also mentioned in 10 points plan how to tackle the Green Deal by ACEA. (10).

Another strategic project in this area is ALBATTS project, which is the Blueprint project for strategic cooperation on skills in Batteries for e-mobility sector. Industry drivers of change were and are discussed and pilot strategies defined in these two still running projects (2020/4). One of the many outcomes led also directly to the need and therefore proposal of the new project, this ECEPE – E-powertrain engineer training skills and training definition project.

2.1 DRIVES PROJECT OVERVIEW

The Development and Research on Innovative Vocational Educational Skills project (DRIVES) delivers human capital solutions to the whole automotive supply chain through the establishment of an Automotive Sector Skills Alliance. This covers all levels of the value chain (vehicle production, automotive suppliers and automotive sales and aftermarket services). Through the network of the full project partners, such as ACEA, CLEPA and ETRMA, and associated partners, such as Stuttgart Region, DRIVES outcomes are disseminated EU-wide to more than 300 associations, bringing together more than 270,450 companies of all sizes, representing over 7 million workers.

The DRIVES project is part of the Blueprint for Sectoral Cooperation on Skills in the Automotive Sector.16 The goal is to establish an Automotive Sector Skills Alliance covering all levels of the value chain and to ensure that needs of industry are reflected by education and training institutions. The Project is based on cooperation between 24 full partners from 11 EU countries17. The duration of the project is from 2018 to 2021.

[16] https://ec.europa.eu/social/main.jsp?catId=1415&langId=en
[17] https://www.project-drives.eu

2.2 ALBATTS PROJECT OVERVIEW

The European workforce will be disrupted or highly affected by the change brought about by the transfer to electro mobility. There will be a need for new training/ reskilling programmes, adapted to the emerging jobs needs.

The Alliance for Batteries Technology, Training and Skills (ALBATTS) aims to be a major contribution to the green mobility in Europe. As the European battery value chain is being developed, organisations from the demand and supply side of skills/competences are brought together, to establish a blueprint for preparedness of future skills across Europe.

VET providers and Universities will work in coordination with the demand side in order to identify and develop the relevant competences required to fulfil their economic activity. The bridging with national authorities will be permanent to assure inclusion of produced curricula and learning materials into the national qualification frameworks. Appropriate measures and education and training materials are to be prepared according to local or horizontal context.

The Project is based on cooperation between 20 full partners from 11 EU countries[18]. The duration of the project is from 2019 to 2023.

2.3 INDUSTRY DRIVERS OF CHANGE

As it was identified by DRIVES project, “drivers of change” are those factors, which are key to transforming an industry. Specifically, a literature review of available automotive reports was undertaken in DRIVES project in order to create an overview of current Drivers of Change and their relevance (performed in the years 2018-2019). The analysis compares the outcomes of the European Automotive Skill Council[19] report and GEAR 2030 report[20], with other available intelligence/reports related to the EU automotive sector in order to identify the main Drivers of Change within the European automotive sector.

After identifying the key Drivers of Change using the European Automotive Skill Council report and GEAR 2030 report, the wider literature review was undertaken in order to validate, review and add

[18] https://www.project-albatts.eu

[19] European Sector Skill Council: Report, Eu Skill Council Automotive Industry, 2013

[20] GEAR 2030, High Level Group on the Competitiveness and Sustainable Growth of the Automotive Industry in the European Union, 2017

new Drivers of Change to this initial list. Through this, approach five main 'macro' Drivers of Change have been identified, these being:

- NEW TECHNOLOGIES AND BUSINESS MODELS
- CLIMATE GOALS, ENVIRONMENTAL AND HEALTH CHALLENGES
- SOCIETAL CHANGES AND CHANGES IN THE WAY THAT CONSUMERS ACCESS, PURCHASE AND USE CARS
- STRUCTURAL CHANGE
- GLOBALISATION AND THE RISE OF NEW PLAYERS

Each 'macro' Driver comprises several more specific Drivers of Change that were identified as relevant. Analysis also focussed on the identification of emerging Drivers of Change. The literature review enabled the mapping of each initial macro Driver of Change against wider research evidence, based on the number of times each Driver was cited in those reports included in the review. This analysis enabled validation of the initial choice of Drivers of Change. Literature review is described on the DRIVES webpage[21] and in published research paper (11).

NEW TECHNOLOGIES AND BUSINESS MODELS

Companies in the automotive sector are facing constant developments in the area of advanced manufacturing, materials and the complexity of global supply chains. This will result in many jobs and processes needing to be redefined to take advantage of the potential that automation offers the sector.

- **Connected and Automated Driving (CAD), Advanced Driver Assistance Systems (ADAS)**

  These are aspects related to the assistance and automation of the driving activities to reduce road fatalities, minimise human errors and move a vehicle without driver active interventions.

- **Alternative power trains**

  The variation from internal combustion to a CO_2 neutral mobility is directly connected to changes in power trains.

- **Electrification**

  It is a fact the running out of crude oil and the CO_2 global reduction is almost inevitable in Europe. Electrification in the whole powertrain is a possible strategy to avoid this issue.

[21] https://www.project-drives.eu/en/results

- **Advanced manufacturing, digitalisation and robotization of the manufacturing process**

  Firms in the automotive sector are facing constant developments in the area of advanced manufacturing, integrating the results of technological research into manufacturing process. Moreover, Manufacturing 4.0 can create efficiency and reduce (indirect) costs.

- **Handling of / access to vehicle data**

  Increasing technology inside a vehicle and the relative necessity to be connected drive the needs to manage and access huge quantities of data quickly. Big data and analytics will allow players to optimise vehicle usage and forecast maintenance requirements (predictive maintenance).

- **3D printing**

  It is a technology that can lead to a reduction in the costs of production as well as a reduction in defects and will have an impact on jobs and skill requirements. Moreover, it is useful for rapid prototyping and advanced manufacturing and enables prototypes to be 'moved' between different players within the supply chain very quickly and efficiently.

- **New communications technologies**

  In the near future the vehicle will be connected, with digital technologies changing the way data is transferred and utilised. These new communication technologies have a key strategic importance in relation to changes in the sector.

- **New / advanced materials**

  Modern car parts are increasingly made of lighter materials and these new / advanced materials are driving the strategies for future evolution in terms of product, design and performance.

CLIMATE GOALS, ENVIRONMENTAL AND HEALTH CHALLENGES

Encouraged by both consumer demand and public actions, the automotive industry is stepping-up efforts to find viable alternatives that can reduce the negative effect of car pollution in the run up to 2030 and beyond.

- **Low and Zero-emission vehicles**

  The automotive market is being challenged to develop more fuel-efficient engines and alternative powertrains to comply with the evolving standards in terms of pollution and CO2 emissions. Due to new international regulations consumers will have the possibility to choose from a mix of powertrains that best meet their lifestyle needs, for example, more efficient internal combustion engines, electric vehicles (EVs), hybrid electric (Plug-in Hybrid Electric Vehicle), and vehicles powered by natural gas.

- **Greater range autonomy**

  The introduction of a new technology must be compared with the existing one. The range autonomy of a vehicle is an essential factor to be considered when a new power train technology arises and innovations relating to this are a key driver of change in the sector.

- **Battery efficiency**

  The necessity to store electric energy into a vehicle is an intrinsic necessity of a car. In the case of an electric vehicle, the battery can be compared to the gasoline tank of an internal combustion engine car: it is the place where the energy to move the vehicle is stored. An increase in its efficiency means more range for the vehicle and a rapid refuelling.

- **Improved charging/refuelling infrastructure**

  The needs for a widespread refuelling infrastructure are a key driver to boost the commercialisation of a technology based on a new fuel. The easier the access to a rapid refuelling infrastructure the quicker will be the development of such new technologies.

SOCIETAL CHANGES AND CHANGE IN THE WAY THAT CONSUMER ACCESS, PURCHASE AND USE THE CARS

The way that consumers access, purchase and use cars and other modes of transport is changing due to increasing connectivity and the greater use of e-commerce. New technologies and the massive use of the internet will have a huge impact on the use and concept of mobility (less product and more service).

- **Increased connectivity / infrastructure (V2X)**

  A vehicle is a connected entity able to monitor, in real time, its own parts and safety conditions around it. This trend is growing, and the car of the future will be connected to other vehicles and to any entity that may affect the vehicle itself. The acronyms V2X refers to a form of technology that allows vehicles to communicate with parts of the traffic system around them and vice-versa. In this context, 5G infrastructure will be deployed along major terrestrial transport paths.

- **Data Access / New Data**

  Higher connectivity of vehicles will also generate large amounts of new data. This will need to be considered as appropriate policy and legal solutions are found for the problems of vehicle integrity, security, road safety and liability. These will support the emergence of new business models and it is likely that this will include provision for direct, safe and secure access to a wide set of vehicle data for the provision of connected services.

- **Mobility as a Service**

  Car-sharing and ride-hailing mobile apps are a couple of examples of how the concept of mobility is changing, with consumers more and more interested in the “final service” than in the product. Using instead of owning might be an important driver to change the approach to product, market and services within the automotive sector.

STRUCTURAL CHANGES

The automotive sector is a major European employer and the impact on the workforce resulting from the transition to new technologies will be significant. The demand for new skills and experience will equally result in a fall in demand for other more traditional skills.

- **Restructuring**

  The European automotive sector is expected to undergo structural changes due to the development of digital technologies and the shift towards low and zero emission mobility. The industry, in particular SMEs, will need to assess and, if necessary, redefine their position in the value chain as well as increase their capacity to integrate digital technologies, alternative powertrains and circular economy concepts in their products portfolio and production processes.

- **Acquisition of new skills**

  The transformation of the automotive industry will have a significant impact on the industry's workforce and the acquisition of news skills will be a key factor enabling employees to be equipped to deal with these changes. These changes will lead to both the creation of new occupations and the need for new skills and competences amongst the existing workforce.

- **Continuous training**

  Continuous training is always useful, but during periods of disruptive change, continuous training is essential to align competences to changing skill requirements. These activities also need to be supported by actions to improve mobility and transferability of skills, linked to the development of an efficient apprenticeship market and encouragement of informal learning.

  In this time, where industrial innovation and changes are so rapid, as it never been in history of humanity, the continuous training, upskilling and reskilling, is becoming the must.

GLOBALISATION AND RISE OF NEW PLAYERS

The EU automotive sector is facing growing competition from non-EU markets and competitors. Over the next few years, production in global markets is expected to grow strongly, whilst EU production is predicted to remain relatively flat. Maintaining the EU's global competitiveness will depend on ensuring high levels of investment in the new and emerging areas, especially in the area of product standardisation, supported by global technical harmonisation to guarantee a stable access to key sub-products.

- **Global technical harmonization**

  The supply chain structure within the automotive sector will need to meet the challenges posed by the introduction of new technology but also meet changing market conditions. New mobility concepts; new standards and product harmonisations will also be necessary to create scale economies and to satisfy a possible increasing request of white label components and unbranded vehicles (for example, the possibility for new car-sharing brands to have a "standard" fleet where the core product is the service and not the car-brand).

2.3.1 Analysis of Drivers of Change influencing the Automotive sector

Based on DRIVES Survey Demand results[22], there was identified following Drivers of Change index, which shows combination of priority and timeframe to each DoC how it was identified by survey.

Figure 9 Drivers of change timeframe * priority index

For each Driver of Change respondents were asked to comment on two key issues:

[22] https://www.project-drives.eu/Media/Publications/4/Publications_4_20190705_154211.pdf

- **Importance**: The relative importance of each Driver of Change for the respondents' particular business using a ranking from 0 to 5
    - o 0 = not applicable
    - o 1 = not important
    - o 2 = Slightly important
    - o 3 = Moderately Important
    - o 4 = Important
    - o 5 = very important

- **Urgency**: Respondents were asked to identify the relative importance of the impact of each specific Driver of Change over the periods up to 2020, 2025 and 2030
    - o by 2020: 5 = very urgent
    - o by 2025, 3 = urgent
    - o by 2030 and later, 1 = not urgent

2.3.1.1 IMPORTANCE OF DRIVERS OF CHANGE GROUPS

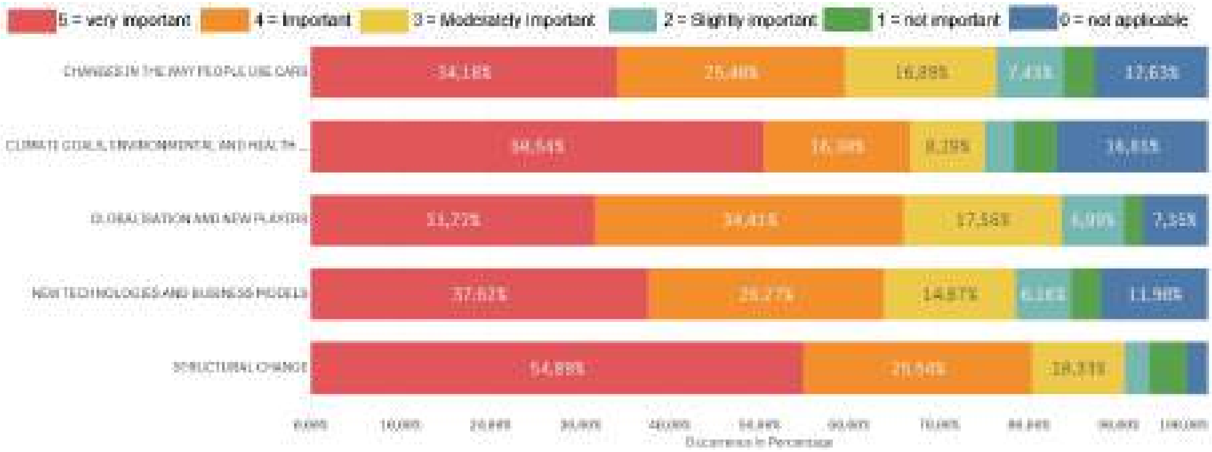

Figure 10 KPI 2.1: DRIVERS OF CHANGE Groups: IMPORTANCE – Overall sample

Based on analysis of those responses identifying the level of importance attributed to each Driver Of Change as 5, Figure 10 indicates that „STRUCTURAL CHANGE" is identified as the most important with 55% of respondents scoring this Driver of Change as 5. This is followed by „CLIMATE GOALS, ENVIRONMENTAL AND HEALTH CHALLENGES"(51%) and „NEW TECHNOLOGIES AND BUSINESS MODELS"(38%). If all responses scoring each Driver of Change between 3-5 are included, the relative importance of each Driver changes. Based on these criteria, „STRUCTURAL CHANGE" remains ranked first on this basis with 91%, with „GLOBALISATION AND THE RISE OF NEW PLAYERS"ranked second (84%) and „NEW TECHNOLOGIES AND BUSINESS MODELS"third (79%).

„CLIMATE GOALS, ENVIRONMENTAL AND HEALTH CHALLENGES"was the Driver of Change associated with the highest number of respondents scoring 0 (not applicable), but was also ranked second in relation to those giving a score of 5 (very important).

2.3.1.2 URGENCY OF DRIVERS OF CHANGE GROUPS

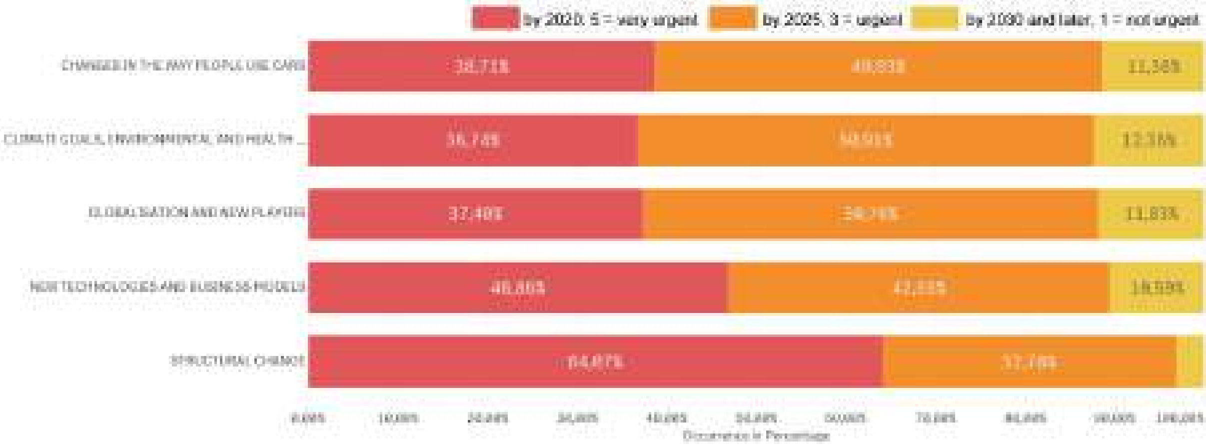

Figure 11 KPI 2.2: DRIVERS OF CHANGE Groups: URGENCY – Overall sample

Figure 11 outlines analysis of the relative urgency of Drivers of Change split into three options: by 2020 (very urgent), by 2025 (moderately urgent) and by 2030 and later (not urgent).

The analysis indicates that most respondents identify that each Driver of Change as either urgent (by 2020) or moderately urgent (by 2025). Looking at respondents identifying each Driver as 'very urgent' it is evident that the "STRUCTURAL CHANGE" with 64% of responses in this category is the most urgent Driver of Change, followed by "NEW TECHNOLOGIES AND BUSINESS MODELS"(47%) and "CHANGES IN THE WAY PEOPLE USE CARS" (38.71%). Examining the most frequent response in terms of level of urgency for each Driver of Change, "STRUCTURAL CHANGE" (scored very urgent by 64% of respondents) is followed by "CLIMATE GOALS, ENVIRONMENTAL AND HEALTH CHALLENGES" (moderately urgent 50.91%), "GLOBALISATION AND NEW PLAYERS" (moderately urgent by 50.76%) and "CHANGES IN THE WAY PEOPLE USE CARS" (moderately urgent by 49.93%).

2.4 SKILL DEMANDS FORECAST FOR 2030

Based on results of DRIVES Survey Demand, this section presents skills demands forecasted. Given the 'open ended' nature of many of the survey questions the harmonisation process was an essential step of the questionnaire analysis and these results sets out analysis of the harmonised responses. In order to present, the findings of the survey a Skills index has been created.

In a simplified form, the SKILLS INDEX is stated as:

Occurrence (of each skill) x **Priority DoC Index (**average for each skill[23])

With this index, it is possible to merge two important sets of information and present this a one number: specifically, how many times a skill has been mentioned in relation to the linked Driver of Change, ranked within one index.

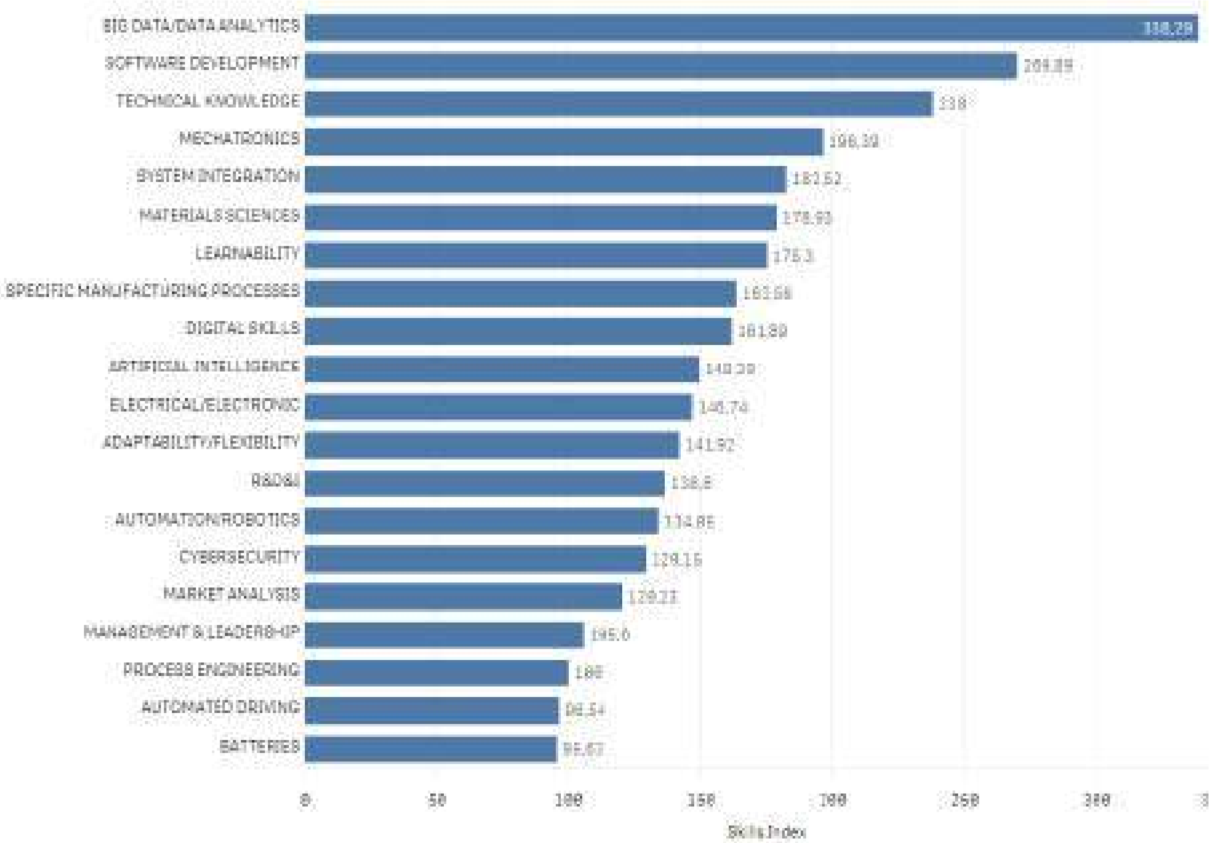

Figure 12 KPI 3.1 Skill Index – Overall sample

23 *Respondents were given the opportunity to indicate for each Skill, the related Drivers of Change interacting with this skill. With this index it is possible to link skills with appropriate Drivers of Change*

Figure 12 outlines the TOP15 Overall Skills ranked according to the Skill Index. Based on the categorisation adopted[24] five skills are TECHNICAL, 3 are relate to DIGITALISATION, with other less frequent occurrences relating to "ELECTRIFICATION", "LIFE CYCLE/PROCESS CHAIN", "MANUFACTURING" and "SOFT SKILLS" profiles. In terms of specific skill areas, "BIG DATA / DATA ANALYTICS" is ranked first with a significant gap to the second highest score relating to "SOFTWARE DEVELOPMENT", with "TECHNICAL KNOWLEDGE" ranked third, underlining the importance of skills required to adapt to technological change in the sector. The first SOFT SKILL - "LEARNABILITY" - is ranked seventh.

Skill Index is also shown on following figure as word cloud:

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24 *Chapter 3.2 normalisation of skills*

2.5 JOB ROLE DEMANDS FORECAST FOR 2030

The same approach and methodology used for Skills has been adopted for analysis of Job Roles, with the creation of an index.

In a simplified form, the JOB ROLE INDEX is stated as:

Occurrence (of each Job Role) x **Priority DoC Index (**average of each Job Role[25])

With this index, it is possible to merge two important sets of information and present this as in one number: specifically, how many times a Job Role has been mentioned in relation to the linked Driver of Change, ranked within one index.

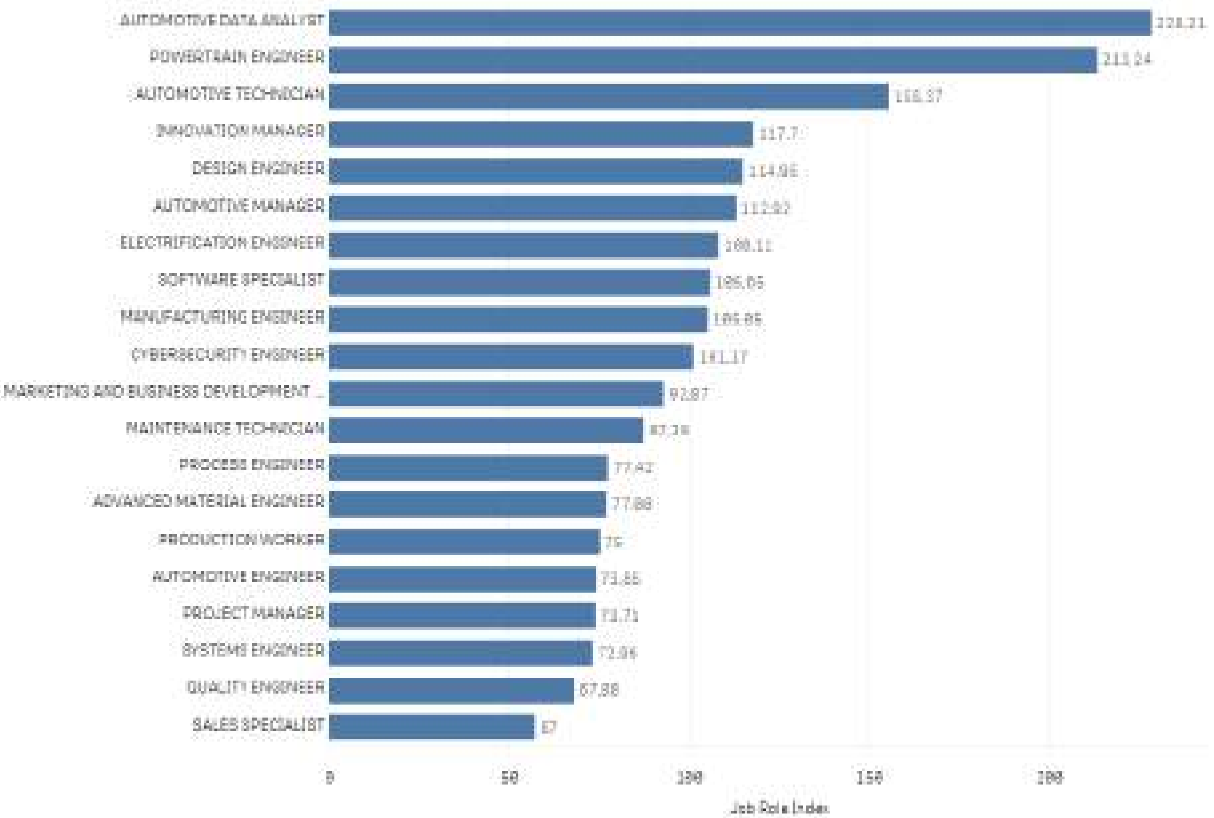


Figure 13 KPI 4.1 Job Role Index – Overall sample

Figure 13 KPI 4.1 Job Role Index – Overall sample outlines the TOP 15 Job Roles ranked according to the Job Role Index. Based on this, the positions ranked first, second and third are all automotive specific roles, these being "AUTOMOTIVE DATA ANALYST", **"POWERTRAIN ENGINEER"** and "AUTOMOTIVE

[25] *Interviewed had possibility to indicate per each JobRole the related Drivers of Change interacting with the JobRole itself. With this index it is possible to link JobRoles with appropriate Drivers of Change*

TECHNICIAN". The first non-automotive specific Job Role is ranked 4th and is "INNOVATION MANAGER".

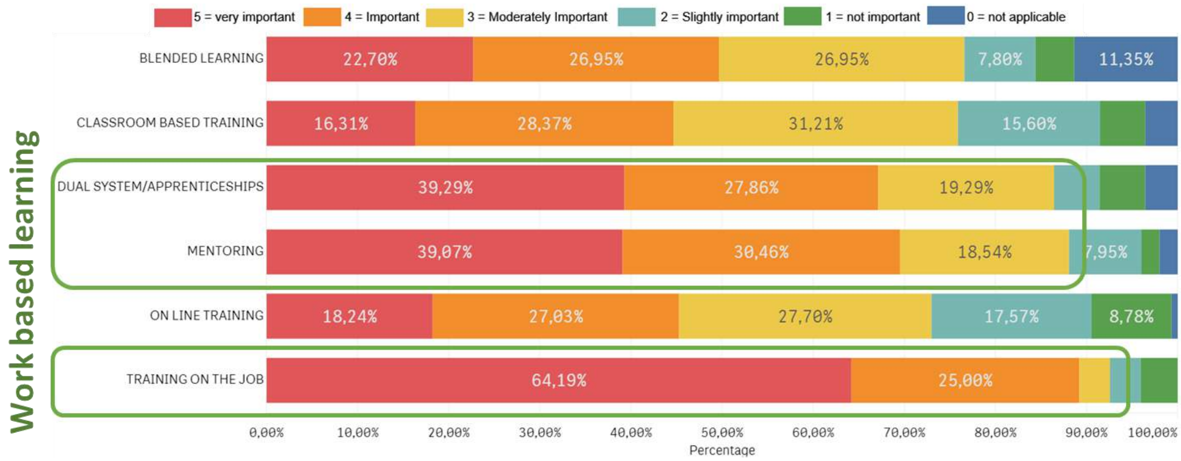
Part of the survey was also the definition of the skills for defined job roles. Table 1 shows normalized skills for **POWERTRAIN ENGINEER** job role, which were defined by respondees and normalized then.

