Training Guide

Module 1:
Engineering Trends

Implementation:

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in Bahia Blanca, Argentina

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Overview

1 Introduction

Module one is dedicated to “Engineering Trends”. It will start with a general introduction of most recent trends and will afterwards treat the topics which have been identified as to be most interesting to our partner institutions – the target group of the ASCENT project.
First FH JOANNEUM from Austria will start the first training by introducing ICE trends and discuss trends related to electric as well as full cell powertrain. Afterwards advanced vehicle aspects and trends are on the agenda. These include trends in body design and in hybrid architectures. Hochschule Düsseldorf from Germany will further continue with the newest trends in production and innovation. Thereby especially inputs and challenges of industry 4.0, the digital factory and agile production are part of these topics. Last but not least partners have expressed their interest and the high importance of quality management in the automotive industry and would like to know in which direction developments might lead us and how effective quality management can be taught at local HEIs (higher education institutions).

1.1 Learning objectives

After attending this training, students (participants) should have better insight what the current state-of-the-art and also the upcoming trends in the automotive industry are.
The training will show examples of current technology, discuss strengths and weaknesses and show possible future improvements and replacements. The focus of this training will be put on power train architectures (concepts and technologies for conventional, electric and hybrid power trains) and advanced vehicle technologies like lightweight design and other innovations.
At the end of this training the participants will be able to compare different technologies and trends and will have a better understanding of their impact on the environment, development effort, production challenges and the experience/feeling for the driver.

1.2 Methodology & Concept

The training will make use of an interactive didactical approach to get the participants involved as much as possible.
Each topic of the training will be presented briefly by the trainers to get all participant on the same level of knowledge. The presentation will be followed up by group activities or discussions. This way it will also be possible to get involved in individual questions that might come up some topics.
Furthermore, the topics and discussions itself are focused on contemporary questions and problems of current engineering processes, this should increase the motivation of the participants to contribute actively in the discussions and activities.
The trainers will also try to link the different topics together as much as possible, as this greatly contributes to get the necessary overview on the current trends in engineering.

Next to the pure technical approach, the training will also take a look on surrounding topics like:

- Drivers for change (climate change, legislation, …)
- Future mobility scenarios (electrified – automated – connected)
- Change of business models (car makers become mobility provider)
- Customer requests (shared mobility, low running costs, …)

3 Engineering Trends in Automotive Development

Trends exist in all areas of life, not only in engineering, but also in economics, politics, science, technology and culture. And all the trends are connected somehow over all areas, influence each other and are equal when it comes to their importance, which can be seen on the following figure. For example, the increasing number of people living in cities is caused by the trend "urbanization". In turn, the higher amount of people on constant amount of space causes changed requirements for mobility, which is one of the trends in engineering.

Figure 1 global mega trends overview (Source: Nasscom)

However, innovation should always be based on those trends to fulfill technological standards, economic necessity and to meet the customers' desires and legal requirements. (Nasscom 2017)

The most obvious trends in automotive engineering, we are experiencing right now are listed in Figure 1:

Figure 2: Electrified, automated and connected (Source: Bosch)

In the following chapter a special focus will be placed at powertrain development, as the powertrain also affects the most critical issues such as CO2 emissions.

But also trend in body manufacturing and the current hype regarding driver assistance function leading finally to automated cars will be presented.

3.1 Powertrain

In general, an increased diversification of powertrain variants can be forecasted. Especially due the demanded worldwide CO2 reduction, only intensified electrification of powertrains can fulfill the envisaged CO2 fleet emissions ensuring the climate goals for 2050.