Table 1 Powertrain engineer skills – DRIVES demand survey

SKILL	LEVEL OF SKILL
ADVANCED POWERTRAIN ENGINEER FOR ALTERNATIVE FUELS	Expert
BATTERIES: CHEMISTRY, ELECTROCHEMISTRY: MANUFACTURE OF ELECTRIC CELLS (STORAGE)	Expert
BATTERY ELECTRO CHEMICAL KH	Awareness
ELECTRIFICATION: ELECTRICAL-ELECTRONIC ASSEMBLY, ELECTRICAL EQUIPMENT, STEEL MACHINING, MECHANICAL MANUFACTURING	Expert
ENGINEERING EXPERTISE REGARDING ELECTRONICS/ SYSTEM INTEGRATION/ ELECTRIFICATION	Practitioner
ENGINEERING SKILLS REGARDING ELECTRONICS/ HYBRIDIZATION/ ELECTRIFICATION; SYSTEM KNOWLEDGE	Practitioner
GEAR DESIGN AND MANUFACTURING	Expert
POWER SWITCHING TECHNOLOGY	Practitioner
SYSTEM ENERGY MANAGEMENT	Expert

2.6 EDUCATION AND TRAINING PROVISION MECHANISMS

Importance of training and education provision mechanisms is depictured on following figure. It clearly shows the need for work-based learning as a delivery approach of training and education. However, during the pandemic times in Q1 2020 there is rising need for online trainings and education as reaction to home office work of the automotive workforce. Anyway, the combination that reflects specific needs of each stakeholder is the most important.



2.7 OUTCOMES & RECOMMENDATIONS & CONSTRAINTS FOR ECEPE

As presented in the previous sections of this chapter, the new e-powertrain concept comes not only from the need of the clean mobility, but also from the structural changes and new technologies drivers of change needs. More generally speaking, it is one of the very specific domain concepts combining the needs of the new modern, clean, digital, and competitive solutions for the future of mobility.

E-powertrain competence is a very needed nowadays and the ECEPE project approach is a possible reaction to that.

Regarding the training mechanism, concept of work-based learning combined with online training is taken into account and skills definitions and training materials of the ECEPE project should reflect that. Moreover, the certification scheme and involvement of the job role e-powertrain into the DRIVES developed framework for pan-European job roles and skills recognition is welcomed. One of the key outputs of this DRVES initiative is the pan-European skills harmonization for the job roles needed in the European automotive sector.

3. AUTOMOTIVE INDUSTRY: SYSTEM ARCHITECTURE AND ENGINEERING VIEWPOINT ON ELECTRIC POWERTRAIN DEVELOPMENT

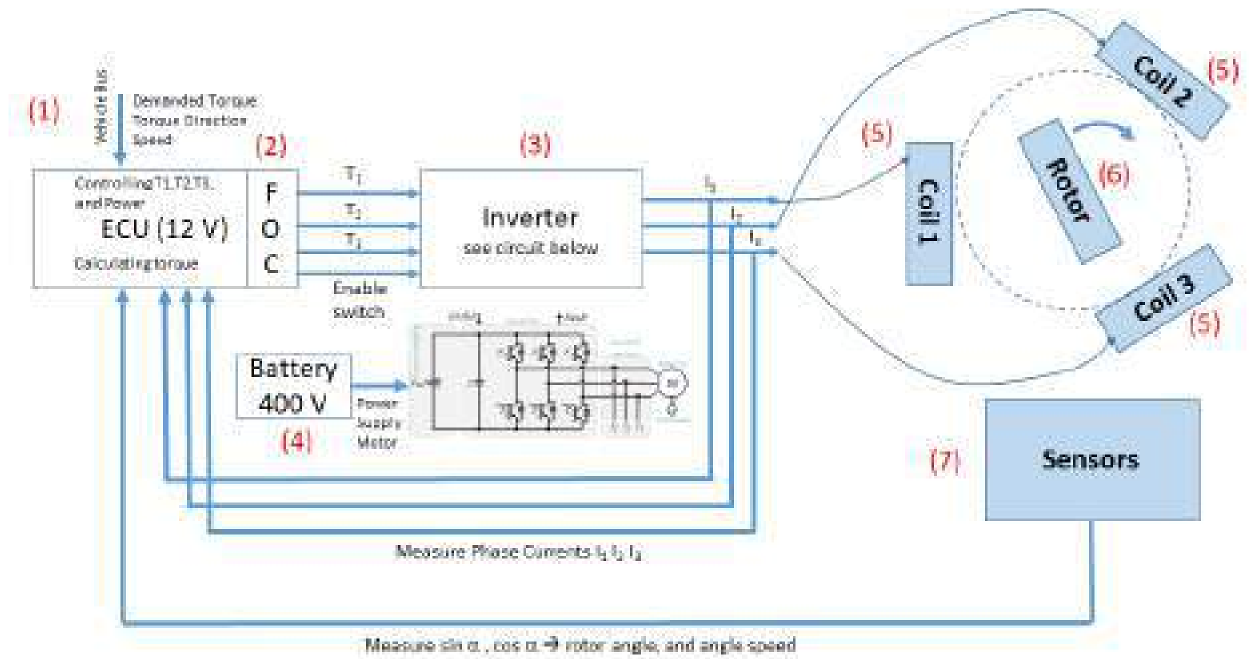
ISCN is a consulting company for leading automotive suppliers and is a VDA certified training provider for Automotive SPICE and an ECQA certified training provider for functional safety. Related to e-powertrain ISCN has some specific industry experiences:

- Improvement coach for ASPICE of the range extender project at BOSCH PS (2018-1019)
- Safety assessor of the first electric motor bike of KTM Motorsport (ZEMC)
- ASPICE assessor of the electric powertrain for e.g. VW golf supplier Magna
- Safety coach for hybrid development in Magna
- Electric power steering assessor (using 3 to 12 phase motors) in BOSCH AS
- Etc.

Besides that, ISCN is coordinator of

- The working party SOQRATES (www.soqrates.de) where leading automotive suppliers (Robert BOSCH, ZF Friedrichshafen AG, Continental Automotive, Magna Powertrain, etc.) are members and who are developing e-powertrain solutions.
- The EuroSPI (www.eurospi.net) conference series where the mechatronics design and safety of e-powertrain solutions is discussed since years in various workshops including different suppliers.

The focus of ISCN is in the development of hardware, electronics and software to control the e-motor or the content and safety of battery management systems. See below example:



(1) The vehicle controller converts the accelerator pedal inputs, speed, etc. into a demanded torque and sends the demanded torque to the electronic control unit (ECU) of the E-motor.
(2) The ECU of the E-motor measures the current rotor speed, calculates the current torque and controls the T1,T2,T3 insulated-gate bipolar transistor (IGBT) switches and power of the motor to achieve the target / demanded torque.
(3) The inverter uses semiconductor elements that can switch the three phase currents I1, I2, I3. This is done in a 120-degree phase shift by a sinusoidal function because the coils are placed in a 120-degree angle position in a circle around the rotor.
(4) The 400 V Lithium Ion battery provides the electric power for the inverter and motor and has its own battery management system.
(5) With the electric power, the coils (in a 120-degree shift) create the magnetic fields to turn the rotor.
(6) In most cases, it is a permanent magnet rotor.

3.1 DESCRIPTION OF THE SURVEY

The survey involved leading automotive suppliers who develop e-powertrain systems that are being delivered to OEMs to be integrated into vehicles.

The list of respondents you find at:

https://soqrates.eurospi.net/index.php/mitgliedschaft

From this group of automotive suppliers a subset answered the questions. There are general meetings and at the meeting at BOSCH Engineering GmbH in Abstatt, Germany, on 5.3.2020 the study has been presented and the partners (see above link) were asked to answer specific questions related to the knowledge required for system control of an e-powertrain.

3.2 AUTOMOTIVE SUPPLIER VIEWPOINTS

In the rating scheme 5 means very important and 1 means not important. The answers come from suppliers in Automotive who develop the electronics, inverters and motors, which are the provided to OEM, plants for vehicle integration.

Q1_2	What skills are needed for e-powertrain engineering?										
	Subquestion	Answers						Valid	Units	Average	Std. deviation
		Very Important	Important	Neutral	Slightly Important	Not Important	Valid				
Q1_2a	Standards/directives/regulations /High Voltage and fire considerations	4 (33%)	7 (58%)	1 (8%)	0 (0%)	0 (0%)	12 (100%)	12	12	4.3	0.6
Q1_2b	Combined controller architectures	1 (8%)	4 (33%)	6 (50%)	1 (8%)	0 (0%)	12 (100%)	12	12	3.4	0.8
Q1_2c	ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)	9 (75%)	3 (25%)	0 (0%)	0 (0%)	0 (0%)	12 (100%)	12	12	4.8	0.5
Q1_2d	Building blocks of ePowertrain (battery, eMotor, inverter, …)	4 (33%)	6 (50%)	1 (8%)	1 (8%)	0 (0%)	12 (100%)	12	12	4.1	0.9
Q1_2e	Safety view point (systems design & item thinking)	4 (33%)	7 (58%)	1 (8%)	0 (0%)	0 (0%)	12 (100%)	12	12	4.3	0.6
Q1_2f	Cyber-Security (basics of Design for CS & threat/attack surface thinking)	1 (8%)	6 (50%)	4 (33%)	1 (8%)	0 (0%)	12 (100%)	12	12	3.6	0.8
Q1_2g	Signal flow / Interfaces Definitions (real-time thinking)	3 (25%)	6 (50%)	3 (25%)	0 (0%)	0 (0%)	12 (100%)	12	12	4.0	0.7
Q1_2h	e-Motor	3 (25%)	6 (50%)	2 (17%)	1 (8%)	0 (0%)	12 (100%)	12	12	3.9	0.9
Q1_2i	Power electronics / inverters	3 (25%)	7 (58%)	1 (8%)	1 (8%)	0 (0%)	12 (100%)	12	12	4.0	0.9
Q1_2j	Hybrid control systems (eMotor/inverter/ECU) - HW	4 (33%)	6 (50%)	2 (17%)	0 (0%)	0 (0%)	12 (100%)	12	12	4.2	0.7
Q1_2k	Hybrid control systems (eMotor/inverter/ECU) - SW Arch.	5 (42%)	4 (33%)	3 (25%)	0 (0%)	0 (0%)	12 (100%)	12	12	4.2	0.8
Q1_2l	eMotor Control	2 (17%)	8 (67%)	2 (17%)	0 (0%)	0 (0%)	12 (100%)	12	12	4.0	0.6
Q1_2m	KERS / recuperation	0 (0%)	8 (67%)	3 (25%)	0 (0%)	1 (8%)	12 (100%)	12	12	3.5	0.9
Q1_2n	ePowertrain Auxiliary Systems (electric power converter, cooling/heating systems, low power systems)	1 (8%)	7 (58%)	2 (17%)	2 (17%)	0 (0%)	12 (100%)	12	12	3.6	0.9
Q1_2o	Battery	2 (17%)	6 (50%)	1 (8%)	3 (25%)	0 (0%)	12 (100%)	12	12	3.6	1.1

Q1_2p	Battery Management System - HW	2 (17%)	4 (33%)	5 (42%)	1 (8%)	0 (0%)	12 (100%)	12	12	3.6	0.9
Q1_2q	Battery Management System - SW	2 (17%)	4 (33%)	5 (42%)	1 (8%)	0 (0%)	12 (100%)	12	12	3.6	0.9
Q1_2r	Battery Management System - Safety	2 (17%)	6 (50%)	3 (25%)	1 (8%)	0 (0%)	12 (100%)	12	12	3.8	0.9

Q1	**Do you consider ePowertrain Engineer a**				
	Answers	**Frequency**	**Percent**	**Valid**	**Cumulative**
	1 (job role)	10	83%	83%	83%
	2 (domain)	2	17%	17%	100%
Valid	Valid	12	100%	100%	

Average	1.2	Std. deviation	0.4

Q2	**Which of the following job roles are affected?**							
	Subquestion	**Units**					**Counts**	
		Frequency	Valid	% - Valid		% -	Frequency	%
Q2a	SW Engineer	3	3	100%	12	25%	3	20%
Q2b	HW Engineer	3	3	100%	12	25%	3	20%
Q2c	Electric Engineer	3	3	100%	12	25%	3	20%
Q2d	Automotive Engineer	2	3	67%	12	17%	2	13%
Q2e	Production Engineer	1	3	33%	12	8%	1	7%
Q2f	Mechanical Engineer	1	3	33%	12	8%	1	7%
Q2g	Chemical Engineer	1	3	33%	12	8%	1	7%
Q2h	Economic Engineer	0	3	0%	12	0%	0	0%
Q2i	Other	1	3	33%	12	8%	1	7%
	Total valid		3		12		15	100%

3.3 CONCLUSIONS FOR ECEPE FROM AUTOMOTIVE SUPPLIERS VIEWPOINT

The survey shows that

- Electric powertrain engineer is a job role
- Electric powertrain engineer is a job roe where the suppliers expect a retraining of
  - SW Engineer
  - HW Engineer
  - Electric Engineer
- Electric powertrain engineer will require specific focus in
  - Standards/directives/regulations /High Voltage and fire considerations
  - ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)
  - Building blocks of ePowertrain (battery, eMotor, inverter, …)
  - Safety view point (systems design & item thinking)
  - Signal flow / Interfaces Definitions (real-time thinking)
  - Hybrid control systems (eMotor/inverter/ECU) - SW Arch.
  - eMotor Control

4. NON-PASSENGER AND COMMERCIAL VEHICLE VIEW ON ELECTRIC POWERTRAIN ENGINEERING

Apart from passenger cars, electric powertrains have great prospects for development in the field of commercial vehicles. Electric vehicles have long been used in public transport, both rail and road. The new trends are mainly related to the pursuit of using autonomous power sources on the vehicle board to replace the overhead contact lines used so far. Operating vehicles without a catenary, for example, with a power source on board the vehicle by charging the power storage device periodically, can provide various benefits compared with the conventional systems (12):

- Reductions in the level of visual intrusion.
- Reduction in the cost of overhead infrastructure.
- Reduction in power usage and CO2.

Visual intrusion is a major problem in building an overhead contact line network through a city centre or urban area with architectural and historical monuments. The non-aesthetic appearance that the contact network imparts can have serious opposition to the design of buildings and squares, especially if the electrical infrastructure is newly constructed and there is not historical importance (Figure 14).

Figure 14 View of the trolleybus overhead contact line network[26].

The costs associated with designing and getting approval for an overhead system may be very high, and as such, in some recent schemes, the overhead has been dispensed with through the use of catenary-free technology, notably at Seville in Spain where the vehicle system operates through the historic city centre using an on-board super capacitor storage system (12). Similar cases are observed in other cities - Luxembourg, Belgrade, and Budapest, where on-board tram energy storages can be used for certain sections of city transport lines[27]. The system was developed by CAF Power & Automation and is called Greentech. It uses an on-board source - supercapacitor and / or battery, and

[26] www.sfgate.com
[27] www.CAF.net

the main benefits of CAF are the optimization of energy consumption and the reduction of visual intrusion in the city centre. For road vehicles, such systems are operated in Marrakech, Landskrona, Prague and others. Trolleybuses with on-board energy sources are operated and in certain sections of the transport line where is no overhead contact line, the current collector rods are removed and driving is provided by the on-board source.

Prague is a city with large variations in elevation and, consequently, many street have extreme slopes. This creates high demands on the parameters of the propulsion system, which also results in an increase in the weight of the battery. One of the ways of solving this problem is with a dynamic charging system for the electric vehicles (13). On the Palmovka-Letňany route (5 km) in Prague, trolleybuses are operated, powered by the overhead contact line only in the section between stops Kundratka and Kelerka. In this way, the overhead catenary network occupies only 20% of the total route length in the steepest part of it (Figure 15). Only non-articulated, battery-powered trolleybuses were used at the start of operation, including the Electron 12T, manufactured by EKOVA (Ostrava) and equipped with Li-Ion LTO (**L**ithium **T**itanate **O**xide) battery with capacity 47 kWh sufficient to travel 12 km on a single charge. Tests are carried out for the operating of articulated trolleybuses among which Škoda 27Tr. It is available in four variants - a conventional trolleybus and trolleybus with on-board power source - battery, supercapacitors or a diesel engine. Fifty trolleybuses of the diesel variant are also operated in Sofia.

Figure 15 The EKOVA Electron 12T trolleybus and the operating route in Prague[28].

Dynamic charging is carried out like the both ends of the route; "roofs" have been installed for the semi-automatic connection of the trolleybus collectors (Figure 15). The built-up section, approximately 1 km long, is too short to fully charge the traction batteries. For this reason, a short section of the trolleybus traction contact wires was built on the Palmovka final stop with "roofs" for semi-automatic connection, in order to charge the vehicles while they are stopped (13).

[28] https://www.youtube.com/watch?v=I06pUa8C8wU&list=LLvt1SI9Regb4Bx4wxFEUMVA&index=171

In Sofia, a demo project and experimental operation of a trolleybus with a hybrid range extender "Battery / Fuel cell" is being developed within the National Scientific Program Low Carbon Energy for Transport and Households (EPLUS)[29]. Combining fuel cells with batteries takes advantage of both technologies. In the National Policy Framework for the development of the alternative fuel market in the transport sector and the deployment of relevant infrastructure, in which specific commitments were made for the period 2020-2030, the "Battery/Fuel cell hybridization" approach was rated as the fastest and most economically viable for the entry of hydrogen-based technologies into the transport sector. The main advantages of the developed vehicle are expressed in[29]:

- Ensuring autonomy and independent movement that is not available on the conventional trolleybus.
- Provision of flexible transport (line extension without the need for electrification).
- Possibility of green fuel supply.
- Motivation for the construction of charging stations.
- Utilization of the production.

According to the National Framework Program for Alternative Fuels and their Infrastructure, Bulgaria is expected to introduce 400 hydrogen vehicles by 2025. With the successful construction of a prototype, a Bulgarian production through retrofitting and modernization of vehicles would assist in the fulfilment of this commitment[29].

At this stage, in the development of catenary-free operation, it is hard to see the costs of the catenary-free operation being outweighed by the reductions in overhead power line infrastructure costs alone; however, it appears likely that the costs of catenary-free technology will fall in the future and when combined with other potential benefits a positive case may exist. In addition, historical bridges have been rebuilt or highways lowered in order to allow vehicles to pass under structures. There are potentially very significant savings in infrastructure modification costs if the vehicle can operate with a reduced height requirement as a result of removing the need for a permanently raised pantograph and overhead power line equipment operators (12).

Catenary-free technology, such as on-board battery or super capacitor systems, allows power savings of up to 20% by using energy from regenerative braking. In the long run, these savings translate into significant power consumption and operating cost reduction for the operators (12). In conventional trolleybus transport, there is potential for regeneration of braking energy, but whether it will be used depends on the presence of other trolleybuses in the same section of the contact line network, which are at the same time in the drive mode. In order to increase efficiency in conventional trolley systems, work is being done to install stationary energy storages in substations to storage the energy from a

[29] https://eplus.bas.bg/bg/results-110

braked vehicle (14). They can then give it to the same or another vehicle in this section when starting and accelerating.

There is a tendency to use dynamic on-line charging of public transport vehicles using wireless technologies. Charging is carried out during driving using the principle of electromagnetic induction. Wireless charging system OLEV (**O**n-**L**ine **E**lectric **V**ehicle) requires the construction of the infrastructure, which contains Road-embedded Power Tracks and devices for power supply. A Pick-Up and Regulator kit for the wireless power transfer installed in or under the electric vehicle (15). The OLEV road-embedded power tracks can be deployed in variable lengths on the route to meet the vehicle operating needs for recharging the battery to maintain the energy balance level or providing sufficient power for its operation. The OLEV road-embedded power tracks are deployed in multiple segments so that only the segment over which the vehicle is moving above is turned on. The underground power supply system generates a two-dimensional magnetic field (perpendicular to the vehicle moving direction), which is picked up by the moving vehicle. It satisfies all international regulations, including safety. Online Electric Vehicles are charged inductively by the application of so-called Shaped Magnetic Field and Resonance (SMFIR) technology. The length of the emitters installed below the road is usually covered by 5-15% of the entire road, which requires only a few sections of the road to be fitted with such a battery charging system. The On-Line Electric Vehicle (OLEV) avoids the problems of conventional, battery-powered EVs—not just the weight but also the volatility of lithium-ion batteries, and the need to recharge the battery—by receiving its electric power dynamically (i.e., while in motion) and wirelessly via roads equipped with an underground power supply system. The battery size for an OLEV bus is 5–20% the size needed for an all-battery-powered EV bus. Due to their lower weight, OLEVs have better dynamic properties with lower energy consumption. A significant advantage is that it will have less impact on the environment due to the longer battery life and smaller size, i.e. less recycling material.

In (15) is noted that electrochemical rechargeable batteries convert electrical energy into chemical energy when charged, then convert it again into electrical energy with energy losses on every cycle. Again in (15) is noted that the deployment of the vehicle's battery energy is inherently an inefficient system and that this is a compelling reason to accelerate the transition to dynamically charged EVs rather than relying on the power of the EVs the battery for the entire route of travel. Online electric vehicles are the first public transport system that uses a "recharging" road and was first launched on March 9, 2010 by The Korea Advanced Institute of Science and Technology (KAIST). The line is operated in the Korean city Gumi (Figure 16).

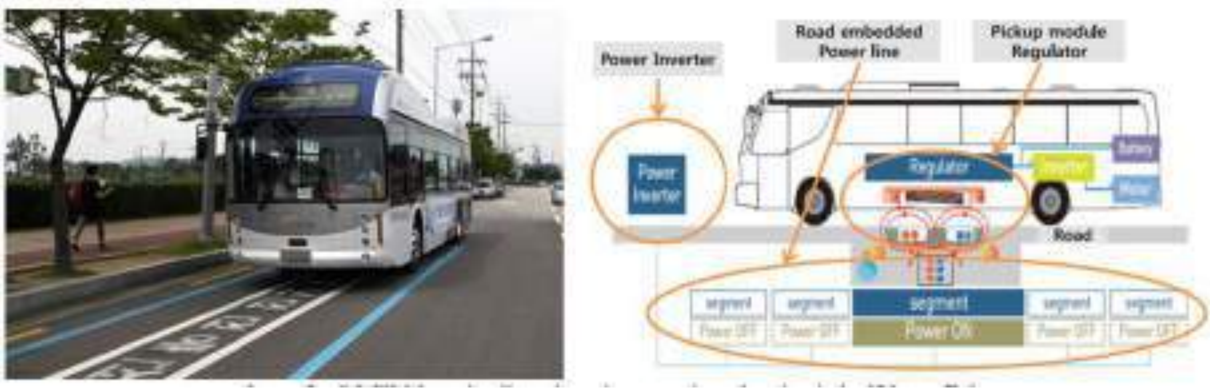


Figure 16 OLEV bus in Gumi and operational principle (15).

According to Kwak Yeon-soo (16) "Commercialization of the wireless on-line charging technology has not been successful, leading to a controversy over the continued public funding of the technology in 2019". However, work is still being done to improve technology in other countries. For example in Sweden, the technology for the inductively charging road comes from the Israeli company Electreon Wireless. Specifically, the consortium is to implement a 1.6 km test section between the airport and the centre of the city of Visby on the west coast of the Swedish Baltic Sea island of Gotland. Inductive wireless charging systems are also being developed for stationary charging on bus stops. This is due to the greater convenience of charging, without the need to stretch heavy cables and improve the appearance of the urban environment without the use of overhead contact lines.

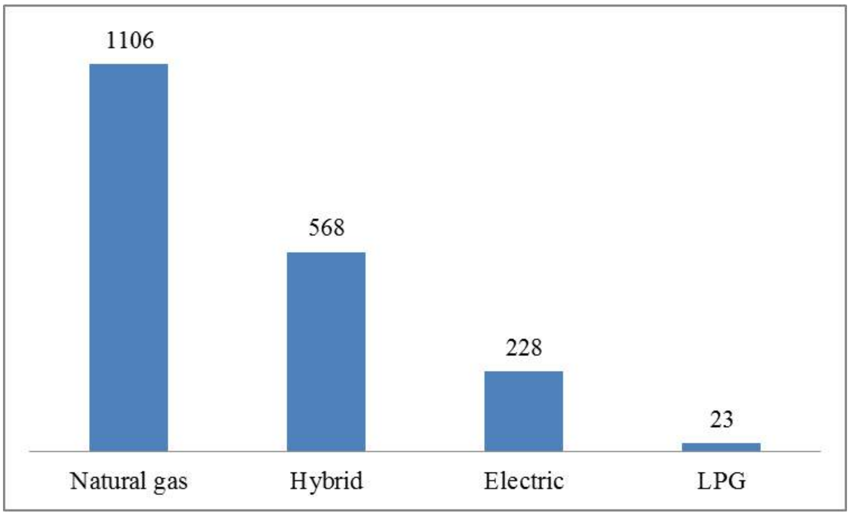


Figure 17 Alternative powertrain buses on German streets in 2019 (17)

The first reason for considering electric buses rather than diesel is that while diesel buses are more efficient than private vehicles, they still make a significant contribution to GHG (**G**ree**n**house **G**as) emissions, which could largely be reduced by utilising electric buses. Many national and regional governments around the world are thus investigating measures to reduce GHG emissions from their public transport fleets by investing in alternative powertrains[30]. For example in Germany, almost 2000 alternative powertrain buses were in operation in 2019 (Figure 17). Around 1100 of these run on natural gas and 568 are hybrids. All-electric powertrain are approved for almost 230 buses, and some buses run on LPG. As of 2019, 99% of the battery electric buses in the world have been deployed in China, with more than 421000 buses on the road, which is 17% of China's total bus fleet. For comparison, the USA had 300, and Europe had 2250[31].

The following technologies, or a combination of them, may be used in electric buses that use full on-board power supply:

- Rechargeable batteries.
- Supercapacitors.
- Fuel cells.

The all-battery electric buses store all required energy in an on-board battery. Energy is transferred to the vehicle via electric charging systems, while regenerative braking is used to recover kinetic energy during operation. Outlined below are some advantages and disadvantages specific to All-battery electric buses[13]:

Advantages:

- no exhaust gas emissions and very low overall emissions if renewable energy sources are used;
- high energy efficiency;
- reduced operating cost, based on current electricity prices, the cost of operating would be much cheaper than diesel buses. This is true even if the current fuel tax was added to the electricity price.

Disadvantages:

- low distance range, current all-battery buses are limited to a reasonably small distance range. The effects of this can be reduced by rapid charging on-route;
- current batteries are heavy, adding to the weight of the bus, potentially limiting what roads they would be able to operate on;
- the increased weight means the vehicle capacity is reduced to stay below maximum axle weight limits;
- all-battery buses require charging infrastructure (either at depots, bus stops, or at both).

[30] https://www.mrcagney.com/case-studies/research/
[31] https://en.wikipedia.org/wiki/Electric_bus

The ultra-capacitor electric buses

Ultra capacitors can be used in hybrid systems as the energy storage system alongside an ICE or a fuel cell, and they are often desirable for this purpose as they charge quickly. However, they can also be used as the sole source of on-board energy, and can be recharged at charging stations, similar to opportunity of all-battery electric buses. The main advantages of supercapacitor electric buses are[32]:

- Can provide up to 10 times more current and power in short-term modes than batteries.
- The number of charge-discharge cycles is up to three times that of the batteries.
- They do not need maintenance.
- Much faster charging than batteries, with greater current values. They are therefore more suitable for intensive regenerative braking and can absorb all the regenerated energy.
- Possibility of dilution up to 0 V and corresponding discharge of all accumulated electricity.
- The electric charge practically does not decrease at low temperatures.
- Safer for the environment due to the lower content of harmful substances than batteries.

Their disadvantages are:

- Short range, ultra-capacitors discharge quickly, so have a small range, however this feature of them also enables them to be recharged very quickly.
- Infrastructure, because ultra-capacitors have a short range, they need to be recharged often, so significant infrastructure is required before they can be deployed on any route.
- Not flexible, as supercapacitors need to be recharged often, the locations of the charging infrastructure limit what routes the buses can follow.

Since the beginning of 2020, 15 supercapacitor electric buses have been put into operation in the city of Sofia. The delivery of the buses is part of the "Project for commissioning of new electric bus lines in the city of Sofia", which is implemented by Sofia Electric Transport, in fulfilment of the company's investment program for the period 2017-2020[33]. The project provide the construction of 6 new bus lines to replace existing bus routes. For this purpose, the delivery of two stages of a total of 30 electric buses and 12 charging stations is planned. Electric buses use state-of-the-art supercapacitor-based fast charging technology, which allows them to charge on the end stops within 5-8 minutes, to regenerate the kinetic energy when brakes and utilize it over a distance of at least 20 km. According to the management of Sofia Electric Transport, the successful implementation of the project will significantly increase the efficiency and attractiveness of the transport service offered, and will help to achieve one of the main goals of European transport and urbanization policy - the transformation of cities into zero emission zones. From greenhouse gases emitted by urban transport. Fast-charging supercapacitor

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32 https://www.mrcagney.com/case-studies/research/
33 http://www.elektrotransportsf.com

buses are gaining popularity as a better alternative to slowly charging battery-powered electric buses, and in this regard, Sofia is not far behind in Western Europe, according to Milen Milev, General Manager of Chariot Motors[34]. In 2013, Cheriot Motors provided one electric bus to Sofia Electric for test use for a period of one year. The purpose is to check the performance of the vehicle under different climatic conditions and to assess whether this type of vehicle has a future in Bulgaria. At that time, Sofia was the only European city in which a fast charging bus with supercapacitors was driving. Demonstrated for the first time in Europe the operational robustness of the supercapacitor powered electric bus and enabled the verification of its unprecedented low energy consumption and operational advantages. Now Chariot Motors supplies electric buses to Belgrade (Serbia), Graz (Austria), La Spezia (Italy) and Tel Aviv (Israel)[35].

Holding Graz Linien, the public operator of the city of Graz, Austria, started a one-year pilot project with two three-doors **Chariot supercapacitor e-buses** in April 2017. This is the first project in Graz and the second one in Austria. The line is equipped with two 340 kW AC/DC charging stations, one at one of the terminals and one at a convenient interim stop. Due to improvements in the charging stations and the charging algorithm, the buses are now being charged only once per lap at one of the terminals, with charging time between 2 and 3 minutes. Holding Graz Linien is testing the new generation of equipped with 32 kWh supercapacitor and ZF wheel hub electric motors. The **Chariot e-buses** are extremely well received by the public-at-large, by the drivers and by the technical personnel, being convenient, ergonomic, reliable and economical.

Figure 18 Supercapacitor e-buses (Chariot) on charging station in Graz and in Sofia.

Electricity consumption is verified by TUV SUD and Belicon University of Landshut of 1,1 kWh/km, which is the lowest value achieved by a vehicle for urban transport. The level of recovery reaching 40%.

[34] www.capital.bg
[35] http://chariot-electricbus.com

Zero emissions in an urban environment. Reduction of more than 45% of CO2 emissions, particulate matter, SO emissions producer of electricity[36].

In some countries **Chariot e-bus** instead of hub drive by ZF is equipped with central drive by Siemens[37]. Charging stations are also available in two variants - AC/DC, which is used, for example, in Graz and DC/DC used in Sofia. Charging takes place by stopping the electric bus to the charging station, and by lifting the pantograph, contact is made with the current rails above it (Figure 18). Only static charging during the standstill of the bus is provided.

The Fuel-cell powered electric buses utilize electricity directly generated from an on-board fuel cell. Many combinations of fuel and oxidant are possible for fuel cells. All oxidations involve a transfer of electrons between the fuel and oxidant, and this is employed in a fuel cell to convert the energy directly into electricity. All battery cells involve an oxide reduction at the positive pole and an oxidation at the negative during some part of their chemical process. To achieve the separation of these reactions in a fuel cell, an anode, a cathode and electrolyte are required. The electrolyte is fed directly with the fuel. Though hydrogen–oxygen is conceptually simple, hydrogen has some practical difficulties, including that it is a gas at standard temperature and pressure and that there does not currently exist an infrastructure for distributing hydrogen (18).

Based on experiences with fuel cell buses for the American market, Van Hool has developed the first European hybrid fuel cell bus with the same passenger capacity as a diesel bus and with all modern comfort. Tests throughout Europe have proven the reliability of this new technology[38]. Public transport agency **Groningen Drenthe** has commissioned the construction of a hydrogen filling station, the supply of hydrogen and the purchase of 20 hydrogen buses. **Shell** Nederland has won the tender for the supply of hydrogen for the buses and is building a hydrogen filling station in Groningen (Netherlands). Transport operator Qbuzz has awarded the bus contract to Van Hool, that is also going to deliver fuel cell buses in Cologne and Wuppertal and in Denmark. The buses and the hydrogen filling station are expected to become operational in December 2020. Hydrogen buses have a **range of 350-400 km on a full tank,** according to manufacturers. During the journey, hydrogen is converted into electricity, which is used to power the electric propulsion system. The range, without intermediate charging, is significantly greater than that of battery buses. These buses can therefore be used not only, as battery electric buses, on city routes, but also in regional lines.

[36] http://www.bblf.bg
[37] http://chariot-electricbus.com
[38] www.vanhool.be

Figure 19 Van Hool A330 Fuel-cell bus on hydrogen filling station.

Fuel cell electric buses are inherently hybrid electric buses using fuel cells and batteries to power the electric motors. The battery has the role of energy buffer: it power assists the fuel cell system during peak power demands (acceleration) and stores energy during braking. Hybrid buses use two or more distinct types of power and the most used combinations are[39]:

- An internal combustion engine and batteries or ultra-capacitors in diesel hybrid buses.
- A fuel cell and batteries in fuel cell hybrid buses.

According to the above definition, it can be said that the combination of overhead electric line and batteries form Trolley hybrid buses.

There are two different types of hybrid systems: parallel and series hybrids.

In a parallel hybrid bus**,** the combustion engine and the electric motor are connected to the transmission independently. The electric motor is designed to provide power during stop-and-go traffic while at highway speeds the vehicle is powered solely by the internal combustion engine. During acceleration, both the electric motor and the combustion engine power the transmission.

A series hybrid bus is exclusively propelled by the electric motor. In a series hybrid bus, the internal combustion engine (ICE) is connected to an electric generator, which converts the energy produced by the ICE into electric power. This electricity powers a motor, which turns the wheels of the vehicle. The generator also recharges a battery pack, which provides supplemental power to the motor. Since the ICE is not connected to the wheels, it can operate at an optimum rate and can even be switched off for short periods of time for a temporary all-electric operation of the bus[39].

[39] www.fuelcellbuses.eu

The same concepts can be applied to the fuel cell hybrid buses. The Fuel Cell series hybrid is the best solution for stop-and-go urban transport due to their advantages:

- Zero exhaust gas emissions in city traffic.
- High comfort due to the electric traction: no gearshifts, which means no jerks in the bus during acceleration and braking.
- Very silent for passengers in and outside the bus.
- No vibrations compared to combustion engines.
- Regenerative braking: depending of the battery characteristics, the fuel consumption decreases dramatically compared to a full fuel cell bus. The fuel efficiency of hybrid FCEB was measured to be double as good as dedicated fuel cell buses (such as in the CUTE = Clean Urban Transport in European cities programme).
- Compared to other zero emission solutions (i.e. trolley buses or some opportunity charged battery buses), there is no visual pollution (catenary lines or charging poles).
- Due to the perfect designed balance between battery power drive, fuel cell drive and combined drive, the FCE buses have autonomy of a 16 hour service day. This balance can be perfectly adapted in function of specific circumstances in every city. (topography, highway driving, step foot traffic, number of traffic lights, a.s.o.).
- Very high efficiency of the fuel cell.

Disadvantages of the fuel cell hybrid buses:

- The production, storage and distribution of hydrogen for use in fuel cells relies heavily on energy from fossil fuels;
- No existing infrastructure;
- Pure hydrogen is expensive and highly flammable.

Due to the disadvantages of fuel cell buses in many cities, hybrid buses using the combination of ICE and rechargeable battery or supercapacitors are preferred. For example, the Volvo Hybrid double deck is a market leader with more than 1100 vehicles entering service in the UK since its introduction in 2009. In addition to substantially reducing emissions, the vehicle has delivered consistent fuel savings and high reliability, thanks to the complete integration of the engine and the parallel hybrid system - all of which are designed and manufactured by Volvo. They estimate that operating one hybrid bus for a year will improve the carbon footprint to the tune of 27 tonnes of carbon dioxide. Typically, that means 12 g less carbon dioxide per passenger mile so the more hybrids in the bus park, the better the result[40]. Volvo also supplies articulated buses to Prague Public Transit Company (DPP) in 2019. The city

[40] www.volvobuses.co.uk

wants to in the long run to reduce reliance on fossil fuels and has been testing and introducing a variety of alternatives including electric buses, trolleybuses and hybrids. The DPP wants to test the Volvo hybrid bus to see its fuel economy, emissions and noise. Volvo 7900 LAH, which has the parallel hybrid technology, driven out of the Hostivař garage for selected connections. The principle of the hybrid lies in the recovery of the brake energy and works by including an electric motor running in the engine or generator mode with the diesel engine in the drive chain. Up to 30 percent fuel, savings can be achieved compared to the classic diesel-fuelled bus. The energy that returns to circulation is stored in traction batteries on the roof of the vehicle and is used especially when starting or accelerating. Volvo introduced the 7900 line of buses in 2011. They are already used in Norway, the UK, Hungary, Estonia, Lithuania, Belgium and Germany[41]. This type of hybrid drive does not require any charging infrastructure because the batteries are being charged while riding. Another type of hybrid technology is based on Flywheel energy storages (FESS). The modern electrically based FESS mainly consists of a flywheel for storing kinetic energy, a motor/generator and power electronic converters. The company GKN Hybrid Power specialises in flywheel-based energy storage systems, which were originally developed for use in Formula 1 racing. The technology has now been successfully introduced to the mass transit market. A high speed carbon fibre flywheel stores the energy generated by a bus as it slows down to stop, and it then uses the stored energy to power an electric motor, which helps accelerate the bus back up to speed. This generates fuel savings of more than 20% at a significantly lower cost than battery hybrid alternatives. GKN Hybrid Power has already won contracts to fit its eco-technology to 750 buses in the UK, initially in London and Oxford since 2015[42]. Figure 20 shows the most used innovative zero-emission bus technologies.

Figure 20 Innovative technology for zero emission bus transport (19)

[41] http://prague.tv/en
[42] http://smmt.co.uk

The trucks are other large group of commercial vehicles. "The trucks are pretty heavy, and need significant amounts of energy, which still isn't available through battery technology," says Stefan Goeller, head of railway electrification at Siemens[43].Germany is joining the ranks of those countries betting on "electric highways" to foster eco-friendly trucking. The country has started real-world tests of an eHighway system on a five kilometre stretch of the Autobahn between Frankfurt and Darmstadt, with an electric-diesel hybrid truck merging into everyday traffic while it received power from overhead cables to keep it from using its combustion engine. Earlier tests in the country relied on either slow nighttime tests or the safety of an unused military airfield. The very first eHighway launched in Sweden in 2016. The concept here is the same - the trucks use pantographs (the pickups on their roofs) to latch on to the overhead contact lines and draw electricity. Trucks can feed electricity into the grid when they brake; making the system particularly useful if there's ever a jam.

The technical features of eHighway[44]:

The overhead contact line:

- Power is transmitted directly from the overhead contact lines into the vehicle, enabling an optimal efficiency level of more than 80%.
- Braking and accelerating trucks can exchange energy with one another via the contact line, for example on sections with a mountainous topography. The trucks are able to recover braking energy and feed it back into the grid.
- Existing overhead lines, for example in trolleybus systems, prove the safety of the technology for road applications.
- Experiences from rail and tram operations confirm its long lifespan and relatively low maintenance and servicing costs.
- The technology can easily be integrated into existing road infrastructure and does not pose an obstacle to other road users.

The hybrid drive system:

- The hybrid drive system enables the truck to remain flexible, for example when overtaking and on non-electrified routes.
- Compared to the conventional combustion engine, the hybrid drive is considerably more efficient, has a longer service life and requires less maintenance.
- The eHighway system is open for a multitude of different hybrid configurations.

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[43] http://www.wired.com

[44] http://balkangreenenergynews.com

The intelligent current collector:

- The intelligent current collector enables the vehicle to connect and disconnect with the contact line system at speeds of up to 90 km/h and compensates for movements of the truck within the drive lane.
- No lane guidance system is required.
- The technology represents an innovation compared to purely electrically driven trolleybuses, which can only run on fixed routes, and the hybrid trucks used in opencast mines.

Figure 21 Moving truck on eHighway[45]

The project eRoadArlanda has chosen to test and develop conductive feeds from below, the method that they have deemed will have the greatest potential to succeed[46].

Figure 22 Moving truck on eHighway[46]

[45] https://www.moz.de/wirtschaft/regionale-wirtschaft/artikel-ansicht/dg/0/1/1595838/
[46] http://eroadarlanda.com

To meet the challenges of an electric vehicle's short range, eRoadArlanda is combining battery power with direct power feeds while in motion. On the minor roads, which form the majority of the road network, the vehicles will run on batteries, while on the major and frequently used roads, the batteries will be recharged continuously. The test track is located on a ten-kilometre section of Road 893 between Arlanda Cargo Terminal and the Rosersberg logistics area, of which two kilometres will be electrified for the demonstration project. The vehicle that are primarily planned to use the electrified road is an 18-ton truck that will be carrying goods for PostNord.

On-board only energy storage electric trucks are also available. For example, Tesla Semi is All-battery semi-trailer truck[47], while Nikola is Hydrogen fuel cell powered[48].

As noted in (20) high moving masses of the commercial vehicles offer a big potential for recuperation and therefore for an increase of the total efficiency. A system developed by SAF-Holland and the Institute of Mobile Machines and Commercial Vehicles at Technische Universität Braunschweig shows that electric systems can be used sensibly not only in the truck but also in the trailer. An electrified trailer axle generates electrical energy during braking, which can be temporarily stored and used for auxiliary consumers or for traction support later. BOSCH also offers an electrified trailer axle. They note that it can also be used to retrofit old trailers and highlight the following advantages[49]:

- Smart, electrified axle recuperates energy during braking.
- Electric refrigerated trailer: significantly quieter, saving up to 9,000 litres of fuel, and thus also CO_2.
- Electricity makes semitrailers independent: important step toward automated semitrailer parking.

Battery-electric trucks are very well suited for urban use in waste management due to the comparatively short and plannable daily routes of up to 100 kilometres with a high proportion of stop-and-go in inner-city traffic. With an anticipatory driving style, electrical energy can be recovered during braking to charge the battery, which further improves range and efficiency. In addition, health problems are caused by asbestos powder from the brakes and regenerative braking would reduce this this (21). Daimler Trucks is taking the next logical step in the electrification of trucks with the battery-electric low-floor truck Mercedes-Benz eEconic. Customer testing of the eEconic for municipal use will begin in 2021. Selected customers will test the vehicles for their everyday practicality in actual applications. The experience gained from customer testing will flow directly into series production of the eEconic, which is to start in 2022. The eEconic is based on the eActros electric truck for heavy

47 http://tesla.com
48 http://nikolamotor.com
49 http://bosch-presse.de

distribution, which will already go into series production in 2021. The eEconic will at first be offered in the configuration 6x2/N NLA and is mainly in demand as a waste-collection vehicle[50].

FAUN offers waste collection truck with diesel-electric hybrid drive. The FAUN Rotopress DUALPOWER is equipped with an electrical braking system that not only promotes energy recovery, it also minimises brake wear. An additional diesel generator, which is activated at the right moment, reduces fuel consumption and CO2 emission levels by one third. This power unit is fitted with a soundproofing capsule, which considerably reduces noise compared to a conventional waste collection vehicle without hybrid drive. The original truck power train continues to be used for covering long distances. When the first loading position has been reached, a mechanical gearbox is used to switch over to electrical operation and the main diesel engine is then switched off. The basic power needed on the waste collection round is now produced by a quiet generator and during peak performance; it is assisted by an energy storage unit. When charging is complete, the vehicle is driven by an electric motor, which in turn serves as a generator that transfers the braking energy needed for the next acceleration into the energy storage unit[51]. As energy storage unit is used a supercapacitor. Nevertheless, on project E3ON: Efficient electric energy storage system for public transport applications (FFG-Project, TU-Graz), the supercapacitor is replaced by flywheel energy storage system. Flywheel energy storage systems are capable of combining a high energy density with a high power density. The utilization of modern (composite) materials for both flywheel and bearing allows the assembly of compact flywheel systems with increased lifetime compared to sophisticated battery systems[52]. The flywheel drives a synchronous reluctance machine with nominal power of 75 kW and maximum power of 145 kW. The speed range is 13,000 to 40,000 rpm (22).

The project participants from TU-Sofia have held a meeting with Mr. Ilia Levkov - Chairman of the Board of Electric Vehicles Industrial Cluster (EVIC), Bulgaria. The purpose of the meeting is to discuss the possibilities of study the requirements of the industry, related to the design, manufacture, testing, diagnostics and maintenance of electric vehicles, regarding the necessary knowledge of electric powertrain engineers. The meeting discussed the necessary topics to be addressed. Mr. Levkov expressed the opinion that in addition to the classic components of the course - electric motors, power electronics and batteries, should also pay attention to the software and programming skills, the related cybersecurity of modern electric vehicles, as well as the electrical safety requirements of vehicles at operation and maintenance, of the battery life cycle and on the new technologies for increasing mileage – graphene and etc. Consideration must also be given to energy-efficient electric drive control.

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[50] https://insideevs.com/news/393591/electric-mercedes-benz-eeconic/
[51] http://faun-zoeller.co.uk
[52] www.tugraz.at/en/institutes/emt/projekte/laufende-projekte/e3on/

In addition to knowledge of the types of resisting forces in the movement of electric vehicles, this is again related to software to implement an appropriate energy-efficient control algorithm, as well as energetics, the energy distribution and storage issues and networks of charging stations.

The possibilities for assistance to EVIC in establishing contacts of TU-Sofia with companies engaged in the production of electric vehicles and special purpose vehicles were discussed:

- Electric sport cars.
- Electric light trucks.
- Electric buses.
- Industrial and communal electric vehicles, etc.

The next meeting held by the members of the TU-Sofia team was at the *Balkancar Record* factory in Plovdiv. Engineer Georgi Valkov (Deputy Director) expressed his opinion on the necessary basic knowledge of engineers designing electric drives for electric forklift and electric platform trucks in the following order:

- Understanding and drawing of electrical schematics of electric drives, as well as of the electrical system. Proficiency in drawing programs such as AutoCAD and other specialized programs;
- Rules for displaying bundles with electrical cables;
- To know the structure of different types of electric motors;
- Be aware of the advantages and disadvantages of different types of rechargeable batteries. Be able to select the battery, so that it achieves the set energy conservation;
- Be able to draw the layout of the vehicle, correctly positioning the units and assemblies in terms of space and mass distribution;
- Be able to perform towing-speed calculations of vehicles - slopes, accelerations, modes of movement at different transport distances and more;
- To know the legal framework - European directives, electrical safety standards, methods and standards for testing vehicles and electric powertrain on noise, vibration, emissions, etc.;
- To know the device of the regulators and the power electronic equipment. Be able to program different modes and protections;
- They must also have knowledge of machine elements, gears, how to choose the optimal gear ratio for the case;
- To take into account the impact of air-conditioning on the reduction of vehicle mileage;
- If the program is extended to a whole specialty, then the specialists must also study design.

Motor sport has always been one of the main generators of new ideas and technologies in automotive technology. Competition teams invest enormous resources in developing effective technologies to win the competitions they participate in. Traditional car racing is about achieving high speeds and good dynamic car performance, with the goal being to finish first. The increasing need to address the problem of depleting fossil fuels, as well as global warming and pollution, are putting strict limits on CO2 emissions from cars. In order to stimulate the development of energy efficient transport, competitions with specially designed low energy vehicles are organized and held. In energy efficiency competitions, fuel efficiency is relied upon. Fuel efficiency is dependent on many parameters of a vehicle, including its engine[53] parameters, aerodynamic drag[54], weight, AC usage, fuel and rolling resistance[55].

An example of such competition is **Shell Eco-marathon,** which is a worldwide energy efficiency competition sponsored by Shell. Participants build automotive vehicles to achieve the highest possible fuel efficiency. There are two vehicle classes within Shell Eco-marathon: **Prototype** - ultra-efficient, lightweight vehicles (generally 3 wheels) and **UrbanConcept** - vehicles that have familiar road car features (always 4 wheels). They can choose the engine, determining the energy category: **battery-electric, hydrogen fuel cell, and internal combustion engine (gasoline, ethanol, or diesel)**. Prizes are awarded separately for each vehicle class and energy category.

There are **two global competitions** within Shell Eco-marathon: **Shell Eco-marathon Mileage Challenge-** Teams compete with student-built vehicles to see who can complete a valid track route using the least amount of energy. There are two vehicle classes: Prototype and UrbanConcept. Each vehicle class has designated time slots to compete on the track. **Shell Eco-marathon Drivers' World Championship-**The most energy-efficient UrbanConcept vehicles return to the track for a race. This time, each vehicle is given an allotted amount of energy and must be the first car to cross the finish line, without running out of energy.

The Shell Eco-marathon's reputation has been built largely on such legendary performances by the top performing teams, which are generally based on partnerships between teachers, students and industry - a key value of this event.

The goal of fuel economy competitions is to develop and race a vehicle that consumes the least possible amount of fuel. The vehicle's performance is evaluated at a minimum average speed of about 30 km/h for a run of twenty or so kilometres. In general, the vehicles start from full stop and complete the 20-km run alone. The final vehicle ranking is determined by calculating the equivalent gasoline

[53] https://en.wikipedia.org/wiki/Engine
[54] https://en.wikipedia.org/wiki/Drag_(physics)
[55] https://en.wikipedia.org/wiki/Rolling_resistance

consumption, regardless of the fuel actually used. This calculation is performed using the lower heating value (LHV) of the fuels, and the results are expressed in kilometres per litre. Thus, for example, the fuel consumption in hydrogen fuel cell vehicle is measured either by using a mass flow meter or by weighing the hydrogen store system before and after the run.

These challenge competitions are open principally to students from a whole range of educational levels (e.g. middle schools, secondary schools, technical colleges, universities and engineering schools). The challenge for the students and their teachers is to design and produce a vehicle that has the lowest possible fuel consumption and complies with the race regulations, while using their own means. Participation provides a unique opportunity in the context of the school curriculum for students to work on a team project that has a firm deadline (the date of the event), a real budget (often quite small) and a chance to compete internationally with other students.

According to its UK website, the Shell Eco-marathon “originated at Shell’s research lab in Illinois (USA)” with friendly wagers between fellow scientists to see who could get the most miles per gallon from their vehicles. From these humble origins, where the winner scarcely achieved 50 MPG, more organized competitions evolved. In 1977, shell organized the first competition at Mallory Park, essentially for student teams.

Several fuel economy challenges are held around the world, in countries like Finland, France, Japan, Scotland, the United Kingdom and the United States of America. Still others have taken place in other places. The various events all differ in terms of their tracks and their regulations, which have evolved over the years.

A fuel economy race is friendly environment for technical innovation. Unfortunately, the majority of the teams do not have enough connections to the worlds of research and industry – particularly the automotive and cycling industries - and have very limited financial support. These are the two primary obstacles to the development of true technical innovations. Still, at least three major automobile manufacturers, namely Ford, Honda and Mercedes-Benz, have participated in these competitions in the past, so there is hope, that the links to industry can be encouraged. Honda also organized from several years some fuel economy competitions called Honda Econo Power in countries like Japan, China and Thailand.

The most remarkable and long lasting of the innovations for fuel-efficient vehicles is probably the so-called “stop-and-go strategy. This strategy consists of switching off the engine when drive power is not required, and using it when is most efficient, for example when vehicle is going uphill. Using the engine at its most efficient operating point is now possible in hybrid vehicles, thank to reversibility of electric drive motor.

One of the main topics is measuring fuel consumption. Two kinds of fuel are considered separately. First, we present so-called “conventional fuels”, which have been used for many years in fuel economy contests and for which the fuel consumption measurement protocol is well established and well known. The "conventional" fuels include gasoline, diesel fuel and Liquefied Petroleum Gas (LPG). The consumption of liquid fuels like gasoline and diesel are measured by either volume or weight. The consumption of LPG, on the other hand, is only measured by weight.

Measurement by volume is the standard measuring system used in the competitions. The vehicles used in the competitions are all equipped with a special glass tank, which has a visible marker on his side, allowing it always to be filled to the same level. Before the start of race, the tank is filled to the level of that marker. After the run, the tank is filled to the same mark. The quantity of fuel added is the quantity of fuel used during the run. The temperature of the fuel is also measured, before and after the run, making it possible to take the fuel's thermal expansion into account, and to convert the volume consumed into the actual mass consumed.

Measurement by weight is reserved for the top teams. This technique is much more precise, but is a complex procedure, which takes much longer. First – the entire fuel supply system is dismantled. The system is filled, weighed and reassembled in the vehicle. After the run, it is again dismantled and weighed. The difference in weight is the weight of fuel consumed. The scales used in the procedure are precise to one hundredth of a gram. Calibrated on the spot, they are used in an air-conditioned room on an anti–vibratory table.

There are two procedures currently in use for measuring hydrogen fuel consumption. One relies on embedded flowmeter to measure the mass flow of hydrogen, and the other weighs the hydrogen tank. They are sometimes used together in order to verify the coherence of the results.

Since 2004, regardless of the fuel really used, the overall ranking of the competitors in the Shell Eco-marathon in France is based on the equivalent consumption of Shell Unleaded 95 gasoline. This regulation was made inevitable by the growing diversity of fuels used for the competition.

Usually, the fuel consumption of a ground transport vehicle is expressed as the number of litres consumed to cover a distance of 100 km under standardized conditions. However, in the final economy competitions, the final result is expressed as the number of kilometres covered per liter of gasoline.

The rules of the competition have been established with the dual purpose of maintaining safety and fairness, with the two ideas sometimes overlapping. A fuel economy competition is just any car race, with its attendant risks of collision or leaving the track. If there have been no accidents or major incidents since the start of these competitions, it is definitely due to the safety regulations, the relatively low vehicle velocity, and the small amount of fuel taken on board.

The first vehicle powered by hydrogen fuel cell, the PAC-Car I developed by ETH Zurich and University of Valenciennes, appeared in 2003. In 2005, the PAC-Car II, developed solely by ETH Zurich, outclassed the ICE (Internal Combustion Engine)-powered vehicles, improving the fuel economy performance to 5,385 km/l.

1. The World's Most Fuel Efficient Vehicle Design and Development

The top performing vehicles are purpose designed for high efficiency. Some vehicles use a coast and burn technique whereby they briefly accelerate from 10 to 20 mph (from 16 to 32 km/h) and then switch the engine off and coast until the speed drops back down to 10 mph (16 km/h). This process is repeated resulting in average speed of 15 mph for the course.

Typically, the vehicles have (23):

- Automobile drag coefficients (Cd) below 0.1
- Rolling resistance coefficients less than 0.0015
- Weight without driver under 45 kg
- Engine efficiency under 200 specific fuel consumption (cc/bhp/hr)

Shell's vision for the future development of the transport is close connected with the Paris Agreement from December 2015[56].

The Paris Agreement central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change. To reach these ambitious goals, appropriate financial flows, a new technology framework and an enhanced capacity-building framework will be put in place, thus supporting action by developing countries and the most vulnerable countries, in line with their own national objectives. The Agreement also provides for enhanced transparency of action and support through a more robust transparency framework.

[56] https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html

4.1 SKY SCENARIO

Drawing lessons from previous Shell scenario work and additional analyses, we now present a possible pathway for achieving the goals of the Paris Agreement, including net-zero emissions from energy use by 2070 – a scenario called “Sky.”

Sky recognises that a simple extension of current efforts is insufficient. The relevant transformations in the energy and natural systems require the deployment of disruptive new technologies at mass scale within government policy environments that strongly incentivise investment and innovation. Sky relies on a complex combination of mutually reinforcing drivers being rapidly accelerated by society, markets, and governments.

Sky is a technologically and macro-economically possible route to achieving the goals of the Paris Agreement.

The Sky scenario brings further to the surface the emerging possibility of multi-lateral collaboration to tackle climate and air-quality issues. It combines the most progressive elements of both Mountains and Oceans.

Leadership to create a shared vision was an essential element of the Paris Agreement, but so, too, was listening and responding to those most at risk from climate change. These developments introduce the notion of a framework for resolution of global issues within which various scenarios could be positioned.

4.1.1 A SCENARIO FOR SUCCESS

In Sky, governments respond positively to the rapid cycle of assessment, review, and improvement of national contributions, as set up under the Paris Agreement. Peer pressure, emerging from the Paris transparency framework, provides an additional push and the five-year ratchet mechanism works.

At national level in Sky, governments implement legislative frameworks to drive efficiency and rapidly reduce CO2 emissions, both through forcing out older energy technologies and by promoting competition to deploy new technologies as they reach cost effectiveness. Government-led carbon pricing emerges in Sky as a suite of taxes, levies, and market mechanisms. By 2030, a common understanding is reached between governments as to the appropriate level of the cost of emissions.

The route to net-zero emissions by 2070 involves change at every level of the economy and energy system. One of the most important trends is electrification – the increasing replacement of direct fossil fuel use (such as gasoline for mobility) by electricity.

In Sky, by the 2070s;

- Electricity exceeds 50% of end-use energy consumption, with the sector nearing five times the size of that seen in 2017.
- Fossil fuels are effectively absent from power generation with solar starting to dominate.
- Biomass generation has emerged, linked with CCS to offer an important carbon sink.

Electrification begins most clearly in the transport system through intergovernmental initiatives and pledges by countries and cities to phase out internal combustion engine passenger cars. As early as 2030, more than half of global car sales are electric, extending to all cars by 2050.

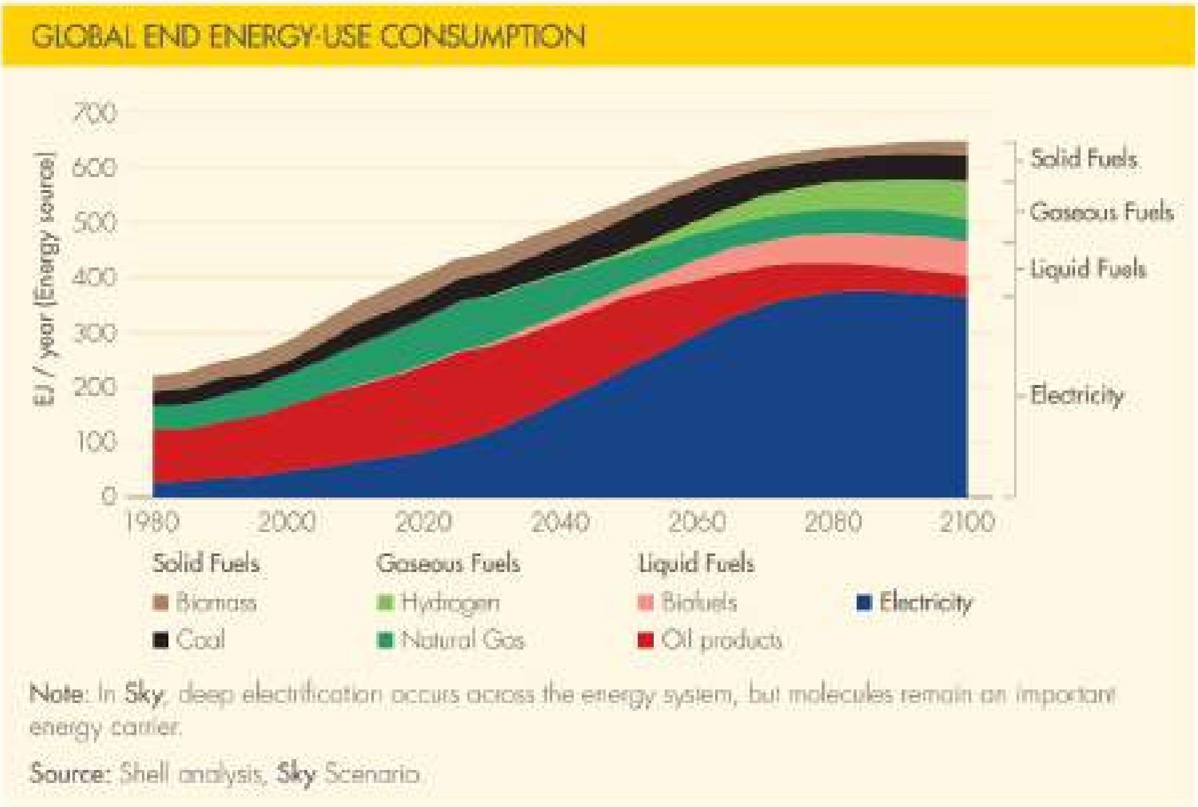

Figure 23 Global end energy-use consumption (Shell) [57]

Across all other forms of transport, biofuels play a critical role in Sky due to continued reliance on liquid fuels as the high energy-density fuel of choice, but set against the need to reduce CO2 emissions. Hydrogen also comes into the mix at scale in the 2030s.

[57] https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html

The shift in industry required for net-zero emissions follows a more incremental path, responding to the ratcheting up of carbon prices by governments. The transformation follows three distinct routes in Sky:

- Efficiency improves continuously.
- Some processes shift towards electricity, with hydrogen also emerging as an important fuel in the 2030s, although not until after 2050 for heavy industry.
- Coal remains important in various processes with CCS applied to manage CO2 emissions.

For fossil fuels in Sky, the first clear signs of the transition emerge in the 2020s;

- Oil demand peaks and begins to decline by the 2030s. By 2070, however, oil production remains at 50 million barrels per day, albeit declining, due to the broad swathe of services that it still supplies. Biofuels increasingly supplement the liquid fuel mix.
- Coal declines rapidly with the peak already behind us.
- Natural gas plays an important early role in supplanting coal in power generation and backing up renewable energy intermittency. Demand then falls after 2040.

By the middle of the century the energy mix is starting to look very different, with solar the dominant primary energy supply source by around 2055. Energy system CO2 emissions peak in the mid-2020s at around 35 Gt, and fall sharply thereafter.

Numerous other human activities have also changed the trace gas composition of the atmosphere, which have also contributed to warming. In Sky, however, significant changes are made in all the greenhouse-gas producing sectors.

Introducing Sky – an ambitious scenario to hold the increase in the global average temperature to well below 2°C.

From now to 2070 –

- A change in consumer mind-set means that people preferentially choose low-carbon, high efficiency options to meet their energy service needs.
- A step-change in the efficiency of energy use leads to gains above historical trends.
- Carbon-pricing mechanisms are adopted by governments globally over the 2020s, leading to a meaningful cost of CO2 embedded within consumer goods and services.
- The rate of electrification of final energy more than triples, with global electricity generation reaching a level nearly five times today’s level.

- New energy sources grow up to fifty-fold, with primary energy from renewables eclipsing fossil fuels in the 2050s.
- Some 10,000 large carbon capture and storage (CCS) facilities are built, compared to fewer than 50 operating in 2020.
- Net-zero deforestation is achieved. In addition, reforesting an area the size of Brazil offers the possibility of limiting warming to 1.5°C

4.1.2 ACHIEVING THE BALANCE

By 2070 in Sky, remaining fossil fuel use from hard-to-mitigate applications equates to some 16 Gt CO_2 per year in potential emissions, albeit continuing to decline. The Paris Agreement recognises this reality when it calls for a balance between emissions by sources and removals by sinks of greenhouse gases. To achieve a balance in the energy sector, Sky utilises three mechanisms that either prevent the release of CO2, or remove CO2 from the atmosphere. Over the course of the century, one trillion tonnes of CO2 are handled in this way.

- CCS applied in large point source emitting facilities such as cement plants.
- CCS applied in power plants operating with a sustainably produced biomass feedstock, resulting in net removal of CO2 from the atmosphere.
- The production of various products, such as synthetic fibres, from fossil fuels or biomass.

In Sky, deforestation also reaches net-zero by 2070. Large-scale reforestation could accompany this, offering the opportunity to further limit warming. This scale of change in the land-use sector will require action by governments. Cooperative mechanisms, such as those within the Paris Agreement, can trigger private sector involvement, which in turn could accelerate the necessary activities.

Delivering Sky will be challenging. Achieving long-term public goals requires long-term public policy to initiate and guide developments that the private sector will need to deliver and the public will need to choose or accept.

4.1.3 THE PARIS AMBITION REALISED

By 2100, warming of the climate system is held to around 1.75°C according to independent expert analysis (MIT Joint Program on the Science and Policy of Global Change) of the energy system emissions trajectory described by Sky. Reforesting globally an area the size of Brazil offers the possibility of reaching the stretch Paris goal of 1.5°C.

The Paris Agreement has sent a signal around the world; climate change is a serious issue that governments are determined to address. By 2070, there is the potential for a very different energy system to emerge. It can be a system that brings modern energy to all in the world without delivering a climate legacy that society cannot readily adapt to. That is the essence of the Sky scenario.

4.2 REVIEW OF ELECTRICALLY POWERED RACE CARS

4.2.1 Introduction

Electric cars were used for racing as early as 1899. At that time, it was not yet clear whether the internal combustion engine would be required as the main propulsion unit for mobile applications.

Nowadays, after the revival of interest in electric cars, electric racing cars are developing. They are mainly divided into two categories - speed racing cars in order to achieve the least amount of tour time (e.g. so-called Formula E) and economical racing cars to minimize the energy consumed per distance unit (e.g. Shell Eco Marathon).

When designing each racecar, particular attention is paid to the power to drive it and how best to use the energy to achieve the desired goal (minimizing time or energy consumption). Therefore, a quantitative assessment of the resistance forces generated during the movement and the corresponding capacities required to overcome them is required. At high speeds, the resistance to air is decisive, and at lower speeds - the rolling resistance. To achieve the greatest possible acceleration at sufficient power is important to investigate and optimize the coefficient of adhesion of the tires with the track and the operating weight of the vehicle. The intensity of acceleration and deceleration, which depend not only on the capabilities of the machine and the objective conditions (track configuration and pavement) but also on the subjective factor (the pilot), are also essential for energy consumption. In addition, especially in the energy-saving competition, it is important to minimize transmission losses from the engine to the drive wheels and the inertia of the rotating parts. The optimum combination of engine and transmission allows the engine to be operated in the most favourable zone in terms of efficiency under various operating conditions. This requires more sophisticated systems to manage these units, as well as on the other vehicle systems. These factors are studied in detail in the theory of the car, but their evaluation is made extremely in an experimental way. In this regard, racecars also make a significant contribution to the improvement of the structures and systems of modern conventional cars and electric vehicles.

Innovative technologies and designs that are tested and applied in racing cars are very often the basis of modern conventional car solutions. Even the majority of electric car manufacturers rely on two-seater sports models with very good dynamic performance, which may not be designed for racing, but use the achievements of racing car designers.

4.2.2 Cars for Formula E

Competition regulation

The regulation of the competition is determined by the International Automobile Federation FIA (Fédération Internationale de l'Automobile) and greatly influences vehicle design, materials, components and systems for management and control. For the first time the Formula E race is being held in Beijing in 2014 - Season 1 (2014/2015) with the participation of ten teams with two pilots for each team. The used electric car called the Spark-Renault SRT_01E is the result of development work for ten months of the company Spark Racing Technology in collaboration with McLaren, Williams, Renault und Michelin. The carbon fibre chassis (CFK - Carbonfaserverstärkter Kunststoff or CFRP - Carbon Fibre Reinforced Polymer) and aluminium is made by an Italian specialist Dalara and meets the same safety requirements as in Formula 1, and its aerodynamic design makes it easier to overtake. (Figure 24)

Figure 24 The car developed for the debut season of the Formula E race - Spark-Renault SRT_01E [58]

For the first season of Formula E each team used two cars with two pilots. They have changed during the race due to insufficient battery capacity. In the following competitions, allow higher power values, while retaining the same regulation. Only in season 5 (2018/2019) increased almost double the capacity of the battery and the teams used one car. (Table 2)

Table 2 Allowable power of Formula E racing cars[59] (23)

Indicators	Season 1	Season 2	Season 3	Season 4	Season 5
Generation of cars	1	1	1	1	2
Chassis and drive top drivers and teams	Spark-Renault SRT 01E	Spark-Renault Z.E 15	Spark-ABT Schaeffler FE02; Spark-Renault Z.E 16	Spark-Renault Z.E 17; Spark-Audi e-tron FE04	Spark-DS E-Tense FE 19
Power in the race, kW	150	150	170	180	200
Power for Qualifying, kW	170	200	200	200	250

58 https://www.motorsport.com/formula-e/news/mclaren-the-power-behind-formula-e/440037/?v=2&s=1&nrt=208
59 https://en.wikipedia.org/wiki/Formula_E#Overview

Power from recovery, kW	100	100	150	150	250
Battery capacity, kWh	28	28	28	28	54

Figure 25 Formula E short track in Monaco, photo: ABB FIA Formula E[60]

The competitions are held in urban areas on specially prepared tracks (Figure 25). In addition to the indicators in Table 2, according to the rules for Formula E, some specific features of the car construction are specified:

- **The minimum operating mass of the vehicle together with the pilot is reduced from 896 to 880 kg;**

This can be achieved by using materials of high strength and relatively low mass. In addition to the chassis made of carbon fiber with cellular structure, this material is also used for other elements of the car construction - brake discs, transmission housing, cooling ducts (Figure 26).

Figure 26 Use of carbon to lighten the racing assembly units

[60] https://drivetribe.com/p/the-reason-formula-e-needs-to-stay-JBP6dKb9SnOIqEM0Nh5s9g?iid=boSD4U-eSZyI7ruzWqEqHA

The carbon fiber is a material for composites, which are made from polyacrylonitrile (PAN). Carbon fibers are ultra-thin fibers. The fiber diameter ranges from 0.005 to 0.010 mm. In colloquial language is also called "carbon" (from the English word). It is especially popular in motor sports, it has been widely used in Formula 1 championships since the early 1990s. It has a very high modulus of elasticity (Young's modulus), fully commensurate with that of steel. In some varieties, its strength reaches about 700 MPa. At the same time, it is on average four times lighter than steel and with 40% lighter than aluminium. Its main disadvantages are the complex production process and the high cost.

Mass of the drive system can be reduced by using high-speed engines (up to 20000 rpm) with relatively lower torque at the same power and simplified and optimized transmission design. For example, the gearbox, main gear and differential are designed not to resize as durably as in ordinary cars, and can only withstand the required resource (about 40 hours) for test time, qualifications and the race itself without being damaged.

Of great importance for the total mass is the mass of the battery, which for a given energy saving of 28 kWh and an operating voltage of 800 V amounts to about 300-350 kg. (The first car battery is a Williams development). For season 5 cars, the battery weight is in the range of 350-400 kg. (Table 3). While the mass of the motor-generator is significantly smaller (according to McLaren only 26 kg):

Table 3 Traction battery parameters for racecars (24)

Parameter \ Generation	Formula E (1)	Formula E (2)	Electric Rally cross eWRX
Weight in kg	310	380	290*
Volume, l	~310	~321	260*
Energy capacity, kWh	28	54	46,5
Maximum power, kW	200	250	500
Cell specific power, kW/kg	1,4	2,2	2,6
Cell specific energy, Wh/kg	174	232	232
* Target values for the first season 2020			

Figure 27 Driven by two transverse engine. 1,2 - liquid-cooled AC motors; gear shift mechanism; 4.5 - differential axles (25)[61]

- **The drive should be only on the rear wheels, with one or two motor- generator sets (MGU - Motor Generator Unit) (**Figure 27**)**

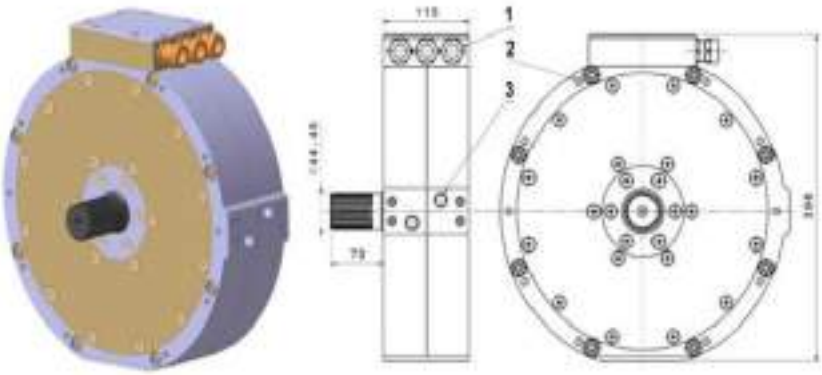

Figure 28 Synchronous motor with permanent magnet excitation and axial magnetic flux (PMAFM-Permanent-magnet axial flux motor): 1- cable connections; 2- mounting holes; 3 – fluid-cooling connections (24)

The engines used for modern EVs are several types, but now more prevalent are AC synchronous motors with permanent magnet excitation. They feature a small mass and size and a higher efficiency, because no electrical power is used for the rotor, but only for the stator windings. But the problem is the high cost of magnets. (Figure 28)

[61] https://www.youtube.com/watch?v=KsCKrixx5Qk How Are Formula E Cars Different in Season 3?

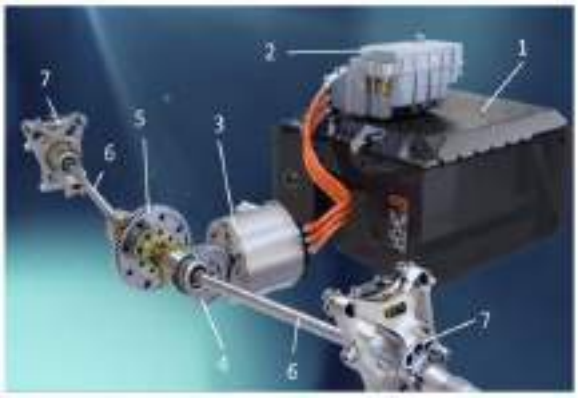

Figure 29 Powertrain of the Formula E cars from season 1

Powertrain of the Formula E cars from season 1:

1 - traction battery;

2 - control electronics;

3 - electric machine;

4 - two-stage gear with a constant gear ratio;

5 – differential;

6 – differential axles;

7 – wheel hubs[62]

For example, a motor-generator unit of the vehicle of Figure 29 is developed by McLaren and consists of an AC brushless synchronous electric machine (PMSM – Permanent Magnets Synchronous Motors) and control electronics - controller and inverter (MCU – Motor Control Unit) (26)

During the first season, all teams have used the motor of McLaren with a maximum power of 200 kW (the same motor as that used in its P1 supercar). But since season two, teams are allowed to build their own electric motor, inverter, gearbox and cooling system. By season 4, the chassis and battery remain the same. So for season 2016/17 traction motors have developed nine manufacturers: ABT Schaeffler, Andretti Technologies, DS-Virgin, Jaguar, Mahindra, NextEV TCR, Penske, Renault и Venturi.

- **Not allowed individually drive each wheel with an electric motor integrated in the wheel and vector control on drive torque (Torque-Vectoring);**

This requirement does not allow the unsprung masses to be increased by the additional mass of electric machines, however small it may be, and to load the suspension (Figure 29a).

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[62] https://www.youtube.com/watch?v=DxaS_8M-8Ws What Makes an Electric Car's Torque So Special? Season 1

In addition, individual control of the drive moment on both wheels is limited. Installation of electric motors in the drive wheels is possible at electric vehicles for other types of racing (Shell Eco Maraton, Formula Student).

Figure 30 Suspension of a Formula E car[63] and mounting a motor in the wheel

- **It is permitted to use only one mechanical differential, which can be self-locking or passive visco-differential**;

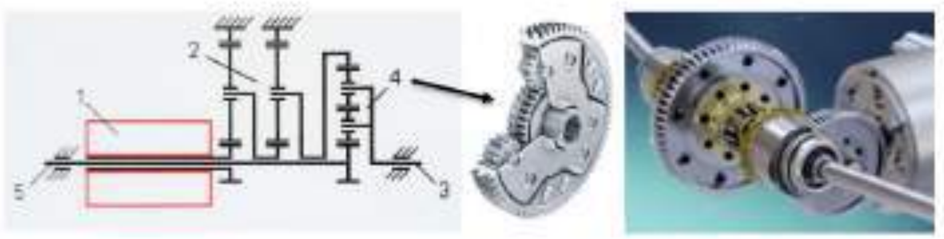


Figure 31 Electric drive axle of a conventional car and drive of a Formula E car

Electric drive axle of a conventional car:

1 – electric motor;

2 – planetary gear;

3,5 – differential axles;

4 – differential[64] (25)

An innovative solution is to use a planetary gear with cylindrical gears instead of the traditional symmetrical differential with conical gears. (position 4 on Figure 31a) Symmetry is ensured by various connections of the planetary mechanism units, which are the inputs and outputs to the drive wheels. The input of differential is not the carrier, but the ring gear wheel. Since two rows of sequentially

63 https://www.schaeffler.de/content.schaeffler.de/de/produkte-und-loesungen/automotive-oem/sytstempartner-automobilindustrie/index.jsp

64 https://www.schaeffler.de/content.schaeffler.de/de/produkte-und-loesungen/automotive-oem/sytstempartner-automobilindustrie/index.jsp

coupled planetary gears are used, the basic kinematics equation describing the relationship between the three angular velocities is of the type:

$\omega_1 - \alpha\omega_{in} = (1-\alpha)\omega_2$,

when $\alpha=2$ (ratio between the number of teeth of the ring gear and the sun gear) is obtained the same relationship between angular speeds, as at ordinary conical differential:

$\omega_1 + \omega_2 = 2\omega_{in}$,

where ω_{in} is the angular velocity of the ring gear - the input, and ω_1 , ω_2 are the angular velocities of the two output shafts (differential axles) - a sun gear and the planetary gears carrier, denoted in the figure with the positions 3 and 5. The new lightweight differential is more compact, lighter, quieter, more efficient and at the same time more powerful. Its volume is reduced by 70% and its weight by 30% compared to the traditional conical differential. Cylindrical gears are arranged in one plane, produced more easily and have less friction loss.

Figure 8a shows a kinematic diagram of an electrically driven axle with a coaxially arranged high-speed electric motor, characteristic of ordinary electric vehicles. Used is such differential and transmission with fixed gear ratio. It is implemented with two planetary rows to achieve a small mass and size and a large gear ratio (in the order of 12). Figure 8b shows a photograph of the construction of a Formula E car with such a lightweight differential. Characteristic of racecar transmissions is their simplicity. Mainly cylindrical gears with straight teeth are used, which have a simpler workmanship, lower losses and are easily interchangeable for optimal gear ratios. Teams can experiment with the number of gears and with the number of engines. Switching is done with simple gear couplings, because the electric motors have the ability to change the torque and speed within the required range in a short time (in the order of milliseconds).

The transmission may be a gearbox with constant ratio or a sequential gearbox with a shift of two to six gears by the driver with buttons located on the steering column or lever. Transmission with automatic gear shifting under load (e.g. dual clutch type) is not permitted

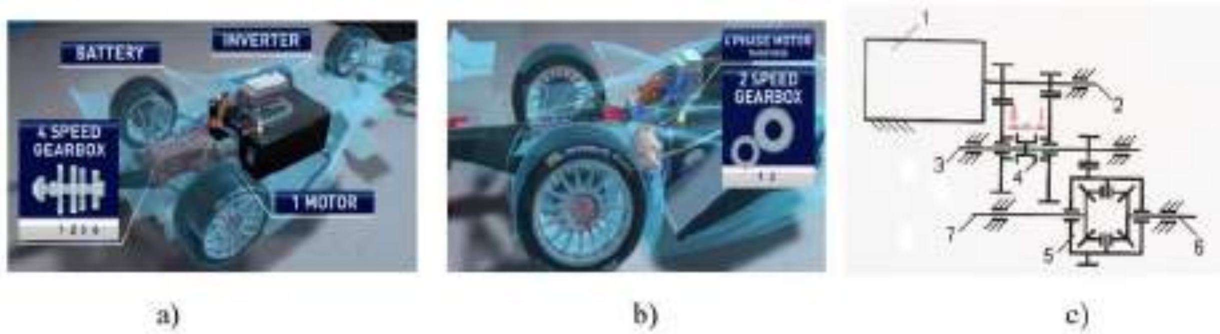


Figure 32 Transmissions for Formula E cars: a) and b) - gearbox variants with different number of gears; c) kinematic scheme of a simple gearbox with two gears for transverse engine: 1 – electric motor; 2 – primary shaft; 3 – secondary shaft; 4 – switch coupling; 5 – differential; 6, 7 – differential axles (25) [65]

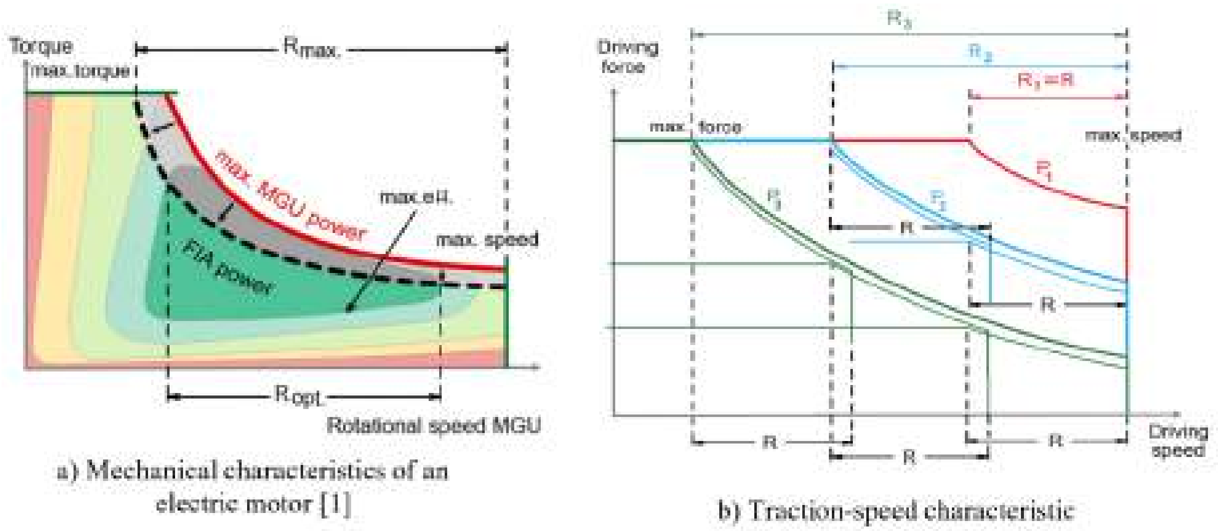


Figure 33 Comparison of the required power of an electric machine at using a gearbox with different number of gears

For the second generation cars (season 5), in addition to the increased battery capacity and drive power, a so-called "attack mode" was introduced. Attack mode increases the maximum power of the vehicle to 225 kW for a period specified by the FIA. Shortly before the race starts, the FIA determines the number of attack mode activations that each driver must complete during the race. The purpose of the attack is to provide drivers with a variable element of strategy to facilitate overtaking with extra power. (23)

Figure 33 shows the theoretical characteristics of a drive with electric motor and gearbox. The characteristics of electric motors are principal more suitable for using in the car, than the

[65] https://www.youtube.com/watch?v=KsCKrixx5Qk How Are Formula E Cars Different In Season 3?

characteristics of an ICE. They approximate the theoretically desired ideal hyperbolic torque curve as a function of the speed, corresponding to constant power (P_1, P_2 or P_3). It is therefore possible to use only one gear in the gearbox. In this case, it is necessary that the engine has the highest power - curve P1 of Figure 33b to achieve maximum driving force and maximum car speed. With acceleration initially, power will grow over a wider range and only in the R1 area will it remain almost constant. The more gears are used, the less maximum power is required by the engine to achieve maximum force and speed. But the area, where power grows with the acceleration narrows and the area, where power is constant expands. For two gears - the zone is R_2 at maximum constant power P_2, and for three gears - respectively R_3 and P_3, etc. The gearbox performs additional torque and speed transformations while maintaining constant engine power, and when there is only one gear, the change of torque and speed beyond the motor area (R) will only occur if engine power is reduced (in partial mode). The reduction in power may be required by the restrictions in the racing regulation or by the route configuration. As can be seen from Figure 33a the maximum range (Rmax) of change in speed and torque by the characteristic of the engine at a given constant power (e.g. by the FIA) will be limited by an increase in losses (reduction in efficiency) at both ends of the range. Moreover, the range in which the engine will operate at maximum efficiency (Ropt) narrows. In this case, if the engine is to be operated more efficiently, more gears could be used, which would use a narrower, but optimum range. However, if you want more acceleration, it's best to use an engine with maximum allowed power. Whether this power will be realized is another matter, since there is also a limit from tire grip. Theoretically, the gearshift time should be taken into account, however small it may be the energy consumption for cooling the units and so on. Because the results are influenced by many objective and subjective factors, there is no definite tendency for a particular type of drive. Teams use gearboxes with different number of gears or with one gear and two engines.

- **Two separate radiators and liquid cooled systems are used to ensure the optimum temperature of the battery, MGU and inverter;**

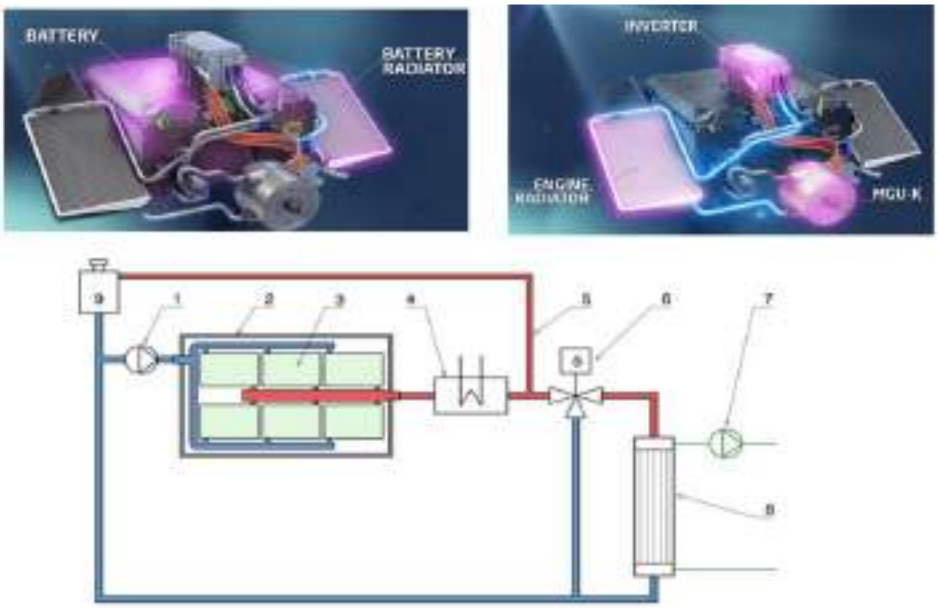


Figure 34 Battery, engine and power electronics cooling systems

Battery, engine and power electronics cooling systems:

1 – pump;

2 – battery with internal cooling system;

3 – battery module;

4 – auxiliary heater;

5 – bleeding line;

6 – thermostatic valve;

7 – air-conditioning (passenger cars only);

8 – heat exchanger;

9 – heater tank[66] (24)

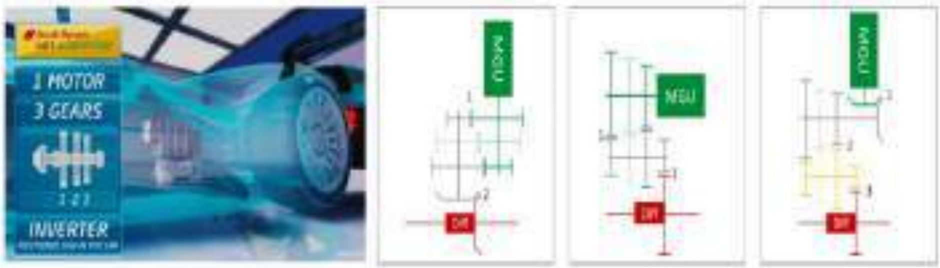
The temperature of the battery and the motor is very important not only for their efficient operation but also for the avoidance of damage. For example, the battery has been found to use 100% of its capacity only at temperatures in the range of 0 to 40^{O}C outside this range, the efficiency is lower.

The impact of the individual design factors described in the introductory section on the lap time is the subject of study through simulation programs. The simulation determines the degree of influence of each of the factors: operating weight, rolling resistance of the wheel, air resistance, inertia of the drive parts, coefficient of adhesion between the tires and road surface, engine power, etc. (23)

66 https://www.youtube.com/watch?v=fREvd4dLY2s How Do Formula E Cars Reduce Overheating?

- **With regard to control systems, in addition to automatic gear shifting, traction control and the use of all types of speed sensors, whether on the engine, via radars or GPS, which go beyond the standard FIA system, are not permitted. For now, drivers need to be able to cope without actively controlled brake systems;**

Formula E car designs for season 4 and season 5 do not differ much in layout. There are several options for the engine and transmission - combinations of longitudinal and transverse arrangement (Figure 34b).The battery and powertrain position must be possible lower, to achieve a low centre of gravity. The inverter is usually above the battery, but there are variants with a lower inverter. (Figure 34a) Cylindrical gears and as few gear pairs as possible are used to achieve a higher transmission efficiency.



a) lower placement of power electronic [18] b) combinations of longitudinal and transverse layout of engine and gearbox [1]

Figure 35 Variants of the cars layout from season 4 and 5

Companies involved in the development of racing cars use Formula E as a test field for the development of advanced automotive drive technology.

The appearance and performance of some Formula E cars in recent seasons are given in Figure 36 and Figure 37.

Figure 36 Race car FIA Formula E, generation 2 of team Audi Sport Abt Schaeffler from season 5 (2018/19) & The new race car ABB FIA Formula E Championship, generation 2, for season 2020/21

Figure 37 Renault Z.E.17 Formula E Race Car, Seas. 4 & Race Car DS E-Tense FE20 Gen. 2

Renault Z.E.17 Formula E Race Car, Seas. 4[67] Specifications:

- Carbon fibre monocoque chassis honeycomb aluminium;
- Weight: Min 880kg with driver;
- Battery: 350kg, 28kWh capacity available during the race;
- Max power: 200 kW (Qualifying), 180 kW permitted in race;
- Two distinct cooling systems – one for the battery and one for the motor;
- Energy recovering power: 150 kW ;
- Supply: 800 V;
- Max speed: 225 km/h (optimised for street circuits);
- 0 to 100 kph: 4 seconds;
- Tyres: Michelin 18” grooved tyres all conditions.

Race Car DS E-Tenses FE20, Gen. 2[68] Specifications:

- Type: Single seater;
- Length x width x height: 5.16m x 1.77m x 1.05m;
- Wheelbase: 3.10m;
- Weight: Min 900kg with driver;
- Battery: 54 kWh capacity, 385kg;
- Max power: 250 kW (338 hp);
- Energy recovering power: 250kW;
- Supply: 900V;
- Brakes: Ventilated carbon discs, 4-piston calliper, rear break-by-wire;
- Max speed: 230KmH (optimised for street circuits);
- 0 to 100 kph: 2.8 seconds;

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[67] https://www.youtube.com/watch?v=JFJNCFOVyBQ Renault Z.E.17 Formula E Race Car
[68] https://sparkracingtechnology.com/know-how/

- Breaking distance: 100m, from 230 to 40 km/h;
- Tyres: Michelin Pilot Sport EV Season 5 (front: 245x40R18, rear: 305X40R18)[69].

4.2.3 Formula Student

Figure 38 Picture of Formula Student Event

Formula Student is a student engineering competition held annually in various places around the world. Student teams from around the world design, build, test and compete with a Formula racing car on a small scale. Cars are rated according to a number of criteria listed below. The race is run by the Mechanical Engineers Institute and uses the same rules as the original SAE formula with additional provisions. The projects are funded by university budgets and sponsored by companies and organizations, which is organized and provided by the students themselves. In addition to internal combustion engines, cars can also be powered by electric motors or hybrid systems (Formula Hybrid).

A separate class for electric vehicles was introduced in 2010 to prepare future young engineers for future technologies such as electric drives and to improve the innovation process. This class focuses on environmental aspects without losing the appeal of a sporty driving style. It is quite remarkable that the fastest electric vehicles already provide the same performance compared to the best racing cars with combustion engines. Projects are evaluated according to two sets of criteria - static and dynamic. Each indicator carries a certain number of points. In addition, a technical inspection is carried out that does not earn points, but without it the team is not allowed into the race and includes six tests: safety, chassis, noise, slope, brakes and technique. The winner of the event is the team with the highest score of maximum 1000[70].

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69 https://www.dstecheetah.com/team/car/
70 http://electric.amzracing.ch/en/formula-student

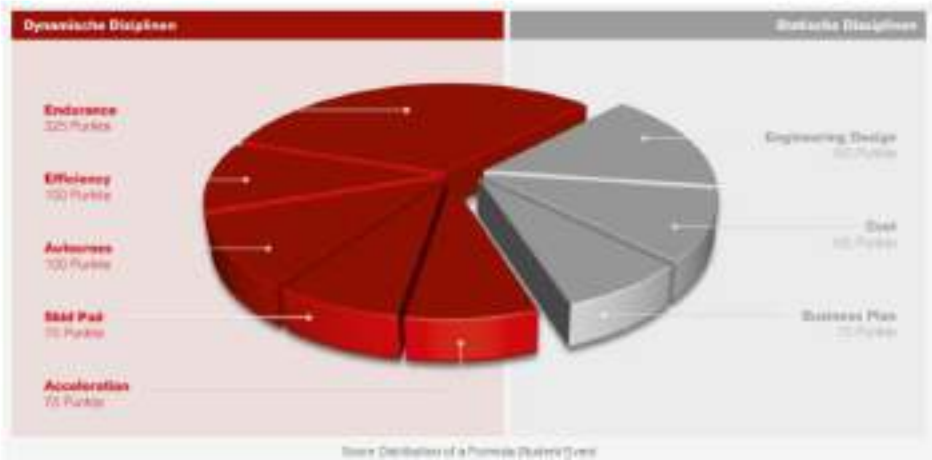

Figure 39 Formula Student Score Distribution

Teams have more freedom in terms of design solutions, layout and appearance of vehicles than those of Formula E. Exemplary designs are given in Figure 40 and Figure 41.

It is possible a powertrain with either one motor or two, mounted on the wheel or on the frame (Figure 40). In the first case, a mechanical differential is used, and in the second, most often planetary mechanisms with a constant gear ratio and an electrical differential connection. The drive can be front. The use of a planetary gearbox can be generally avoided, but the requirements for the motor become high and contradictory - at the same time having a small mass and dimensions and low speeds with relatively high torque.

Serious attention must also be paid to the suspension of the wheels, as the speeds are high and the weight of the wheels is higher in the decision to using electric motors inside wheels.

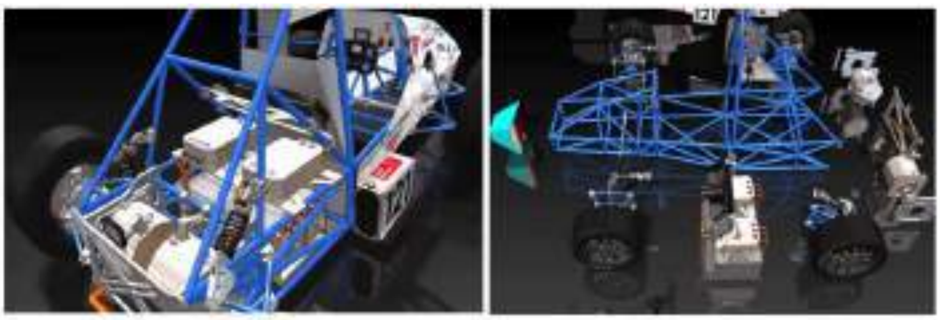

Figure 40 UWE Formula Student Electric Design

Figure 41 Formula Student Electric Assembly Animation

4.2.4 Shell Eco-Marathon

The Shell Eco-Marathon is a worldwide energy efficiency competition sponsored by Shell. The aim is to provoke young people from all over the world who have an interest in technology, to design and build special cars designed only for the race. Participants build cars by applying innovative solutions freely to maximize fuel or battery efficiency. The rules regarding structures are not as stringent as in Formula E, and the speeds are much lower. Therefore, there is a great deal of variety in the vehicles of the participants. The teams are made up of students or students from secondary schools who design and manufacture most of the vehicle's products themselves. Car companies usually do not participate directly in the development of car components and systems, but support the projects through donations, sponsorships and more. Within the Shell Eco-marathon, two classes of vehicles have been identified: **Prototype** and **Urban Concept**, in three energy categories:

- electric batteries;
- hydrogen fuel cells;
- internal combustion engine (gasoline, ethanol or diesel).

Figure 42 Appearance of electric cars Prototype (left) and Urban Concept (right)[71]

Prizes are awarded separately for each vehicle class and energy category. The top of the race is the World Eco Marathon Championships, where the most energy efficient cars compete with limited energy.

In each category, the team with the least amount of energy consumed wins a cash prize of € 1,000. In addition to the economy car, there are prizes (from 300 to 800 euros) and for:

- design;
- ecology;
- technical innovation;
- vehicle safety;
- team spirit;
- marketing and communications.

Shell Eco-marathon competitions are held all over the world. For example, the 2018 racing season included events held in Singapore, California (USA), Paris (France), London (United Kingdom), Istanbul (Turkey), Johannesburg (South) Africa), Rio de Janeiro (Brazil), India and China. Participants are students from a variety of academic backgrounds, including university teams such as past finalists at Duke University, University of Toronto, University of Michigan, and University of California, Los Angeles. In 2018, over 5,000 students from over 700 universities in 52 countries participated in the Shell Eco-Marathon[72].

There are no special requirements for team strategy. For example, some apply acceleration to about 30 km / h and then shut off the engine until the speed drops to about 15 km / h. This process is repeated, resulting in an average speed of about 23 km / h for the course.

71 https://twitter.com/terakkiteam/status/1075681589726732288?lang=bg
72 https://en.wikipedia.org/wiki/Shell_Eco-marathon

Vehicles typically have:

- aerodynamic drag coefficient (Cx) below 0,1;
- rolling resistance coefficient (f_R) of less than 0,001;
- bearing friction coefficient (μ) below 0,0015;
- weight with a driver under 85 kg.

The vehicles are highly specialized and event-optimized and are not intended for everyday use. The designs represent what can be achieved with current technologies and offer a glimpse into the future of automotive design based on minimal environmental impact in a world of diminished oil reserves. Participants' work can be used to show how manufacturers can redesign their products.

The prototype class electric cars are characterized by aerodynamic shape, bicycle-type light-alloy wheels with minimal rolling resistance, and the wheels are closed with streamlined shapes, to reduce the resistance to the swirling air around the wheels. (Figure 43) Much attention is paid to all drive elements that cause system losses[73]:

- energy minimization for control electronics;
- reduction of friction through the use of hybrid ceramic bearings;
- electric motor with silver wire windings to reduce the active resistance;
- modelling of the powertrain.

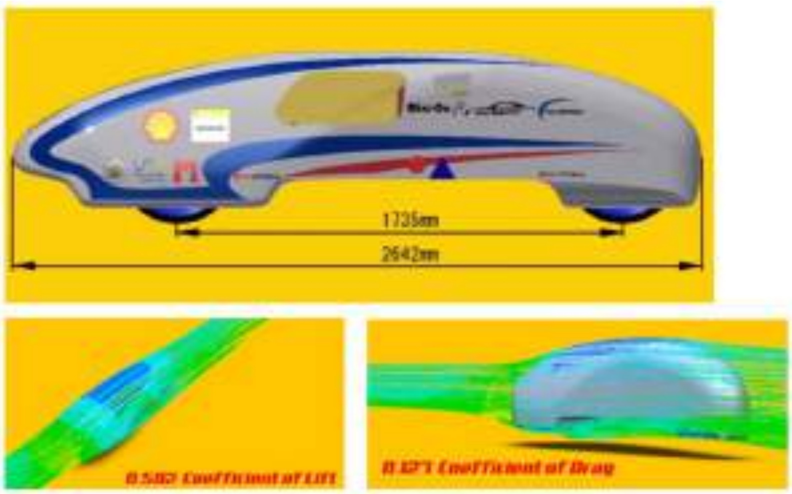

Figure 43 Kumbolo Electric Vehicle for Shell Eco-Marathon Asia 2018

[73] https://tufast-eco.de/en/guinness-world-record-2/

The drive most commonly uses a DC motor and a simplified gear, chain or friction. The electricity source can be a battery, fuel cells, or a combination of two sources: a battery and fuel cells, or a battery and a supercapacitor (aka hybrid electric drive). This achieves optimization of driving modes - one with higher specific power is used in acceleration and one with higher energy efficiency in permanent speed-state mode.

The teams also use devices to measure the electricity used (joule meter), which must be approved by the judges Figure 45). When using fuel cells, the supply voltage is 14 to 18 V. An electric vehicle can be driven by one, two or more motors, working only one or more motors together, as appropriate. The required power of the wheel when traveling at about 30 km / h is in the order of 300W. The gear ratio of the gearbox from engine to wheel is 25: 1 and the target efficiency of the fuel cell to wheel system (includes power electronics, engine and transmission) is 90% (27).
Suspension is usually missing or are simplified due to the relatively low travel speeds. However, there are also various interesting steering and tilting designs of the wheels to improve cornering stability and reduce rolling resistance. (Figure 44)

Figure 44 Nanyang Venture 9 for Shell Eco Marathon Asia 2015[74]

[74] https://www.youtube.com/watch?v=lHrvM81Sclg Nanyang Venture 9 for Shell Eco Marathon Asia 2015

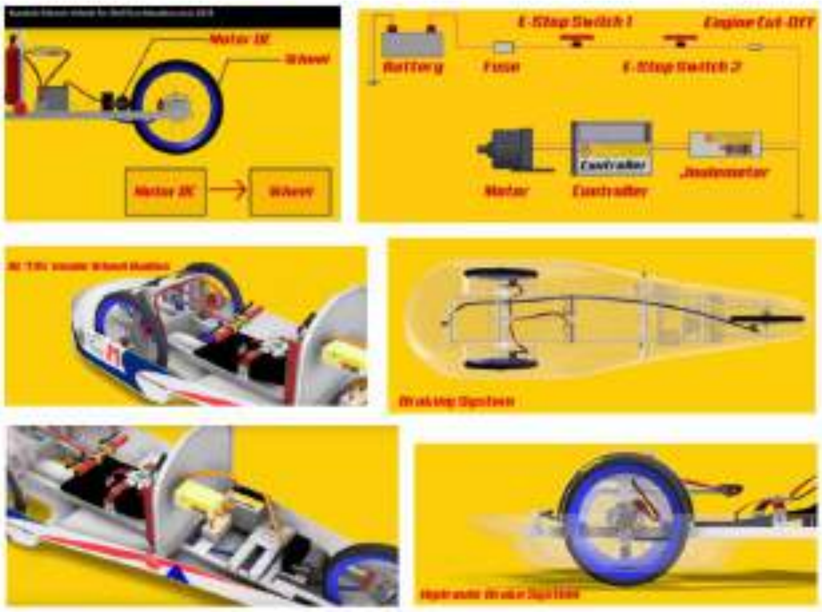

Figure 45 Kumbolo Electric Vehicle for Shell Eco-Marathon Asia 2018[75]

In this decision, the mechanism responds to the vector of the resultant force, obtained from the geometric sum of the centrifugal force and the force of the weight.

It turns out that at these speeds the rolling resistance can exceed the air resistance when cars are moving on a track with a smaller radius. (Figure 46).

Air resistance in the Prototype class is also reduced by minimizing frontal area, with the pilot position almost horizontal.

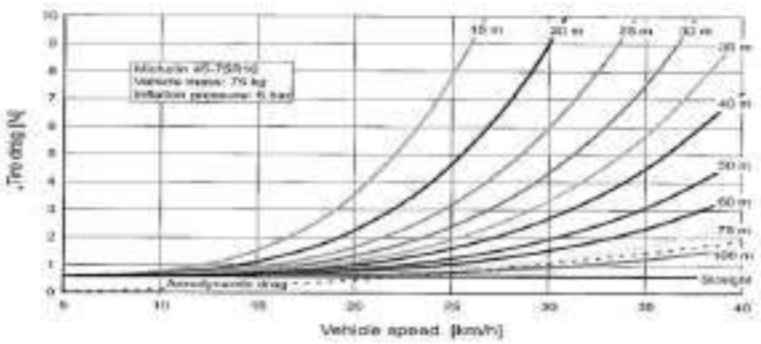

Figure 46 Tire drag provided by the uni-cycle vehicle model for different speeds and turn radii (27)

The absolute world records for the least amount of energy per unit of mileage, respectively for the highest mileage per unit of energy, are owned by electrically driven cars, as internal combustion engines are far less efficient than electric motors. The best teams have achieved remarkable results,

[75] https://www.youtube.com/watch?v=819h4To1yoE Kumbolo Electric Vehicle for Shell Eco-Marathon Asia 2018

and yet it is considered that not all the possibilities for reducing energy consumption and environmental pollution have fully utilized. (Figure 47)

Figure 47 Team picture winning teams

4.2.5 Hybrid racing cars

Along with purely electric drives, the competition also features categories of hybrid drive - using an ICE and an electric motor. Like the Formula SAE, Hybrid competition also includes acceleration, autocross and durability tests, as well as engineering and construction static events. Unlike the Formula SAE, the Formula Hybrid places greater emphasis on powertrain innovation and fuel economy.

Figure 48 Renault Energy F1®: The New Power Unit[76]

The FIA also announced its intention to change 2.4-liter V8 engines to 1.6-liter V6 turbo engines for the 2014 season. New regulations include multiple energy recovery systems and fuel consumption restrictions to attract more commercial partners. They sounded very different because of the brand

[76] https://www.youtube.com/watch?v=1RlZF9j3NoE Renault Energy F1®: The New Power Unit

new hybrid units MGU-H and MGU-K. To replace the units with natural aspiration, a 1.6 litre turbocharger was produced.

The energy recovery systems known as KERS had a power of 160 hp. and 2 mega joules per tour. KERS was renamed Motor-Generator Unit - Kinetic (MGU-K), i.e. Motor-generator set that returns kinetic energy from the wheels and charges the battery when braking. Exhaust gas thermal systems under the name Motor-Generator Unit - Heat (MGU-H) are also permitted. For this purpose, such a hybrid system may have two electric machines, each of which may be operated as appropriate in generator or electric motor mode together with the internal combustion engine. One of the possible modes of such a hybrid system (at overtaking) can be seen in Figure 48. The one electric machine works as a motor and supports the ICE, while the other - as a generator and is mechanically connected to the turbocharger and produces electricity that can in principle return to the battery or directly feed the other machine[76].

4.3 VIEWS ON E-MOBILITY TOPICS FROM WORLDWIDE INDUSTRY

4.3.1 Mercedes Benz

Mercedes Benz (28):

With the unveiling of the EQC production-ready SUV in Stockholm (Sweden) in early September 2018, Daimler has launched its model offensive for battery-electrically powered vehicles under the brand EQ. Ten further models will follow by 2022. The EQC enables us to start with a pure electric drive in the SUV segment – a segment that enjoys considerable customer demand. This will be followed by a complete family of electric vehicles ranging from a compact car up to luxury segment. Overall, Mercedes Benz Cars will be investing more than 10 billion euros in the expansion of its electric vehicle fleet

In addition, there is the Mercedes-Benz GLC F-cell, with plug-in fuel-cell drive, special hybrid with fuel cell. It operates on innovative fuel cell and battery technology for the first time: apart from electricity, it also run on pure hydrogen.

Further fuel-cell vehicles are not planned for the moment. The company will clearly focus on scaling-up their BEVs and use GLC F-Cell fleet, among other things, to gain further experience and create standards that are essential for cost reduction in particular.

Today Mercedes Benz sells around two million vehicles per year. Their official planning is that approximately 15 to 25% of all Mercedes vehicle sales will be purely battery-electrically powered by 2025, which corresponds to 300,000 to 500,000 BEVs per year.

China is currently the leading market for electric mobility and sales expectations are correspondingly high. People in the USA and Northern Europe are also already convinced of the merits of electric

mobility. The potential customers in Germany also expect a well-established infrastructure. Although there is a palpable dynamic in the construction of such infrastructure, it is not yet well established.
The company Mercedes Benz is being supplied with the best battery cells worldwide and construct with them the safest and most powerful energy storage systems. In the research and development of the cells, the company is playing leading role. They never wanted to build electric motors their selves, but the experts know very well, what an electric motor can deliver, and which motor types are best suited for which operating areas. Two differently designed electric motors will be integrated in the EQC – one of the front axle optimized for efficiency, which, for example, covers urban driving, and one on the rear axle optimized for dynamics and performance, which ensures acceleration and high output.
Fuel-cell vehicles in combination with plug-in technology are seen as long-haul alternatives to diesel. The fuel cell could serve as range extender in this case and could supplement the battery-driven drive.

4.3.2 ZF-Friedrichshafen AG

ZF-Friedrichshafen AG, interview with Winfried Gründler, Head of the business unit Truck and Van Powertrain Technology and of the Electro-Mobility Project House (29).
Currently makes no sense to use a battery-electric powertrain to cover the daily power needs for long-haul traffic in the heavy-duty truck segment. The heavier the vehicle, the larger the required battery capacity is for the same range. The higher weight of the traction battery reduces the capacity to carry load. In addition, if range is of great importance, such as in the logistics sector, then a poor charging infrastructure is a critical factor.
There is current agreement in the EU to reduce the level of CO_2 emissions of light and heavy-duty commercial vehicles by up to 30 % by 2030 compared to 2019.
These directives really do represent a huge challenge. It will no longer be sufficient to rely on the development of combustion-relevant measures or improved aerodynamics. Even running part of the fleet purely electrically will not suffice. **In addition to electric vehicles, hybrids are a very promising technology to help comply with these limits.** The hybrid powertrain is the correct approach in this case because the vehicle can run electrically in the inner city and be powered by an efficient diesel engine for long-haul routes. There is need to design the powertrain in such a way that fuel savings between 7 and 10 % can be achieved. Then we are on the safe side of calculations for Total Cost of Ownership (TCO).
It is realistic to assume that 50 % of all trucks in 2030 will still be powered by a combustion engine. It is immaterial whether it uses LNG/CNG, diesel or a synthetic fuel. It is also to expect a 30-% share of hybrid vehicles and 20 % of vehicles powered by a purely electric powertrain – we are speaking of heavy trucks, so 40 t vehicles.

If you are talking about mining vehicles or the really large construction machines, then electrification is currently an important technology whose importance will increase. Battery-electric vehicles are being prepared and are already being sold for use in underground mines. The business case for this specific application is enabled by the high costs for air ventilation during the operation of conventional vehicles. The really large vehicles will certainly continue to use combustion engines, but the powertrain will be diesel-electric as the market is too small for the development of conventional gearboxes and axles.

The combustion engine will remain as the standard power source for a tractor. However even in this sector, the market entry of battery-electric vehicles is already visible in the compact segment.

Large tractor attachments such as ploughs or liquid manure tanks will use an additional electric motor. The system traction performance is thus divided over additional wheels. The system traction available for difficult ground conditions will increase. Thanks to the additional drives, either larger tractor attachments can be operated or the weight of the tractor unit can be reduced. This will increase productivity, lower fuel consumption and reduce soil compaction. The concept of an electrically powered wheel hub eTrac integrated in a plough was presented at the Agritechnica in 2017. These approaches were unthinkable just a few years ago.

The market today uses an automated transmission. The first generation of hybrid transmissions is supplemented with an electric motor, an inverter and a hybrid strategy. This is considered as a bridging technology for the next few years until highly specialized hybrid transmissions, Dedicated Hybrid Transmissions (DHT), assert themselves. These are transmissions that have been designed solely for hybrid drives. A dedicated hybrid requires fewer mechanical gear stages and load shifts are carried out electrically. Under certain circumstances, the reverse gear can also be constructed electrically. A final consequence is that even the clutch can be eliminated. This enables us to implement completely new features.

ZF Team assumes so and has established their project system house for electro-mobility accordingly to develop a modular set of components. The components, from electric motors to inverters, can be used for trucks, buses, agricultural and construction machines. There is a need to consider that the number of units for each application is modest and will remain so in the medium term. The aim is to create the highest amount of synergy in previously mentioned powertrain mix. The same is true for the development of control units and software systems.

4.3.3 MAN

MAN (30):

At the 40th Engine Symposium in Vienna (Austria), MAN introduced their new 9-l engine series D15 and E18 to the expert audience. The features of the D15 and E18 are discussed as well as powertrain technologies of the future with Markus Raup, the Deputy Head of Engine Development at MAN in Steyr (Austria), and Moritz Späth, Senior Design Engineer in the 9-l engine series design department at MAN in Nuremberg (Germany).

The new 9-l six-cylinder D15 engine for the commercial truck sector and the E18 for bus applications are introduced in Vienna.

Main features of these engines are compact, optimized regarding weight, low technical complexity, high robustness thanks to the further increased use of simulation and validation. The new engine series also offer different fuel options are also possible such as diesel, HVO or CNG as well as operation as a mild-hybrid in the MAN Efficient Hybrid System.

The D15 engine closes a gap in Man's series portfolio. It is positioned between the small 7-l series and the 10.5-l D20 series and thus completes the portfolio. D15 is launched for different applications- first for the agricultural machine sector, then as an application for use in buses and then for the construction machine sector. It was clear that the new engine series will be mounted in trucks, buses and in off road sector. The base engine is identical. The specifics such as the interfaces in the vehicles for different applications are developed according customer requirements. The applications differ however in the engine software that they use, or rather the calibration of the control units. This is an initial element for the control of the engine, for example with regard to combustion and exhaust after treatment. These aspects have to be designed specifically for each application to ensure completely different emissions targets are met.

The D15 can be combined with the Efficient-Hybrid System in Bus applications. The development of the Efficient Hybrid System was targeted at the stop-and-go operation in the bus segment.

The E18 will be mounted in the MAN Lion City G. This has type 4 CNG gas cylinders mounted on the roof under an aerodynamic hood. The E18 boasts very high fuel efficiency.

MAN will offer the complete range of technologies in the bus sector – diesel for compliance with Euro VId and Euro Vie legislation. A gas-powered bus is very popular. The company will also be offering a battery-electric bus to complete the portfolio. Battery-electric buses will not replace the combustion engine powered bus from one day to the next. The company is having intensive discussions with the government, bus operators and communities. A city bus is designed for an operating life of twelve years and will not be replaced just because new technology is available. The fleet will be successively renewed and this needs to be budgeted for. **This means that the renewal of the fleet towards Euro VI or a conversion to gas and battery-electric buses is certainly the focus of the next few years**.

In conclusion, the information from an online meeting of the TU-Sofia team with Dr. Eng. Zlatina Dimitrova, Innovation Project Manager at the Scientific and Research Department of PSA Peugeot

Citroën is presented. The purpose of the interview is to study the requirements of the industry related to the design, manufacture, testing, diagnostics and maintenance of electric vehicles, regarding the necessary knowledge and skills of engineers working in this field.

The meeting discussed the most important issues and areas of knowledge that participants should consider when training engineers. Assoc. Prof. B. Gigov noted that technologies in this field are developing very fast, which is why the training of the personnel in the technical schools is most often behind the needs of the business. Dr. Z. Dimitrova expressed the same opinion. There are many new things in the area, some of which are even hidden from companies and there is a great need for multidisciplinary knowledge in the field of electric vehicles. She shared her vision as a manager at PSA Peugeot Citroën for the special knowledge and skills of engineers involved in the production, testing and maintenance of electric vehicles at individual units and systems, for which she was previously directed by Assoc. Prof. N. Pavlov. It is very important to pay attention to the battery because it is the most expensive element associated with mileage and environmental hazards. Moreover, its efficiency and life cycle depend on the temperature of the battery. In this regard, it is important for engineers to have knowledge of **electrochemistry**, to know the chemical elements used in the designs of modern batteries and the tendency to move from liquid to solid electrolyte, and to have knowledge of **thermodynamics and heat transfer**. In addition, in order to secure the battery in the event of a rollover or impact in the vehicle, knowledge of **mechanics** and mechanical structures is required.

Assoc. Prof. N. Pavlov also paid attention to the battery management system (BMS), which must control the respective inverters (DC-AC, AC-DC and DC-DC), which are part of the power electronics, of the trends of use of high-voltage batteries and in this connection with the need for knowledge of electrical engineering and electronics, programming, safety engineering and the requirement of a special certificate for high voltage operation.

Assoc. Prof. B. Gigov asked if there were any data on the reliability of electronics at very high and very low ambient temperatures.

Dr. Z. Dimitrova added that it is of particular importance for electric vehicles to have emergency programs in the event of various adverse modes - for example, exhaustion of battery capacity, failures in electronics, etc. In such cases, the computer system must to warn the driver and automatically enter the default mode. In addition, the engineers who design and test this system must know the relevant software products.

The same applies to electrical machines requiring knowledge of **electromagnetic field and torque (Matlab Simulink) software**, a control and cooling system, and a default mode on the host computer in an emergency.

Participants in the conversation noted that the most sophisticated is the software for **hybrid drive systems**, in which the task is to achieve energy minimization in real time by choosing the most advantageous use of both engines.

Assoc. Prof. N. Pavlov believes that the hybrid management strategy should not be predetermined but adjusted according to the specific driving conditions, similar to self-adjusting gearboxes for conventional second-generation automatic transmissions.

With regard to hybrids, Dr. Z. Dimitrova believes that in addition to knowledge and use of software products, it is imperative to know the various connection schemes and modes of operation depending on the degree of hybridization.

Assoc. Prof. B. Gigov added that this is related to the knowledge of **machine elements, planetary gears, theory of machines and mechanisms, automatic control systems**, etc., which are also necessary in the study of conventional propulsion systems.

With regard to the charging of the traction batteries of electric vehicles, Dr. Z. Dimitrova pointed out that in addition to domestic slow charging with relatively low power - up to 8 kW for single-phase and up to 11 kW for three-phase network, fast charging through charging columns with power is also applied up to 50 kW. For motorways with a larger flow of cars, charging systems with much higher capacities are discussed - in the range of 100 to 350 kW, which is required in connection with the trends of increasing the range of electric vehicles and the use of batteries with higher capacity. Assoc. Prof. N. Pavlov noted that there are problems with cooling both the systems themselves and the connectors that are special (for reducing the arc), and the power for the cooling systems can reach up to 40% of the electric power for charging. Dr. Z. Dimitrova expressed the opinion that in this regard the engineers who will solve these problems should be able to evaluate the technological solutions from the **economic point** of view, as these facilities are quite expensive. They must also have knowledge of the **power grids**, since the use of such high power is also linked to the capabilities of the grids and combinations of high voltage and high currents.

Assoc. Prof. B. Gigov noted that the rapid charging of batteries with very high currents is likely to have a detrimental effect on their life (reducing the number of charge-discharge cycles). This problem is also being investigated as a trend and the issue is partially resolved by intensive cooling.

The question arises as to whether large cities will be prepared for congestion of the electricity grid with a significant increase in the number of electric vehicles. Dr. Z. Dimitrova believes that in this case, electric vehicles will also serve as stabilizers of the electrical contact network, since they will not only consume, but also deliver energy to the grid.

Dr. M. Stefanova-Pavlova questioned whether this would happen, but it is still an interesting hypothesis. Assoc. Prof. N. Pavlov added that it would probably have such an effect with a sufficient increase in the number of electric vehicles and at peak network loads.

Dr. Z. Dimitrova also pointed out that the participants in the conversation agreed that when it comes to electro mobility, the most important issue is the issue of **life cycle assessment** of components and energy. How is energy and the car itself produced and how is it recycled? Are very expensive and harmful materials inserted into the battery, electronics, and electrical machines? Some studies show that a battery over 13 kWh pollutes more than one conventional car.

Assoc. Prof. N. Pavlov drew attention to the fact that in cities there will be a positive effect on the cleanliness of the air from electro mobility, especially when the batteries will deliver energy to the grid, as well as on the issues of **cybersecurity and autonomous cars**.

Dr. M. Stefanova-Pavlova noted that the **life-cycle assessment** discipline must be well structured and well taught in order to be interesting and sought after by students.

4.4 OUTCOMES & RECOMMENDATIONS & CONSTRAINTS FOR ECEPE

From the literature review and the conducted meetings and interviews, it can be concluded that the standard requirements for the commercial vehicle and racecar electric powertrain engineers are the same as for passenger cars. In addition, they need specific requirements in the fields of:

- Dynamic charging - conductive and inductive.
- Contact lines, substations, electrical energy distribution.
- Pantograph and other type conductive current collectors.
- Wireless charging technology and relating to them EMC issues.
- Hydrogen fuel cells and supercapacitors.
- Regenerative braking issues due to high mass and high proportion of stop-and-go in inner-city traffic.
- Two or more speed mechanical gearboxes for improving the dynamics of sports and racecars, etc.

As a summary of the review of the circumstances of non-passenger electric vehicles, may be recommend inclusion in the study material and of questions, which relate to the "conventional" knowledge and skills of Automotive Engineers. This is important in terms of environmental protection and the introduction of increasingly stringent emission requirements that are generate not only by the cars themselves, but also in the production of electricity, hydrogen, alternative fuels, etc. It is therefore logical that the more efficient a driving system is and the less energy used is to do the same work the less harmful emissions will be generated in the atmosphere. In order to minimize the losses of a single car (electric vehicle) under different driving modes, are examined all factors that influence them more or less, respectively on the lap time for Formula cars or on the energy per unit travelled way.

Along with issues related to the electrical part due account must also be taken of factors relating to the construction of the mechanical part and the exploitation of the vehicle. This includes such questions of the Vehicle Theory and Design as:

- **Impact of self-weight** (weight of construction) and the operating weight on the economy of the vehicle and minimizing it by using lightweight materials of sufficient strength and structures of units and systems with less specific mass (especially the battery).
- **Influence of mass inertia** of the rotating parts (wheels and other drive elements) on the forces balance and power balance of the vehicle. During acceleration, energy is necessary for both the linearly moving masses and the rotating masses.

- **Types of moving resistance** and constructive factors and performance factors on which they depend (tires material, tires dimensions and constructions, hysteresis losses in the tire - pressure in the tire , body shape and dimensions, air ducts, speed, etc.).
- **Grip and skid of the driving wheel** - restrictions on the drive torque and braking torque of the wheel. The individual torque control applied to the wheel requires a reliable electronic stabilization system and corresponds to the tangential and lateral forces that arise in the contact between the wheel and the road. These issues are important for the speed loss from skid and for the stability and security of traffic.(In road with asymmetrical grip it is better to provide mechanical or electrical differential connection between the left and right wheels to avoid any destabilizing torque due to the difference in forces).
- **Friction losses and hydraulic losses in transmission of Electric and Hybrid Vehicles** - gears, CVT, Torque Converter, etc. (To overcome them, additional energy consumption is required. Some are proportional to the transmitted useful torque and some to the square of the angular velocity).
- **Gearbox Selection** - Regarding the control, type and range of gearbox change in order to maintain the optimum MGU (Motor Generator Unit) mode in real time under different operating conditions. (To provide such a combination of torque and angular speed of the electric machine at which it operates in the area with maximum efficiency, both when transmitting the power flow from the engine to the wheels and when transmitting from the wheels to the generator – recovery).

5. ENGINEERS VIEW ON ELECTRIC POWERTRAIN ENGINEERING

According to (31), do universities have the potential to play a vital role in the way to equip Europe with the skills and competences necessary to succeed in a globalised, knowledge-based economy. In order to overcome mismatches between graduate qualifications and the needs of the labour market, university programmes should be structured to enhance directly the employability of graduates and to offer broad support to the workforce more generally. Therefore, universities should offer innovative curricula, teaching methods and training programs, which include broader employment-related skills along with the more discipline-specific skills. These ambitions, among others, have led internationally to develop curricula to the Bologna Process and ultimately the establishment of the European Qualifications Framework for Lifelong Learning (EQF).

Traditional ways of designing a study programs at universities focus on topics that students should know after the completion of their degree, in some cases these curricula have a very teaching-cantered view as they only describe subjects, topics, etc. taught, but they leave out the student centred view. Mainly in technical oriented universities the curriculum included practical work, laboratory exercises, seminars and projects, but the abilities and competences acquired in the course of a program have rarely been topic for discussion in most of the responsible commissions.

Only in very rare cases, the University degree actually entitles to a certain profession, so there was no real pressure coming from professional bodies to define the requirements. The development in the recent years led to a different view on university education, reflecting the changing world with its growing mobility, and the necessity of transparency and comparability. The newly introduced student programs should state clearly, what the student has learnt and what he or she is or should be capable to know and do. These outcomes need to be described in learner oriented terms, which is a new and different view on how to present information and competences accumulated during the learning process.
To that aim, the standards and guidelines by the European Association for Quality Assurance in Higher Education (2005) already indicate that stakeholders such as employers and labour market representatives should also have an opportunity to give feedback to higher education institutions on the quality of the study program and the intended qualification profile.

The contribution of **this chapter is to present the viewpoint of automotive engineers and their employer** on the usefulness and employment-related skill trainings provided by universities of technology. To that aim, the automotive partner network of Graz University of Technology has been

surveyed for their needs and skill gaps of graduates to be employed directly in the automotive cluster companies of Graz region. The focus was set on ePowertrain engineering topics (focus of the ECEPE project) and analysed for the viewpoint of (a) large suppliers (e.g. Magna International), (b) large engineering companies (e.g. AVL List GmbH), (c) device supplier (e.g. Infineon), (d) SMEs (e.g. CISC), and (e) research institutions (e.g. VIF).

5.1 AUSTRIAN UNIVERSITIES IN CONTEXT OF CONTINUED EDUCATION

The first initiatives to align university's degree in context of continued education and training started in early 1990ies. In the course of the implementation of the UOG 93 (Universities Organisation Act) in March 1996, multiple rectors from Austrian universities came to a round table to exchange experiences and to explore the potential of university continuing education and staff development. This evolved into a network called AUCEN - Austrian University Continuing Education and Staff Development Network.

AUCEN is a forum for the common interests and specific needs of both subject areas, university continuing education and staff development, which was first provided with staff resources financed by the Federal Ministry for Education, Science and Culture to coordinate and then evolved to a registered, formal association with its office financed by the member universities.

AUCEN is a platform where responsible persons for continuing education and staff development at Austrian universities can exchange their experiences. The available competencies and experiences shall be advanced and professionalised jointly and in a division of labour to develop and assure standards in the constant challenge of continued education.

At Graz University of Technology, Life Long Learning (32) is the place to search for university-level continuing education in engineering and science subjects. LLL designs courses by focusing on the needs of target groups and developing innovative subjects and formats to meet those needs. Further, LLL is used to up-to-the-minute teaching and learning technologies developed at TU Graz to create flexible learning settings and onside courses for industrial partner.

Specialised continuing education is offered in areas shared by institutions of higher education and business with increasing frequency. TU Graz also cooperates with companies on a continually expanding basis to offer courses in a variety of ways, for example, as part of subsidized qualification networks.

The funding programme "R&D Competences for Industry" from the Austrian Research Promotion Agency (FFG) supports the development and implementation of university qualification programmes for companies. First, this programme helps companies (primarily SMEs) systematically train their current research and development staff members, as well as help them gain specialised qualifications. Second, the programme ensures that fields of expertise that are relevant to companies are promoted at Austrian universities and technical colleges and provides an impetus for higher sectoral mobility.

TU Graz Life Long Learning, the department at TU Graz responsible for continuing education. TU Graz LLL supports companies in bringing their staff up to date with the latest developments in science, commerce and technology. The continuing education courses can also be organised as in-house training sessions where companies can talk to lecturers and adapt the courses to their individual needs. As an example, see the following automotive courses:

- Automotive Quality Manager[77]

  This university course provides you with theoretical and practical skills that enable you to understand key processes in the development of automobiles. In addition, you can obtain the "ECQA Certified Automotive Quality Manager" certificate.

- Automotive Mechatronics[78]

  The university course delivers knowledge on three levels: (a) basic knowledge, which is necessary to gain a better understanding of and ability to interpret mechatronic systems and their development processes; (b) specialised knowledge and new insights, which are particularly relevant for the development and evaluation of new products; and (c) practical application of the knowledge acquired in (a) and (b) by carrying out exercises and project work.

5.2 APPROACH FOR MINING OF ENGINEERS VIEWPOINT

In this section, the approach to gather the automotive engineers viewpoint of TU Graz's partner network is described to get feedback on the ECEPE approach on training for ePowertrain engineering. The intention was to get a more holistic view on the skill needs of employers and skill gaps of graduates to better bridge the gap via trainings, such as proposed by ECEPE.

The acquiring of the engineer's viewpoint was done via personal meetings and discussions on the ePowertrain engineering topic and a brief presentation of the proposed structures of the course, followed by a discussion on the individual points of interest.

[77] https://www.tugraz.at/en/studying-and-teaching/degree-and-certificate-programmes/continuing-education/university-courses-courses-and-seminars/automotive-quality-manager-aqua/

[78] https://www.tugraz.at/en/studying-and-teaching/degree-and-certificate-programmes/continuing-education/courses-and-seminars/automotive-mechatronics/

This section summarizes the different view point of representatives of (a) large suppliers (e.g. Magna International), (b) large engineering companies (e.g. AVL List GmbH), (c) device supplier (e.g. Infineon), (d) SMEs (e.g. CISC), and (e) research institutions (e.g. VIF) based on the individual discussion logs.

The initial list of topics for discussion included the following points:

- Intro
  - Grant societal changes / drivers of change / environmental impact
  - Specifics of automotive domain (complexity / safety / C2x / security)
  - Communication between players / customers (supply/value chain / separation of concerns)
  - V cycle development approach
  - Standards / directives / regulations / HV & fire considerations
  - Life Cycle (product / 2nd life / difference for spec. Parts)
  - Infrastructure (charging, service stations)
- Vehicle
  - Novel E/E architectures
  - ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)
  - Building blocks of ePowertrain (battery, eMotor, inverter, …)
  - Communication layers/means
  - Connected vehicle communication (e.g. maintenance)
  - EMC - Electromagnetic compatibility
- Function-based-Development
  - Focus on user functions rather than individual system components
  - Safety view point (systems design & item thinking)
  - Cyber-Security (basics of Design for CS & threat/attack surface thinking)
  - Signal flow / Interfaces Definitions (real-time thinking)
- Propulsion systems
  - eMotor / generator
  - Combustion engines / range-extender
  - Power electronics / inverters
  - Hybrid control systems (eMotor/inverter/ECU) - HW
  - Hybrid control systems (eMotor/inverter/ECU) - SW Arch
  - eMotor Control
  - KERS / recuperation
- ePowertrain Auxiliary Systems

  - Electric power converter -> low power systems
  - Cooling/Heating system (electronics/passenger)
  - (Electric?) energy storage systems
  - Battery
  - Fuel cell
  - Super capacitor
  - BMS - HW
  - BMS - SW
  - Mechanical storage systems (prop. Out of scope?)
  - HV system thinking - isolation monitor
- Life Cycle Management
  - Intro to Life Cycle management
  - Product LC (design, usage, EoL)
  - Sustainability
  - Life cycle costing
  - Life cycle data management (data collection, feedback/optimising with fleet data feedback)
  - Life cycle Service Models / LC Business Models (novel approaches for earning money)
- Transmission
  - Transmission types (mechanical designs / changes due to hybridisation / final drive (2gear reduction-drive for ePowertrain))
  - Transmission control systems - HW
  - Transmission control systems - SW Arch

Critics on university institutions claim that the actual development of course curricula is often left to commissions that have a clear view on the subject, but little or no experience in the practical aspects of designing qualifications profiles. The points of criticism mention that, selecting a proper set of necessary and obtainable knowledge, skills and competences, and on how to map those outcomes to learning processes and courses is not always properly done. Therefore, multiple ways of formal collaboration and cooperation between business world and educational institutions can be found, but the most common approach is the external review process, where representatives of social partners or members with professional backgrounds belong to the peer teams respectively the accreditation agencies.

To that aim, the approach to gather the automotive engineers viewpoint of TU Graz's partner network is used to get such an adequate feedback in a tailored manner.

5.3 SKILL PROFILE EXPECTATIONS OF EPOWERTRAIN ENGINEERS

Aim of this section is to gather the skill expectations for ePowertrain engineers by the different interviewees. The focus of this section is to get a better view on the typical skill profiles of engineers working with ePowertrain and to grasp the cross-domain knowledge expected.

From an organizational management perspective, individual abilities, experiences, competencies, and qualifications of human resources build a success factor in organisations, which enable entrepreneurial strategies of increasing flexibility and continuous learning (33).

5.3.1 Common knowledge expectations

The following statements can be seen as common expectations of the different organisations:

- Contribute to break silos in a manner which avoids unproductive and error prone processes
- Ability to communicate with involved engineering teams
- Engineers with the skill to communicate and document their core objective (safety, design, etc.)
- Fast intro to core developments and the core knowledge of the company. Doing so could save significant time, money and risks.
    - Includes team player capabilities
    - Serious appearance
    - Adequate language and technical terminology knowledge

5.3.2 Large suppliers view

The view of large suppliers in the Graz cluster is split into two main groups:

1. **Production-oriented group** brought up the following skill expectations:

- Communication between players / customers (supply/value chain / separation of concerns) – high interest, detailed knowledge required
- Standards / directives / regulations / HV & fire considerations – high interest, detailed knowledge required
- Building blocks of ePowertrain (battery, eMotor, inverter, …) – some interest
- eMotor / generator – some interest
- Combustion engines / range-extender – some interest
- Power electronics / inverters – some interest
- eMotor Control – some interest
- ePowertrain Auxiliary Systems – high interest, detailed knowledge required
- Electric power converter and battery – high interest, detailed knowledge required

- For battery, especially HV system & isolation monitor – high interest, detailed knowledge required
- Product LC (design, usage, EoL) – high interest, detailed knowledge required
- Life cycle costing – high interest, detailed knowledge would be very beneficial for technical engineers
- Life cycle data management (data collection, feedback/optimising with fleet data feedback) – high interest, detailed knowledge required and higher invests to come
- Transmission types (mechanical designs / changes due to hybridisation / final drive – some interest

2. **Development-oriented group** had the following expectations:

- Communication between players / customers (supply/value chain / separation of concerns) – high interest, detailed knowledge required
- V cycle development – high interest, detailed knowledge required
- Standards / directives / regulations / HV & fire considerations – high interest, detailed knowledge required
- Life cycle– high interest, detailed knowledge required
- Building blocks of ePowertrain (battery, eMotor, inverter, …) – some interest
- Novel E/E architectures – high interest, detailed knowledge required
- ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts) – some interests, basic knowledge required
- Building blocks of ePowertrain (battery, eMotor, inverter, …) – high interest, detailed knowledge required
- Connected vehicle communication (e.g. maintenance) – interesting, but only for feedback for production
- EMC - Electromagnetic compatibility – high interest, detailed knowledge required (only specific skill team)
- Safety view point (systems design & item thinking) – high interest, detailed knowledge required (only specific skill team)
- Cyber-Security (basics of Design for CS & threat/attack surface thinking) – high interest, detailed knowledge required (only specific skill team)
- Signal flow / Interfaces Definitions (real-time thinking) – high interest, detailed knowledge required (system integrator view)
- Hybrid control systems and battery management systems (HW & SW) – high interest

- eMotor Control – high interest
- KERS / recuperation – high interest on recuperation strategies
- Life Cycle Management – high interest of skill teams related to SoP management
- Sustainability – high interest of skill teams related to SoP management
- Life cycle costing – high interest of skill teams related to SoP management
- Transmission types (mechanical designs) – high interest of related skill teams
- Transmission control systems – embedded systems – high interest of related skill teams

5.3.3 Large engineering companies view

In the view of large engineering companies, their engineering focus domain is of highest importance. Thus, the following skill expectations are brought up:

- E/E architectures and ePowertrain building blocks and architecture concepts
  - need to be understood and aware
  - some skill teams even raise deep knowledge required
- Propulsion systems mentioned:
  - eMotor / generator – basic knowledge and understanding
  - Combustion engines / range-extender – basic knowledge and understanding
  - Hybrid control systems (eMotor/inverter/ECU) - SW Arch – detailed knowledge and understanding required
- Battery – detailed knowledge and understanding required
- KERS / recuperation – high interest on recuperation strategies
- Fuel cell – detailed knowledge and understanding would be highly required, but scarcely available
- Battery management system HW & SW – detailed knowledge and understanding required
- Life Cycle Management – detailed knowledge and understanding required, but is understood as engineering life cycles (V cycle development) rather than product LC
- Basic system and SW engineering concepts are highly required as well as SW development skills

5.3.4 Device supplier view

The view of device suppliers, like semiconductor suppliers and special part suppliers (such as sensor suppliers), differs a little from other views. From this perspective, the following skills and knowledge are expected from new employees with strong emphasis:

- Safety view point (especially HW)
- Cyber-Security (basics of Design for CS & threat/attack surface thinking)

- Signal flow (timing of signals)
- Hybrid control systems (eMotor/inverter/ECU) - HW
- eMotor control components
- Electric power converter - high power semiconductor
- Battery cell monitoring – cell aging and SoC/SoH characteristics knowledge
- Battery management system HW

5.3.5 SME's view

SMEs are often seen as the backbone of the global players in the automotive industry. With around 3.7 million companies, small and medium-sized enterprises (SMEs) account for 99.95 percent of the total number of companies in Germany and employ over 30 million people[79].As a supporting pillar of the economy, it is therefore justified and sensible that SMEs are the focus of several economic policy and that they are key drivers in Industry 4.0, IoT, new mobility, etc.

As different as SMEs and their service offerings can be, they also share certain characteristics: they possess great innovative power and a high degree of specialisation, they usually adapt quickly to changes in their clients and seek long-term, stable customer relationships. Thus, they must be able to maintain and contribute these strengths very fast even in times of transformation. Qualification will play an essential role in the transformation process.

High emphasis of SMEs is thus put on modular, flexible and personalized format of trainings and its adapts to the needs of the respective company. In the Graz region mainly SW driven and service oriented SMEs are located, thus the mainly requested skills and knowledges are requested for:

- Communication between players / customers (supply/value chain / separation of concerns)
- Standards / directives / regulations / HV & fire considerations
- Novel E/E architectures – especially SoA approaches
- Communication layers/means – especially V2x and connected vehicle
- Function-based-Development and novel SW functionalities
- Safety and cyber-Security (mainly risk assessment and mitigation techniques)
- Signal flow / Interfaces Definitions (real-time thinking)
- Hybrid control systems (eMotor/inverter/ECU) - SW architectures
- Battery management system SW algorithms
- Life Cycle management (with special focus on agile development and dependability engineering approaches)

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79 https://blog.iao.fraunhofer.de/automobilwirtschaft-das-transformationsdilemma-der-kmu-und-wie-es-geloest-werden-kann/

5.3.6 Industry research institutions view

Industry research institutions act as bridge between university research and industrial development and focus on transferring technologies from low TRL to TRLs close to prototype and series development. Due to that focus, the view of industry research centres is mainly aligned with the needs of the local automotive community and tightly coupled to the research roadmaps and strategic research plans.

Therefore, the interest spectrum covers on general terms:

- Grant societal changes / drivers of change / environmental impact
- Specifics of automotive domain (complexity / safety / C2x / security)
- V cycle development approach
- Standards / directives / regulations / HV & fire considerations
- Infrastructure (charging, service stations)
- ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)
- Building blocks of ePowertrain (battery, eMotor, inverter, …)
- Safety view point (systems design & item thinking)
- Cyber-Security (basics of Design for CS & threat/attack surface thinking)
- eMotor / generator
- Combustion engines / range-extender
- Power electronics / inverters
- Cooling/Heating system (electronics/passenger)
- Sustainability
- Life cycle costing
- Transmission types (mechanical designs / changes due to hybridisation)

The following skills and knowledge has been mentioned to require more deep know-how:

- Novel E/E architectures
- Connected vehicle communication (e.g. maintenance)
- Interfaces Definitions (real-time thinking)
- Hybrid control systems SW architecture
- Battery control systems
- Fuel cell
- Super capacitor
- Life Cycle management
- Life cycle data management (data collection, feedback/optimising with fleet data feedback)
- Transmission control systems

5.4 CURRICULUM STRUCTURE

In this section, the feedback of the five company groups for the proposed curriculum structure is collected and analysed. In this section of the document, the stakeholders have been asked to provide feedback for the following main questions:

- What skills should be part of the curriculum (general/specific)?
- What do you expect as basic knowledge in ePowertrain?
- How would you structure the course?

Generally, all companies were asked to give feedback on the level of details that should be taught on the specific topic (basic or detailed level) and if the knowledge of the specific topic is compulsory and should be mandatory included or optional.

Additionally, if they find additional topics to be provided and/or if a rearrangement of the topics/sub-topics would be required.

5.4.1 Large suppliers view

Table 4 gives an overview from large suppliers perspective on compulsory knowledge that is required to be transferred and suggested level of detail for the key interest groups.

Table 4 Curriculum feedback from large suppliers perspective

	Large Supplier Detail level	Large Supplier compulsory knowledge
Intro		
Grant societal changes / drivers of change / environmental impact	basic	
Specifics of automotive domain (complexity / safety / C2x / security)		x
Communication between players / customers (supply/value chain / separation of concerns)	detailed	x
V cycle development approach	detailed	x
Standards / directives / regulations / HV & fire considerations	detailed	x
Life Cycle (product / 2nd life / difference for spec. Parts)		
Infrastructure (charging, service stations)		
Vehicle		
Novel E/E architectures	detailed	x
ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)	basic	x
Building blocks of ePowertrain (battery, eMotor, inverter, …)	detailed	x
Communication layers/means		
Connected vehicle communication (e.g. maintenance)	basic	
EMC - Electromagnetic compatibility	basic	
Function-based-Development		
Focus on user functions rather than individual system components		
Safety view point (systems design & item thinking)	detailed	
Cyber-Security (basics of Design for CS & threat/attack surface thinking)	detailed	
Signal flow / Interfaces Definitions (real-time thinking)	detailed	
Propulsion systems		
eMotor / generator	basic	x
Combustion engines / range-extender		x

Power electronics / inverters	detailed	
Hybrid control systems (eMotor/inverter/ECU) - HW	detailed	
Hybrid control systems (eMotor/inverter/ECU) - SW Arch	detailed	x
eMotor Control	detailed	
KERS / recuperation	basic	
ePowertrain Auxiliary Systems		
Electric power converter -> low power systems	detailed	
Cooling/Heating system (electronics/passenger)	detailed	
Energy storage systems		
Battery	detailed	x
Fuel cell		
Super capacitor		
BMS - HW	detailed	
BMS - SW	detailed	
Mechanical storage systems		
HV system thinking - isolation monitor	detailed	x
Life Cycle Management		
Intro to Life Cycle management		
Product LC (design, usage, EoL)	detailed	x
Sustainability	detailed	
Life cycle costing	detailed	x
Life cycle data management (data collection, feedback/optimising with fleet data feedback)	detailed	x
Life cycle Service Models / LC Business Models (novel approaches for earning money)		
Transmission		
Transmission types (mechanical designs / changes due to hybridisation)	basic	x
Transmission control systems - HW	basic	
Transmission control systems - SW Arch	basic	
Additional		

5.4.2 Large engineering companies view

Table 5 provides the overview from large engineering company perspective. Compulsory knowledge that is required to be transferred is mentioned, as well as, a suggested level of detail for the key interest groups.

Table 5 Curriculum feedback from large engineering company perspective

	Large Engineering	
	Detail level	compulsory knowledge
Intro		
Grant societal changes / drivers of change / environmental impact		
Specifics of automotive domain (complexity / safety / C2x / security)	basic	x
Communication between players / customers (supply/value chain / separation of concerns)	basic	
V cycle development approach	detailed	x
Standards / directives / regulations / HV & fire considerations	basic	x
Life Cycle (product / 2nd life / difference for spec. Parts)	basic	
Infrastructure (charging, service stations)		
Vehicle		
Novel E/E architectures	detailed	x
ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)	detailed	x
Building blocks of ePowertrain (battery, eMotor, inverter, …)	detailed	x
Communication layers/means		
Connected vehicle communication (e.g. maintenance)	detailed	x
EMC - Electromagnetic compatibility		
Function-based-Development		
Focus on user functions rather than individual system components	detailed	x
Safety view point (systems design & item thinking)	basic	
Cyber-Security (basics of Design for CS & threat/attack surface thinking)	basic	
Signal flow / Interfaces Definitions (real-time thinking)	detailed	x
Propulsion systems		
eMotor / generator	detailed	x

Combustion engines / range-extender	detailed	x
Power electronics / inverters		
Hybrid control systems (eMotor/inverter/ECU) - HW	basic	
Hybrid control systems (eMotor/inverter/ECU) - SW Arch	detailed	x
eMotor Control	detailed	x
KERS / recuperation		
ePowertrain Auxiliary Systems		
Electric power converter -> low power systems		
Cooling/Heating system (electronics/passenger)		
Energy storage systems		
Battery	detailed	x
Fuel cell		
Super capacitor		
BMS - HW	basic	
BMS - SW	detailed	
Mechanical storage systems		
HV system thinking - isolation monitor	basic	
Life Cycle Management		
Intro to Life Cycle management		x
Product LC (design, usage, EoL)	basic	
Sustainability	basic	
Life cycle costing	basic	
Life cycle data management (data collection, feedback/optimising with fleet data feedback)	detailed	
Life cycle Service Models / LC Business Models (novel approaches for earning money)	basic	x
Transmission		
Transmission types (mechanical designs / changes due to hybridisation)	detailed	x
Transmission control systems - HW		
Transmission control systems - SW Arch	detailed	

5.4.3 Device supplier view

Table 6 gives the summary of the curriculum feedback from device supplier perspective. In addition, those companies were asked to provide feedback on compulsory knowledge that is required to be transferred and suggested level of detail for the key interest groups.

Table 6 Curriculum feedback from device supplier perspective

	Device Supplier Detail level	Device Supplier compulsory knowledge
Intro		
Grant societal changes / drivers of change / environmental impact		
Specifics of automotive domain (complexity / safety / C2x / security)	basic	x
Communication between players / customers (supply/value chain / separation of concerns)		
V cycle development approach		
Standards / directives / regulations / HV & fire considerations		x
Life Cycle (product / 2nd life / difference for spec. Parts)		
Infrastructure (charging, service stations)	basic	
Vehicle		
Novel E/E architectures		x
ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)	basic	
Building blocks of ePowertrain (battery, eMotor, inverter, …)	basic	x
Communication layers/means		
Connected vehicle communication (e.g. maintenance)		
EMC - Electromagnetic compatibility	detailed	x
Function-based-Development		
Focus on user functions rather than individual system components		
Safety view point (systems design & item thinking)	detailed	x
Cyber-Security (basics of Design for CS & threat/attack surface thinking)	detailed	x
Signal flow / Interfaces Definitions (real-time thinking)	detailed	x
Propulsion systems		
eMotor / generator		x

Combustion engines / range-extender		
Power electronics / inverters	detailed	x
Hybrid control systems (eMotor/inverter/ECU) - HW	detailed	x
Hybrid control systems (eMotor/inverter/ECU) - SW Arch		
eMotor Control	detailed	
KERS / recuperation		
ePowertrain Auxiliary Systems		
Electric power converter -> low power systems	detailed	x
Cooling/Heating system (electronics/passenger)		
Energy storage systems		
Battery	detailed	x
Fuel cell		
Super capacitor	basic	
BMS - HW	detailed	x
BMS - SW	detailed	x
Mechanical storage systems		
HV system thinking - isolation monitor	detailed	x
Life Cycle Management		
Intro to Life Cycle management		x
Product LC (design, usage, EoL)		
Sustainability	basic	
Life cycle costing	basic	x
Life cycle data management (data collection, feedback/optimising with fleet data feedback)		
Life cycle Service Models / LC Business Models (novel approaches for earning money)		
Transmission		
Transmission types (mechanical designs / changes due to hybridisation)		
Transmission control systems - HW		
Transmission control systems - SW Arch		

5.4.4 SME's view

The overview of the SME perspective on compulsory knowledge that is required to be transferred and suggested level of detail for the key interest groups is given in Table 7. Additionally, two skills have been mentioned which should also be included in the ECEPE course program.

Table 7 Curriculum feedback from SME perspective

	SME	
	Detail level	compulsory knowledge
Intro		
Grant societal changes / drivers of change / environmental impact		
Specifics of automotive domain (complexity / safety / C2x / security)		x
Communication between players / customers (supply/value chain / separation of concerns)	detailed	x
V cycle development approach	detailed	x
Standards / directives / regulations / HV & fire considerations	detailed	x
Life Cycle (product / 2nd life / difference for spec. Parts)	detailed	x
Infrastructure (charging, service stations)	detailed	
Vehicle		
Novel E/E architectures	detailed	x
ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)		
Building blocks of ePowertrain (battery, eMotor, inverter, …)		x
Communication layers/means	detailed	
Connected vehicle communication (e.g. maintenance)	detailed	x
EMC - Electromagnetic compatibility		
Function-based-Development		
Focus on user functions rather than individual system components	detailed	x
Safety view point (systems design & item thinking)	detailed	x
Cyber-Security (basics of Design for CS & threat/attack surface thinking)	detailed	x
Signal flow / Interfaces Definitions (real-time thinking)	detailed	x
Propulsion systems		
eMotor / generator		x
Combustion engines / range-extender		
Power electronics / inverters		x
Hybrid control systems (eMotor/inverter/ECU) - HW	basic	
Hybrid control systems (eMotor/inverter/ECU) - SW Arch	basic	x

eMotor Control	basic	x
KERS / recuperation	basic	
ePowertrain Auxiliary Systems		
Electric power converter -> low power systems		
Cooling/Heating system (electronics/passenger)		
Energy storage systems		
Battery	detailed	x
Fuel cell		
Super capacitor		
BMS - HW		
BMS - SW	detailed	x
Mechanical storage systems		
HV system thinking - isolation monitor		x
Life Cycle Management		
Intro to Life Cycle management		
Product LC (design, usage, EoL)	detailed	x
Sustainability		
Life cycle costing		
Life cycle data management (data collection, feedback/optimising with fleet data feedback)	detailed	x
Life cycle Service Models / LC Business Models (novel approaches for earning money)	detailed	
Transmission		
Transmission types (mechanical designs / changes due to hybridisation)		
Transmission control systems - HW		
Transmission control systems - SW Arch		
Additional		
agile SW development	**basic**	**x**
dependability engineering	**basic**	**x**

5.4.5 Industry research institutions view

The curriculum feedback from industry research institutions perspective is given in Table 8. The list of compulsory knowledge and suggested level of detail for identified key interest groups is rather broad, which represents also the broader activity focus of these institutions.

Table 8 Curriculum feedback from industry research institutions perspective

	Industry Research Institute	
	Detail level	compulsory knowledge
Intro		
Grant societal changes / drivers of change / environmental impact	detailed	x
Specifics of automotive domain (complexity / safety / C2x / security)	detailed	x
Communication between players / customers (supply/value chain / separation of concerns)	detailed	x
V cycle development approach	detailed	x
Standards / directives / regulations / HV & fire considerations	detailed	x
Life Cycle (product / 2nd life / difference for spec. Parts)	detailed	x
Infrastructure (charging, service stations)		x
Vehicle		
Novel E/E architectures	detailed	x
ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)		x
Building blocks of ePowertrain (battery, eMotor, inverter, …)	detailed	x
Communication layers/means		
Connected vehicle communication (e.g. maintenance)	detailed	x
EMC - Electromagnetic compatibility		
Function-based-Development		
Focus on user functions rather than individual system components	detailed	x
Safety view point (systems design & item thinking)	detailed	
Cyber-Security (basics of Design for CS & threat/attack surface thinking)	detailed	
Signal flow / Interfaces Definitions (real-time thinking)	detailed	x
Propulsion systems		

eMotor / generator	basic	x
Combustion engines / range-extender		x
Power electronics / inverters		x
Hybrid control systems (eMotor/inverter/ECU) - HW		
Hybrid control systems (eMotor/inverter/ECU) - SW Arch	detailed	x
eMotor Control	detailed	x
KERS / recuperation		
ePowertrain Auxiliary Systems		
Electric power converter -> low power systems		x
Cooling/Heating system (electronics/passenger)		
Energy storage systems		
Battery	detailed	x
Fuel cell		x
Super capacitor		x
BMS - HW	basic	
BMS - SW	detailed	x
Mechanical storage systems		
HV system thinking - isolation monitor		x
Life Cycle Management		
Intro to Life Cycle management	basic	x
Product LC (design, usage, EoL)	basic	x
Sustainability	basic	x
Life cycle costing	basic	x
Life cycle data management (data collection, feedback/optimising with fleet data feedback)		
Life cycle Service Models / LC Business Models (novel approaches for earning money)		
Transmission		
Transmission types (mechanical designs / changes due to hybridisation)	basic	
Transmission control systems - HW		
Transmission control systems - SW Arch	basic	

5.5 OUTCOMES & RECOMMENDATIONS & CONSTRAINTS FOR ECEPE

Table 9 summarizes the combined detail level (if more than 3 suggestions where on equal suggested detail level) and the number of mentions that the specifics sub-topic should be compulsory. This number can be interpreted as importance value of the topic for the ECEPE training materials.

Which indicates that the following **topics** are **of lowest importance**, according to the received feedbacks:

- Communication layers/means
- KERS / recuperation
- Cooling/Heating system (electronics/passenger)
- Mechanical storage systems
- Transmission control systems - HW
- Transmission control systems - SW Arch

While the following topics are of highest importance from the survey (4 or 5 mentionings):

- Overview on Specifics of automotive domain (complexity / safety / C2x / security)
- Overview on Standards / directives / regulations / HV & fire considerations
- Overview on V cycle development approach
- Novel E/E architectures
- Building blocks of ePowertrain (battery, eMotor, inverter, …)
- Signal flow / Interfaces Definitions (real-time thinking)
- eMotor / generator
- Hybrid control systems (eMotor/inverter/ECU) - SW Architecture
- Battery systems
- HV system thinking - isolation monitor

In general, the **feedback on the proposed curriculum structure** of the ECEPE training material was well appreciated and accepted; **no major topic lacking** has been identified and the **overall structure fits the general context** of automotive ePowertrain engineering. The questionnaire did not reveal any major missing points or shortcoming.

Table 9 Summary of survey feedbacks

	Detail level	compulsory knowledge
Intro		
Grant societal changes / drivers of change / environmental impact		1
Specifics of automotive domain (complexity / safety / C2x / security)	basic	5
Communication between players / customers (supply/value chain / separation of concerns)	detailed	3
V cycle development approach	detailed	4
Standards / directives / regulations / HV & fire considerations	detailed	5
Life Cycle (product / 2nd life / difference for spec. Parts)		2
Infrastructure (charging, service stations)		1
Vehicle		
Novel E/E architectures	detailed	5
ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)		3
Building blocks of ePowertrain (battery, eMotor, inverter, …)		5
Communication layers/means		0
Connected vehicle communication (e.g. maintenance)	detailed	3
EMC - Electromagnetic compatibility		1
Function-based-Development		
Focus on user functions rather than individual system components	detailed	3
Safety view point (systems design & item thinking)	detailed	2
Cyber-Security (basics of Design for CS & threat/attack surface thinking)	detailed	2
Signal flow / Interfaces Definitions (real-time thinking)	detailed	4
Propulsion systems		
eMotor / generator		5
Combustion engines / range-extender		3
Power electronics / inverters		3
Hybrid control systems (eMotor/inverter/ECU) - HW		1
Hybrid control systems (eMotor/inverter/ECU) - SW Arch		4
eMotor Control	detailed	3

KERS / recuperation		0
ePowertrain Auxiliary Systems		
Electric power converter -> low power systems		2
Cooling/Heating system (electronics/passenger)		0
Energy storage systems		
Battery	detailed	5
Fuel cell		1
Super capacitor		1
BMS - HW		1
BMS - SW	detailed	3
Mechanical storage systems		0
HV system thinking - isolation monitor		4
Life Cycle Management		
Intro to Life Cycle management		3
Product LC (design, usage, EoL)		3
Sustainability		1
Life cycle costing		3
Life cycle data management (data collection, feedback/optimising with fleet data feedback)		2
Life cycle Service Models / LC Business Models (novel approaches for earning money)		1
Transmission		
Transmission types (mechanical designs / changes due to hybridisation)		2
Transmission control systems - HW		0
Transmission control systems - SW Arch		0

6. MANAGEMENT AND PRODUCTION VIEW ON ELECTRIC POWERTRAIN ENGINEERING

The University of Applied Sciences Düsseldorf (HSD), Germany is responsible for the management and production view on the topic of electric powertrain-engineering. The aim of the questionnaire is to get a deeper knowledge on the topic from the view of different industries. To get an overall perspective the HSD contacted their network of different industries. The aim is to get as many different perspectives as possible. For the HSD the view of different viewpoints is more valuable than lots of participants. For the success of the project, it is necessary to collect and evaluate different viewpoints on the topic of electric powertrains in order to present tailored solutions. The different viewpoints, which are collected by the HSD, are from the automotive industry, from suppliers to the automotive industry, so called OEM (Original Equipment Manufacturer), from the agricultural machinery industry and from the research environment. To get a full view on the topic, all participants are experts in the field of electric powertrains and are working in the management or the production department.

In the following, a description of the survey with the results of every industry is given from point 6.1 onwards. Also, a summary of the gathered information is given in point 6.1.5. to complete the survey. From point 6.2 onwards, the outcomes of the survey and recommendations and constraints for the ECEPE project are stated.

6.1 DESCRIPTION OF THE SURVEY

In general, all answers to the questions were collected online in an anonymized form to secure data privacy. Tool of the survey is the platform umfrageonline.com. In total five participants from four different industries took part.

The survey at hand focusses on the management and production viewpoint on the topic. The survey is divided into four parts. The first part focusses on the participants and their expertise in their job area. Included here is the industry in which they are working in and how many years of expertise they actually have. This is a proof if they can be considered as relevant experts for our survey.

The second question is considered the most relevant in the survey, providing first-hand information which topics are relevant within the production and management process. The HSD expects to get a better knowledge on which topics should play a bigger role in designing the new course with regards to management and production view of the electric powertrain-development. The second question includes in total 27 parts of the electric powertrain-development which are deeply known in management and which are highly relevant within the production of ECEPE course material. The participants were asked to provide their opinion with a Likert scale from not important to very important for electric powertrain-development.

The third part of the survey focusses on different job roles and their linkage to the topics, which are necessary to fulfil the development of electric powertrains. The questions of part two and three deal with the same topic. The third question aims to assign different job roles to the topics. Job roles, which were assigned to the topic during the project meeting in Graz, are Software Engineer, System Engineer, Electric Engineer, Automotive Engineer and Industrial Engineer.

The last section of the survey contains two open questions regarding cross-domain- knowledge and sustainability, Corporate Social Responsibility (CSR) and financial issues in the field of electric powertrain engineering. The last section of the questionnaire aims to collect missing topics, which should be part of the final curriculum.

6.1.1 Automotive Industry Viewpoint

The project ECEPE is mainly designed to train future engineers who would like to work in the automotive industry in their professional future. Due to that, this point shows the answers on the survey at hand from a participant out of the automotive industry.

The participant from the automotive industry works in the production process of a German car manufacturer in Düsseldorf, which is also producing electric cars. The participant has more than five years of work experience and is therefore considered as an expert in the topic of electric powertrains.

Figure 49 shows the participant's answers to the question of which knowledge is necessary for the development of electric powertrains from the perspective of management and production.

As described in chapter 6.1 this question includes subject areas out of the topic of electric powertrain-development. The participants of the survey weighted these topics on a 5-part Likert scale from not important to very important. As mentioned above, the answers were given from the point of view of management and production. The answers therefore only represent necessary knowledge from this perspective. In total, 27 subject areas were asked and answered.

	Not Important (1)		Slightly Important (2)		Moderately Important (3)		Important (4)		Very Important (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	±
Societal and environmen...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Supply Chain / Value Cha...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Development procedure ...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Regulations (eg. safety, ...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Cyber-Security	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Infrastructure (charging ...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
ePowertrain architectur...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Building blocks of ePowe...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Electromagnetic compat...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
eMotor / generator	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Combustion engines (in c...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Hybrid control systems	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
eMotor control	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
KERS / recuparation	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Electric power converter	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Cooling/heating system	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Battery	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Fuel cell	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Battery management sys...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Life cycle management (...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Product life cycle	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
sustainability	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
life cycle costing	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle data managem...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
life cycle models	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
transmission types	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
transmission control sys...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00

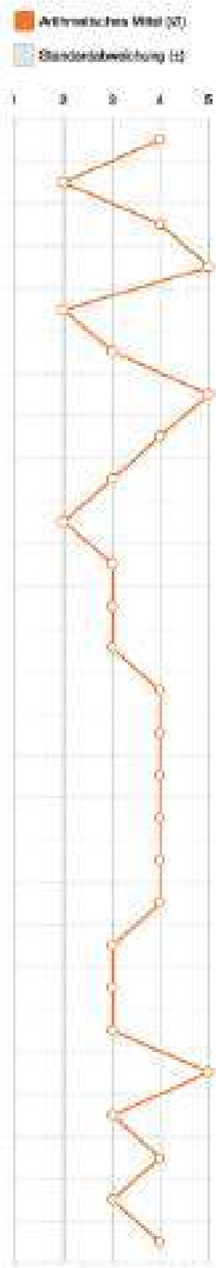

Figure 49 Needed knowledge ePowertrain development, automotive industry, management & production view

As shown in Figure 49 no subject area was evaluated as not important.

Nevertheless, three subject areas were rated as only slightly important. These areas were

- supply-chain/value-chain,
- cyber-security
- and the eMotor which is surprising.

The participant rated the following subject areas infrastructure (charging, service stations), electromagnetic compatibility, combustion engines (in case of range-extender), hybrid control systems, eMotor control, life cycle management, product life cycle, sustainability, life cycle data management and transmission types as moderately relevant.

Knowledge in the subject areas societal-/environmental-changes, development procedures, building blocks of electric powertrains, KERS / recuperation, electric power converter, cooling-/heating- system, battery, fuel cell, battery management system, life cycle models and transmission control systems was rated as important.

Knowledge in the subject areas regulations (e.g. safety and homologation), electric powertrain-architecture and life cycle costing was rated as very important.

To get an awareness about which job roles should be addressed with the course the aim of the second question is to assign the needed knowledge to the job roles.

Figure 50 shows the assignment of the knowledge to different job roles by the participant. The participant assigned at least one subject area to every job role.

Knowledge in the subject area cyber-security was assigned to software engineers.

Knowledge in the subject areas societal-/environmental-changes, supply-chain / value-chain, Infrastructure, life cycle management, product life cycle, sustainability, life cycle costing, life cycle data management and life cycle models was assigned to system engineers.

Knowledge in the subject areas electromagnetic compatibility, hybrid control systems, eMotor control, electric power converter and battery system management was assigned to electric engineers.

The following subject areas development procedures, regulations, electric powertrain-architecture, building blocks of electric powertrains, eMotor, combustion engines, KERS / recuperation, cooling-/heating- system, battery, fuel cell, transmission types and transmission control systems were assigned to automotive engineers.

The knowledge in the development of electric powertrains, which is assigned to industrial engineers according to the participant from the automotive industry, is not needed.

The participant from the automotive industry did not expect cross-domain knowledge beyond the named subject areas. Furthermore, the participant did not answer the question if sustainability, CSR and financial issues have to be considered by electric powertrain engineers.

	Software engineer (1)		System engineer (2)		Electric engineer (3)		Automotive engineer (4)		Industrial engineers (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	±
Societal and environmen...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Supply Chain / Value Cha...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Development procedure ...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Regulations (eg. safety, ...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Cyber-Security	1x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
Infrastructure (charging ...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
ePowertrain architectur...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Building blocks of ePowe...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Electromagnetic compat...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
eMotor / generator	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Combustion engines (in c...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Hybrid control systems	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
eMotor control	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
KERS / recuparation	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Electric power converter	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Cooling/heating system	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Battery	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Fuel cell	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Battery management sys...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Life cycle management (...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Product life cycle	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
sustainability	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
life cycle costing	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
life cycle data managem...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
life cycle models	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
transmission types	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
transmission control sys...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Mehrfachauswahl nicht m...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00

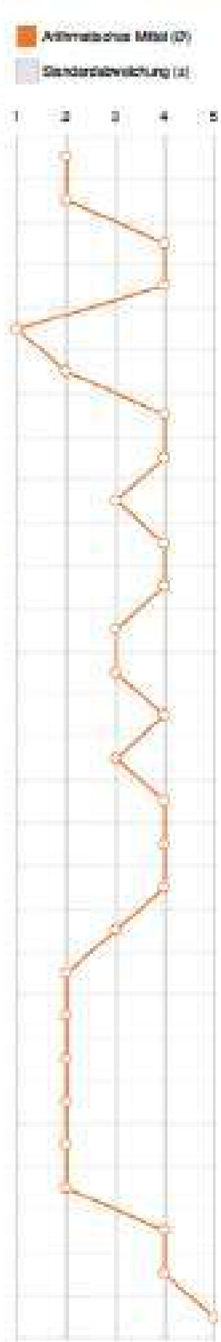

Figure 50 Typical job roles, automotive industry, management and production view

6.1.2 Supplier to Automotive Industry Viewpoint

Supplier are in close collaborations with the automotive industry. The supplier delivers many parts for electric powertrains and due to that, they need a deep knowledge in electric powertrain related topics.

This point shows the answers on the survey at hand from two participants from supplier to the automotive industry.

The two participants from the supplier area work in the management of their companies and deliver electronic components and further equipment to car manufactures such as the Audi AG. The work experience of the two participants is between three and five years. They are therefore considered as experts in the management of developing electric powertrains.

Figure 51 shows the participant's answers to the question of which knowledge is necessary for the development of electric powertrains from the perspective of management and production.

As described in chapter 6.1 this question includes subject areas out of the topic of the electric powertrain-development. The participants of the survey weighted these topics on a 5-part Likert scale from not important to very important. As mentioned above, the answers were given from the point of view of management and production. The answers can therefore only represent necessary knowledge from this perspective. In total, 27 subject areas were asked and answered by two participants who work in the supplier industry. To evaluate the answers from the view of supplier the average given answers are used. It is conspicuous that the individual answers differ a lot. For more detailed information please have a look at Figure 51.

On the average, no topic was rated as not important. The lowest average score is slightly important, which is five times the case in the topic’s development procedures, were reached by the subjects life cycle management, sustainability, life cycle costing and life cycle data management.

Ten times the average of the answers was between slightly important and moderately important. This is the case with the topics supply chain/value chain, infrastructure, electric powertrain-architecture, building blocks of electric powertrains, combustion engines, hybrid control systems, KERS / recuperation, product life cycle, life cycle models and transmission control systems.

The average of moderately important is selected seven times. Moderately important topics due to the answer are regulations, cyber-security, electromagnetic compatibility, eMotor, battery, battery management systems and transmission types.

The highest average score is 3.5, which is between moderately important and important. This score is reached five times in the topics societal-/environmental-changes, eMotor-control electric power converter, cooling/heating system and fuel cell.

	Not Important (1)		Slightly Important (2)		Moderately Important (3)		Important (4)		Very Important (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	±
Societal and environmen...	-	-	-	-	1x	50,00	1x	50,00	-	-	3,50	0,71
Supply Chain / Value Cha...	1x	50,00	-	-	-	-	1x	50,00	-	-	2,50	2,12
Development procedure ...	-	-	2x	100,00	-	-	-	-	-	-	2,00	0,00
Regulations (eg. safety, ...	1x	50,00	-	-	-	-	-	-	1x	50,00	3,00	2,83
Cyber-Security	1x	50,00	-	-	-	-	-	-	1x	50,00	3,00	2,83
Infrastructure (charging ...	1x	50,00	-	-	-	-	1x	50,00	-	-	2,50	2,12
ePowertrain architectur...	1x	50,00	-	-	-	-	1x	50,00	-	-	2,50	2,12
Building blocks of ePowe...	1x	50,00	-	-	-	-	1x	50,00	-	-	2,50	2,12
Electromagnetic compat...	-	-	1x	50,00	-	-	1x	50,00	-	-	3,00	1,41
eMotor / generator	-	-	1x	50,00	-	-	1x	50,00	-	-	3,00	1,41
Combustion engines (in c...	-	-	1x	50,00	1x	50,00	-	-	-	-	2,50	0,71
Hybrid control systems	-	-	1x	50,00	1x	50,00	-	-	-	-	2,50	0,71
eMotor control	-	-	1x	50,00	-	-	-	-	1x	50,00	3,50	2,12
KERS / recuparation	-	-	1x	50,00	1x	50,00	-	-	-	-	2,50	0,71
Electric power converter	-	-	1x	50,00	-	-	-	-	1x	50,00	3,50	2,12
Cooling/heating system	-	-	1x	50,00	-	-	-	-	1x	50,00	3,50	2,12
Battery	1x	50,00	-	-	-	-	-	-	1x	50,00	3,00	2,83
Fuel cell	-	-	1x	50,00	-	-	-	-	1x	50,00	3,50	2,12
Battery management sys...	1x	50,00	-	-	-	-	-	-	1x	50,00	3,00	2,83
Life cycle management (...	1x	50,00	-	-	1x	50,00	-	-	-	-	2,00	1,41
Product life cycle	1x	50,00	-	-	-	-	1x	50,00	-	-	2,50	2,12
sustainability	1x	50,00	-	-	1x	50,00	-	-	-	-	2,00	1,41
life cycle costing	1x	50,00	-	-	1x	50,00	-	-	-	-	2,00	1,41
life cycle data managem...	1x	50,00	-	-	1x	50,00	-	-	-	-	2,00	1,41
life cycle models	-	-	1x	50,00	1x	50,00	-	-	-	-	2,50	0,71
transmission types	-	-	1x	50,00	-	-	1x	50,00	-	-	3,00	1,41
transmission control sys...	-	-	1x	50,00	1x	50,00	-	-	-	-	2,50	0,71

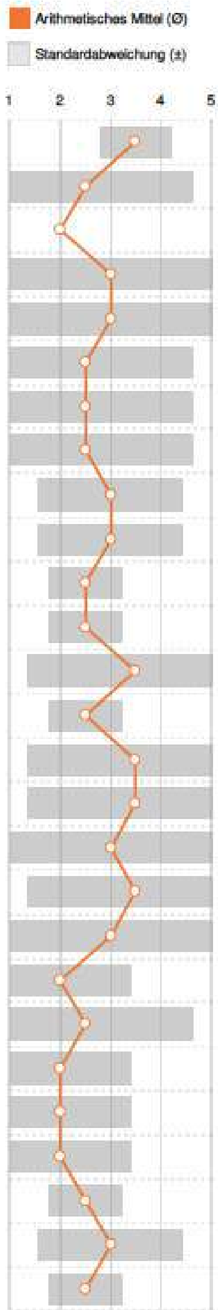

Figure 51 Needed knowledge ePowertrain development, supplier industry, management & production

The assignment from the topics to job roles only was fulfilled by one of the two participants. Due to that, the average in this case is also the exact answer from the participant.

To get an awareness about which job roles should be addressed with the course the aim of the second question is to assign the needed knowledge to the job roles.

Figure 52 shows the assignment of knowledge to different job roles by the participant. The participant assigned at least one subject area to every job role.

	Software engineer (1)		System engineer (2)		Electric engineer (3)		Automotive engineer (4)		Industrial engineers (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	s
Societal and environmen...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Supply Chain / Value Cha...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Development procedure ...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Regulations (eg. safety, ...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Cyber-Security	1x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
Infrastructure (charging ...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
ePowertrain architectur...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Building blocks of ePowe...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Electromagnetic compat...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
eMotor / generator	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Combustion engines (in c...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Hybrid control systems	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
eMotor control	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
KERS / recuparation	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Electric power converter	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Cooling/heating system	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Battery	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Fuel cell	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Battery management sys...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Life cycle management (...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Product life cycle	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
sustainability	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle costing	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle data managem...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle models	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
transmission types	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
transmission control sys...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00

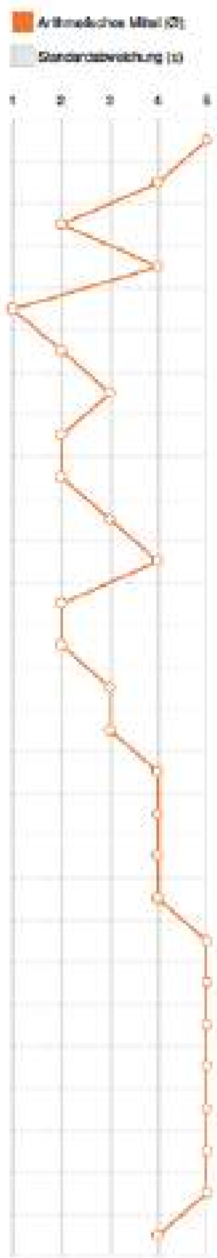

Figure 52 Typical job roles, supplier industry, management and production view

Knowledge in the subject area cyber-security was assigned to software engineers.

Knowledge in the subject areas development procedures, infrastructure, building blocks of electric powertrains, electromagnetic compatibility, hybrid control systems and eMotor control was assigned to system engineers.

Knowledge in the subject areas electric powertrain-architecture, eMotor, KERS / recuperation and electric power converter was assigned to electric engineers.

The following subject areas supply-chain/value-chain, regulations, combustion engines, cooling/heating systems, battery, fuel cell and battery management systems were assigned to automotive engineers.

The topics which are assigned to industrial engineers according to the participant are societal-/environmental-changes, life cycle management, product life cycle, sustainability, life cycle costing, life cycle data management, life cycle models and transmission types.

According to the participant, cross-domain knowledge in quality management is expected from ePowertrain engineers. Furthermore, the participant didn't answer the question of what sustainability, CSR and financial issues have to be considered by electric powertrain engineers.

6.1.3 Agricultural Machinery Industry Viewpoint

Electric mobility also has an influence on the agricultural machinery industry. Therefore, this part of the conducted survey lays eye on this industry and their viewpoint on this topic.

The participant from this branch has an expertise in his working environment of more than 5 years.

The first question of the survey is pointed at the needed knowledge to develop electric powertrains. In the following Figure 53 the 27 knowledge subject areas are listed together with their rating by the participant of the agricultural machinery industry showing what knowledge is important for electric powertrain engineers. These will be shown in more detail in the following.

	Not Important (1)		Slightly Important (2)		Moderately Important (3)		Important (4)		Very Important (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	±
Societal and environmen...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Supply Chain / Value Cha...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Development procedure ...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Regulations (eg. safety, ...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Cyber-Security	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Infrastructure (charging ...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
ePowertrain architectur...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Building blocks of ePowe...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Electromagnetic compat...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
eMotor / generator	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Combustion engines (in c...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Hybrid control systems	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
eMotor control	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
KERS / recuperation	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Electric power convertor	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Cooling/heating system	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Battery	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Fuel cell	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Battery management sys...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Life cycle management (...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Product life cycle	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
sustainability	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
life cycle costing	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
life cycle data managem...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
life cycle models	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
transmission types	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
transmission control sys...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00

Figure 53 Needed knowledge for ePowertrain development, management & production view

As the illustration shows, all of the presented subject areas/ skills seem to be at least moderately important for the electric powertrain-development. The participant classified 14 areas, so more than 50%, as very important. These include areas from different topics, ranging from economic state points, over electric engineering and information technology to mechanical engineering topics. Amongst other things the supply chain, cyber security, battery management systems and transmission typed were ranked as very important.

Going back from very important subject areas to important ones, it can be seen that one third of all areas were ranked on this level. Here the subjects reach from infrastructural issues (loading stations), over combustion engines to sustainability and life cycle costing, so in a range similar to the range of the very important subjects.

The last four subject areas, according to this participant, are moderately important. Here environmental and societal issues, as well as knowledge about the fuel cell and the life cycle management were ranked.

Coming from that first question, the second question of the survey uses the same knowledge subject areas to link them to different job roles. In Figure 54 you can see the participants view on what subject areas are important for what job roles.

	Software engineer (1)		System engineer (2)		Electric engineer (3)		Automotive engineer (4)		Industrial engineers (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	±
Societal and environmen...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Supply Chain / Value Cha...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Development procedure ...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Regulations (eg. safety, ...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Cyber-Security	1x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
Infrastructure (charging ...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
ePowertrain architectur...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Building blocks of ePowe...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Electromagnetic compat...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
eMotor / generator	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Combustion engines (in c...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Hybrid control systems	1x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
eMotor control	1x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
KERS / recuperation	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Electric power converter	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Cooling/heating system	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Battery	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Fuel cell	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Battery management sys...	1x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
Life cycle management (...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Product life cycle	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
sustainability	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle costing	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle data managem...	1x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
life cycle models	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
transmission types	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
transmission control sys...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00

Figure 54 Typical job roles management and production view

As you can see the five job roles, already described in 6.1.1, were used to be linked to the subject areas below. For the first three job roles, which will be described in the following, the distribution of the number of subject areas are almost equal.

Talking about software engineers, according to this participant, knowledge in cyber security, hybrid control systems, eMotor controls, battery management systems and life cycle data management seem to be important to this topic.

For system engineers the development procedure, different regulations (legal, safety etc.), the building blocks of an electric powertrain, knowledge about combustion engines and about recuperation seem to be important.

Having a look at the electric engineers of course, knowledge about the electric components is the most important part. Knowledge about electric power converter, the cooling and heating system, the battery, the eMotor/ generator, electromagnetic capabilities and the fuel cell are in focus. Furthermore, the general electric powertrain-architecture is important for these kind of engineers.

Now looking at the automotive engineers, according to the participants, only two subject areas, the transmission types and transmission control systems, are of relevance.

Finally yet importantly, the industrial engineers seem to need knowledge in most subject areas. Here the needed knowledge reaches from societal and environmental issues, over infrastructural topics to the whole concepts of life cycle management and its different models.

Following up to these two first questions, an open question regarding the consideration of sustainability, CSR and financial issues in the field of electric powertrain was asked. Here the participant pointed out that raw material sourcing, the sourcing countries and the salvage of used material need to be focussed on by engineers working in that field.

6.1.4 Research Viewpoint

In order to get information on how a curriculum for a course for electric powertrain engineers should look like, the view from researchers and university staff is crucial. The following paragraph will focus on this view by laying down the opinion of the survey's participant from university, which has also been working in this field for over 5 years.

As in the chapters before, at first we will focus on the importance of the knowledge subject areas presented in illustration of Figure 55.

	Not Important (1)		Slightly Important (2)		Moderately Important (3)		Important (4)		Very Important (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	±
Societal and environmen...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Supply Chain / Value Cha...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Development procedure ...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Regulations (eg. safety, ...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Cyber-Security	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Infrastructure (charging ...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
ePowertrain architectur...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Building blocks of ePowe...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Electromagnetic compat...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
eMotor / generator	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Combustion engines (in c..	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Hybrid control systems	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
eMotor control	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
KERS / recuparation	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Electric power converter	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Cooling/heating system	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Battery	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Fuel cell	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Battery management sys...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Life cycle management (...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Product life cycle	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
sustainability	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle costing	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle data managem...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle models	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
transmission types	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
transmission control sys...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00

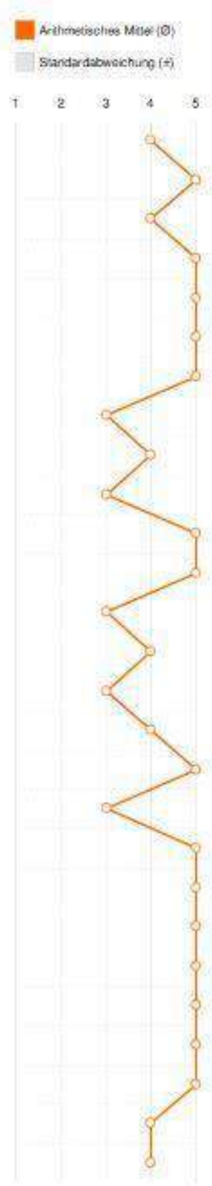

Figure 55 Needed knowledge for ePowertrain development, management & production view

As can be seen from this participants point of view, every subject area is at least moderately important as well, although more than 50% are ranked as very important.

Five out of the 27 subject areas were ranked as moderately important. These where the building blocks of electric powertrains, the e-Motor/generator, e-Motor control, electric power converter and the fuel cell.

Ranked as important were broader subject areas, reaching from societal and environmental issues, over electromagnetic capabilities to the transmission types and transmission control systems.

Now coming to the most dominant part, the subject areas ranked as very important. Here the range of areas is also very broad and the focus lies on every of these subject areas. The supply chain, cyber security, combustion engines, batteries as well as life cycle management are here from importance, according to the participant.

Coming from that first question, the second question of the survey uses the same knowledge subject areas to link them to different job roles. In Figure 56 you can see the participants view on what subject areas are important for what job roles.

As you can see, the classification of the job roles are obviously the same as in the sub chapter before. Here the distribution is not as equal as in the chapter beforehand. From this participants point of view 1/3 of the knowledge subject areas are linked to industrial engineers, such as the societal and environmental issues, the development procedure as well as the whole concept of life cycle management.

For automotive engineers amongst others the subject areas of regulations (legal/safety etc.), the architecture of electric powertrains, hybrid control systems and transmission types are of interest.

The subject area of electronics and its sub areas of electromagnetic compabilities, e-Motors, e-Motor control, recuperation systems and electric power converter are of interest for electric engineers.

On the other hand, combustion engines, also in combination with e-Motors, cooling/heating systems, batteries, fuel cell and battery management systems are relevant for system engineers, according to the participant from the research area.

Finally yet importantly, the subject of cyber security is of relevance for software engineers.

The last section of the survey, following up on the first two questions, contains two open questions. These are about what cross-domain knowledge is expected from an engineer in electric powertrain development and again about the sustainability, CSR and financial issues.

	Software engineer (1)		System engineer (2)		Electric engineer (3)		Automotive engineer (4)		Industrial engineers (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	±
Societal and environmen...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Supply Chain / Value Cha...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Development procedure ...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Regulations (eg. safety, ...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Cyber-Security	1x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
Infrastructure (charging ...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
ePowertrain architectur...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Building blocks of ePowe...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Electromagnetic compat...	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
eMotor / generator	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Combustion engines (in c...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Hybrid control systems	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
eMotor control	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
KERS / recuparation	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Electric power converter	-	-	-	-	1x	100,00	-	-	-	-	3,00	0,00
Cooling/heating system	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Battery	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Fuel cell	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Battery management sys...	-	-	1x	100,00	-	-	-	-	-	-	2,00	0,00
Life cycle management (...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Product life cycle	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
sustainability	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle costing	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle data managem...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
life cycle models	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
transmission types	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
transmission control sys...	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00
Quality	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00

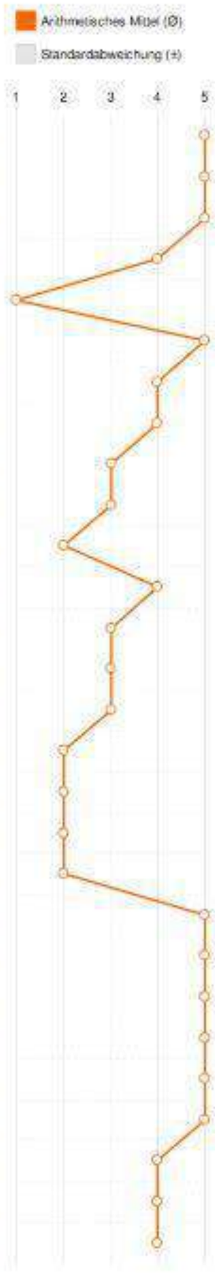

Figure 56 Typical job roles management and production view

As cross-domain, knowledge stated here is the quality management, which should also be included in the curriculum for an electric powertrain engineer. Talking about the sustainability, CSR and financial issues and the economic calculation of the processes need to be talked about.

6.2 OUTCOMES & RECOMMENDATIONS & CONSTRAINTS FOR ECEPE

As a conclusion of the conducted survey, a summary of all results will be presented as well as a few points, which need to be discussed in a more detailed way.

In the following, the complete survey with all average scores will be presented to get a general overview of the needed knowledge and the assigned job roles. After that, an interpretation and discussion form the author's side will be given to finalize the outcomes into recommendations and constraint for ECEPE.

As can be seen, the chapter before the distribution of the participants is almost equally spreaded across the different industries. Two participants were suppliers for the automotive industry and one participant each from automotive industry, research and agricultural machinery industry. All of the participants were experts in their field and have job experiences of one to more than five years.

In order to evaluate the outcomes of the survey the average score will be used and the individual answers can be seen in Figure 57.

As can be seen in Figure 57 no average score lies under 3,0 which is moderately important. Every individual subject area has their reason to be listed and to be considered for the curriculum of the ECEPE project. Only 5 out of the 27 subject areas were able to get a score above 4,0, which are covering the topics of batteries, safety regulations and the e-Powertrain architecture. Derived from these results, these topics seem to be the most important ones and therefore need to be focused on in a course.

The distribution of the participants imply that in every industry more or less knowledge in the same subject areas is needed. This shows there is demand for such a course in every questioned industry so that these industries should be addressed while compiling such a course.

Coming from the needed knowledge to the assignment of the different job roles, Figure 57 shows this connection in detail.

	Not Important (1)		Slightly Important (2)		Moderately Important (3)		Important (4)		Very Important (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	σ
Societal and environmen...	-	-	-	-	2x	40,00	3x	60,00	-	-	3,60	0,55
Supply Chain / Value Cha...	1x	20,00	1x	20,00	-	-	1x	20,00	2x	40,00	3,40	1,82
Development procedure ...	-	-	2x	40,00	-	-	3x	60,00	-	-	3,20	1,10
Regulations (eg. safety, ...	1x	20,00	-	-	-	-	-	-	4x	80,00	4,20	1,79
Cyber-Security	1x	20,00	1x	20,00	-	-	-	-	3x	60,00	3,60	1,95
Infrastructure (charging ...	1x	20,00	-	-	1x	20,00	2x	40,00	1x	20,00	3,40	1,52
ePowertrain architectur...	1x	20,00	-	-	-	-	1x	20,00	3x	60,00	4,00	1,73
Building blocks of ePowe...	1x	20,00	-	-	1x	20,00	2x	40,00	1x	20,00	3,40	1,52
Electromagnetic compat...	-	-	1x	20,00	1x	20,00	2x	40,00	1x	20,00	3,60	1,14
eMotor / generator	-	-	2x	40,00	1x	20,00	1x	20,00	1x	20,00	3,20	1,30
Combustion engines (in c...	-	-	1x	20,00	2x	40,00	1x	20,00	1x	20,00	3,40	1,14
Hybrid control systems	-	-	1x	20,00	2x	40,00	1x	20,00	1x	20,00	3,40	1,14
eMotor control	-	-	1x	20,00	2x	40,00	-	-	2x	40,00	3,60	1,34
KERS / recuperation	-	-	1x	20,00	1x	20,00	3x	60,00	-	-	3,40	0,89
Electric power converter	-	-	1x	20,00	1x	20,00	1x	20,00	2x	40,00	3,80	1,30
Cooling/heating system	-	-	1x	20,00	-	-	2x	40,00	2x	40,00	4,00	1,22
Battery	1x	20,00	-	-	-	-	1x	20,00	3x	60,00	4,00	1,73
Fuel cell	-	-	1x	20,00	2x	40,00	1x	20,00	1x	20,00	3,40	1,14
Battery management sys...	1x	20,00	-	-	-	-	1x	20,00	3x	60,00	4,00	1,73
Life cycle management (...	1x	20,00	-	-	3x	60,00	-	-	1x	20,00	3,00	1,41
Product life cycle	1x	20,00	-	-	2x	40,00	1x	20,00	1x	20,00	3,20	1,48
sustainability	1x	20,00	-	-	2x	40,00	1x	20,00	1x	20,00	3,20	1,48
life cycle costing	1x	20,00	-	-	1x	20,00	1x	20,00	2x	40,00	3,60	1,67
life cycle data managem...	1x	20,00	-	-	2x	40,00	1x	20,00	1x	20,00	3,20	1,48
life cycle models	-	-	1x	20,00	1x	20,00	2x	40,00	1x	20,00	3,60	1,14
transmission types	-	-	1x	20,00	1x	20,00	2x	40,00	1x	20,00	3,60	1,14
transmission control sys...	-	-	1x	20,00	1x	20,00	2x	40,00	1x	20,00	3,60	1,14

Figure 57 Overall view of needed knowledge

	Software engineer (1)		System engineer (2)		Electric engineer (3)		Automotive engineer (4)		Industrial engineers (5)			
	Σ	%	Σ	%	Σ	%	Σ	%	Σ	%	Ø	±
Societal and environmen...	-	-	1x	25,00	-	-	-	-	3x	75,00	4,25	1,50
Supply Chain / Value Cha...	-	-	1x	25,00	-	-	1x	25,00	2x	50,00	4,00	1,41
Development procedure ...	-	-	2x	50,00	-	-	1x	25,00	1x	25,00	3,25	1,50
Regulations (eg. safety, ...	-	-	1x	25,00	-	-	3x	75,00	-	-	3,50	1,00
Cyber-Security	4x	100,00	-	-	-	-	-	-	-	-	1,00	0,00
Infrastructure (charging ...	-	-	2x	50,00	-	-	-	-	2x	50,00	3,50	1,73
ePowertrain architectur...	-	-	-	-	2x	50,00	2x	50,00	-	-	3,50	0,58
Building blocks of ePowe...	-	-	2x	50,00	-	-	2x	50,00	-	-	3,00	1,15
Electromagnetic compat...	-	-	1x	25,00	3x	75,00	-	-	-	-	2,75	0,50
eMotor / generator	-	-	-	-	3x	75,00	1x	25,00	-	-	3,25	0,50
Combustion engines (in c...	-	-	2x	50,00	-	-	2x	50,00	-	-	3,00	1,15
Hybrid control systems	1x	25,00	1x	25,00	1x	25,00	1x	25,00	-	-	2,50	1,29
eMotor control	1x	25,00	1x	25,00	2x	50,00	-	-	-	-	2,25	0,96
KERS / recuparation	-	-	1x	25,00	2x	50,00	1x	25,00	-	-	3,00	0,82
Electric power converter	-	-	-	-	4x	100,00	-	-	-	-	3,00	0,00
Cooling/heating system	-	-	1x	25,00	1x	25,00	2x	50,00	-	-	3,25	0,96
Battery	-	-	1x	25,00	1x	25,00	2x	50,00	-	-	3,25	0,96
Fuel cell	-	-	1x	25,00	1x	25,00	2x	50,00	-	-	3,25	0,96
Battery management sys...	1x	25,00	1x	25,00	1x	25,00	1x	25,00	-	-	2,50	1,29
Life cycle management (...	-	-	1x	25,00	-	-	-	-	3x	75,00	4,25	1,50
Product life cycle	-	-	1x	25,00	-	-	-	-	3x	75,00	4,25	1,50
sustainability	-	-	1x	25,00	-	-	-	-	3x	75,00	4,25	1,50
life cycle costing	-	-	1x	25,00	-	-	-	-	3x	75,00	4,25	1,50
life cycle data managem...	1x	25,00	1x	25,00	-	-	-	-	2x	50,00	3,25	2,06
life cycle models	-	-	1x	25,00	-	-	-	-	3x	75,00	4,25	1,50
transmission types	-	-	-	-	-	-	3x	75,00	1x	25,00	4,25	0,50
transmission control sys...	-	-	-	-	-	-	4x	100,00	-	-	4,00	0,00
Mehrfachauswahl nicht m...	-	-	-	-	-	-	-	-	1x	100,00	5,00	0,00
Quality	-	-	-	-	-	-	1x	100,00	-	-	4,00	0,00

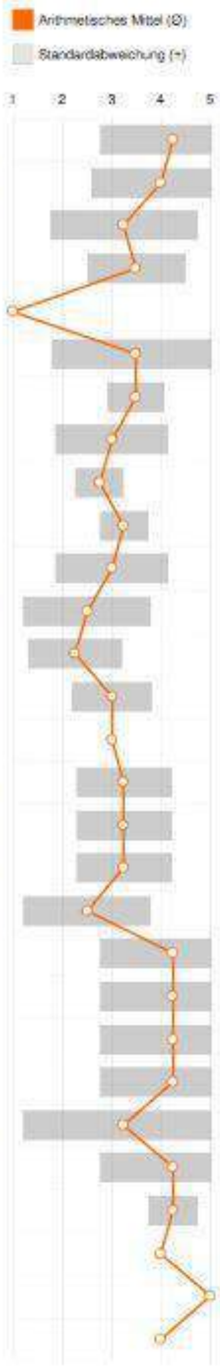

Figure 58 Connection of knowledge and job roles

As can be seen in the Figure 58 above, every listed job role is of importance for the development process of electric powertrains. On the contrary to the survey the HSD, which is expert on life cycle management, is of the opinion that every life cycle including topics should be assigned to the working files of industrial engineers. Due to a lack of information of the participants knowledge, the HSD thinks that their might have been a confusion concerning the terms of industrial engineering and the German pendant of “Wirtschaftsingenieur”. No other of the listed job roles has a deeper knowledge on life cycle management due to the fact that their studies are technically based and do not focus on economical topics in depth.

In addition to these results, further knowledge in quality management, raw material sourcing, sourcing countries and salvage of used material should be included in the curriculum of such a course.

To sum this topic up, from a management and production view the preliminary work in the project was successful due to a broad coverage of all necessary subject areas.

7. SUMMARY & CONCLUSION

As presented in the previous sections, the new ePowertrain concept comes not only from the need of the clean mobility, but also from the structural changes and new technologies drivers of change. More generally, it is one of the very specific domain concepts combining the needs of the new modern, clean, digital, and competitive solutions for the future of mobility. ePowertrain competence is a very needed nowadays and the ECEPE project approach is a possible reaction to that.

Regarding the training mechanism, concept of work-based learning combined with online training is taken into account and skills definitions and training materials of the ECEPE project should reflect that.

The survey shows that electric powertrain engineering is a job role where the industry expects a retraining of SW, HW, and electric engineers with specific focus on topics depending on different the business fields.
The survey of stakeholders clearly indicate that tailoring of the topics is of utmost importance, as well as, a general adaptation on the audience.

Generally, the following topics are of highest importance for all surveyed parties:

- Overview on Standards / directives / regulations / HV \& fire considerations
- ePowertrain architectures (BEV, HEV, plugin HEV, fuel cell EV, in-wheel concepts)
- Building blocks of ePowertrain (battery, eMotor, inverter, etc.)
- Signal flow / Interfaces Definitions (real-time thinking)
- Hybrid control systems (eMotor/inverter/ECU) - SW Architecture
- Safety view point (systems design & item thinking)
- eMotor / generator control
- Battery systems

The feedback on the proposed curriculum structure of the ECEPE training material was well appreciated and accepted; no major topic lacking has been identified and the overall structure fits the general context of automotive ePowertrain engineering. The questionnaires did not revile any major missing points or shortcoming. The distribution of the participants imply that in every industry more or less knowledge in the same subject areas is needed. This shows there is demand for such a course in every questioned industry so that these industries should be addressed while compiling such a course.

In addition to these results, further knowledge in quality management, raw material sourcing, sourcing countries and salvage of used material should be included in the curriculum of such a course. In addition, from the literature review and the conducted meetings and interviews, it can be concluded that the standard requirements for the commercial vehicle and racecar electric powertrain engineers are the same as for passenger cars.

Nevertheless, it is important in terms of environmental protection and the introduction of increasingly stringent emission requirements that are generate not only by the cars themselves, but also in the production of electricity, hydrogen, alternative fuels, etc. In order to minimize the losses of a single car (electric vehicle) under different driving modes, are examined all factors that influence them more or less. Along with issues related to the electrical part also, factors related to the construction of the mechanical part and the exploitation of the vehicle need to be taken into account.

This includes also basic questions of the vehicle theory and design as:

- Impact of weight of construction
- Influence of mass inertia of the rotating parts
- Types of moving resistance and performance factors
- Friction losses and hydraulic losses in transmission
- Gearbox Selection - Regarding the control, type and range

Regarding the training mechanism, concept of work-based learning combined with online training is taken into account and skills definitions and training materials of the ECEPE project should reflect that. The aim of this analysis was to establish a basis of skills required by those companies, which are developing electric powertrain solutions of the future and develop an adequate training concept for future electric powertrain engineers. The target audience for the training material is related to higher education of students participating in any automotive related courses program.

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ECEPE

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ABBREVIATIONS

Abbreviation	Meaning
µC	Micro-Controller
AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
ADAS	Advanced Driver Assistance Systems
AUCEN	Austrian University Continuing Education and Staff Development Network
BEV	battery electric vehicle
bhp	brake horsepower
BMS	battery management system
BN	Business Need
C2x	car to anything communication
CCS	Carbon capture and storage
Cd	drag coefficient
CFRP	Carbon Fiber Reinforced Polymer
CLEPA	European Association of Automotive Suppliers
CNG	Compressed Natural Gas
CO2	carbon dioxide
CS	cyber-security
CSR	corporate social responsibility
CUTE	Clean Urban Transport in European
CVT	continuously variable transmission
DC	Direct current
DHT	Dedicated Hybrid Transmissions
DoC	Driver of Change
E/E	electric and electronic
ECEPE	ECQA Certified Electric Powertrain Engineer
ECQA	European Certification and Qualification Association
ECU	Electronic Control Unit
EMC	electromagnetic compatibility
EoL	end of life
EQF	European Qualifications Framework for Lifelong Learning
ETRMA	European Tyre & Rubber Manufacturers Association
EU	European Union
EV	electric vehicle
EVIC	Electric Vehicles Industrial Cluster
eWRX	electro World Rally championship
FESS	Flywheel energy storages
FEV	fully electric vehicle
FFG	Austrian Research Promotion Agency
FIA	Fédération Internationale de l'Automobile
GHG	Green House Gas
HEV	hybrid electric vehicle
HSD	University of Applied Science Düsseldorf
HV	high voltage
HVO	Hydro treated Vegetable Oils
HW	Hardware
ICE	internal combustion engine
IGBT	insulated-gate bipolar transistor
IoT	Internet of Things
KERS	kinetic energy recovery system
KPI	Key Performance Indicator
LC	life cycle
LHV	low heating value
LLL	TU Graz Life Long Learning

LNG	Liquefied Petroleum Gas
LPG	liquefied petroleum gas
MCU	motor control unit
MGU	motor generator unit
OEM	original equipment manufacturer
OLEV	On-Line Electric Vehicle
PMSM	Permanent Magnets Synchronous Motors
R&D	research & development
SAE	Society of Automotive Engineers
SME	Small & Medium-sized Enterprises
SoA	Service oriented Architectures
SoC	State of Charge (battery)
SoH	State of Health (battery)
SUV	sports utility vehicle
SW	Software
TCO	total cost of ownership
Tier	automotive supplier
TRL	technology readiness level
TUV	Technical inspection association (Germany)
UOG	Universities Organisation Act
V cycle	system life cycle process model
VET	Vocational Educational Training