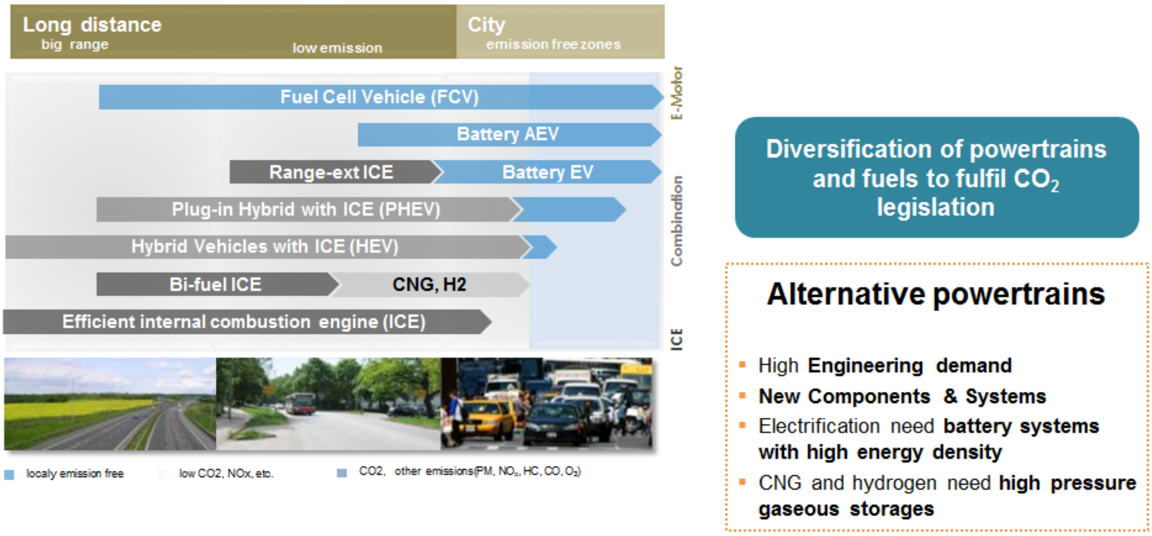

Figure 3: Forecasted powertrain diversification in different traffic zones

In the recent years a trend can be seen, that even Communities start with their own emission legislation and restrict the entrance of “polluting” vehicles to their territory. This trends started with congestion charges (London), banning older diesel engines (German cities) etc. As can be seen from Figure 1 only vehicles with a high electrification will survive in cities in the long term. Especially vehicles with ice will be banned from cities and will be only used for long distance driving. In all respects and disciplines – at least from today’s view – the fuel cell electric vehicle will be the most promising solution for the future.

3.1.1 ICE Trends: Efficiency increase and environmental protection

The conventional ice driven powertrain is experiencing increasing political pressure. First of all, because of the continued use of limited fossil fuels. It is meanwhile understood that the availability of fossil fuels will be limited and could be also regarded as a waste and is furthermore one of the major contributor of global warming by its CO_2 emissions. Second the Volkswagen NOx scandal – VW and others were using cheating software in their emission control systems, which produced less NOx emission and higher CO_2 while tested, but higher NOx and less CO_2 (better fuel consumption) in real life driving.

The consequences are severe: the governments change and intensify the testing schemes and their checking activities. Together with the dawn of the electrification age, most OEMs reduce or even stop new development activities for new generations of ice. This will have negative impact on existing production plants, jobs, sales and service organizations.

Although nobody can imagine a transportation world without ices at the moment, the trend goes to electrification – at least in form of hybrids – especially Plug-In- Hybrids (PHEV) where the ice engine is operating in a limited operational range, especially for long distance, whereas for urban driving the electric powertrain is used.

Ice's in general will be used in operating regimes where they have their biggest advantages: long distance and high power (torque) demand.

How will the future ice population look like?

In the lower power demand application area spark ignited engines will dominate. This not only refers to motorcycles but also to small and medium cars. Fuel will gradually change from fossil (gasoline) to renewable bio-fuels such as ethanol and methanol.

Many analysts assume that the diesel engine will not survive in the displacement range below 2 liter swept volume for passenger cars, although from CO_2 standpoint these engines have still a 10 to 20% advantage over spark ignited engines. This is due to the higher costs especially for the sophisticated injection and aftertreatment systems and also due to their inherent NOx behavior. In the field of long-haul trucks, ships and in remote power generation, where high power over a longer time period is required, the diesel engines will survive much longer than in the passenger cars.

Anyhow – also beyond the year 2050 – there is strong believe that optimized ice engines will be operated in passenger car hybrid models, heavy duty powertrains such as long haul trucks, locomotives, ships, aero applications and stationary applications.

The target of research activities all over the world must be efficiency increase and to achieve "zero-impact emissions". This can be achieved also by the introduction of bio and synthetic fuels. A CO_2-lean or CO_2-free fuel can be more efficient and environmental friendlier than a pure electric propulsion system.

General improvement measures for all ice engines

As CO_2 emissions and fuel consumption are directly linked together, there is big demand for ice engines to reduce fuel consumption. The major engineering trends in this field are:

- **"right sizing"**: this is a combination of "downsizing" (using the smallest possible displacement for the required performance and "down speeding" (designing engines for reduced rated speed and higher low end torque).

- **Friction reduction** by new materials and coatings not only in the ice engine (in combination with down speeding, which is a measure for friction reduction too) but also in the transmission

- **Improve thermodynamics** of the engine's processes such as reduction of wall heat losses, better heat management systems, introduction of Rankine processes and other waste energy recovery processes etc.

- **Increase variability's** in the ice engine such as variable compression ratio, variable auxiliaries (demand driven by electrification and demand driven control systems) such as variable oil pumps, water pumps and generators.
- **New combustion systems** both engine types could make use of advanced combustion systems which would offer extremely low engine out emissions. These combustions systems aim for air/fuel ratio and temperature ranges where NOx and Soot formation is not

possible. Unfortunately, these combustions systems suffer still from two shortcomings: they are not feasible across the whole engine map and they need sophisticated and expensive control, i.e. for EGR (exhaust gas recirculation).

- **Supporting technology developments in transmissions,** which helps to operate the ice engines in the best efficiency operating area

- **Enforced development activities for synthetic fuels** and their production processes for the sake of global CO_2, improvement of combustion characteristics and reduction of local toxic emissions.

Further all ice engines are undergoing developments for further **reduction of toxic emissions**, that means further development of aftertreatment systems (improving working range, and most important improved control etc);

Gasoline specific

Measures on gasoline engines focus to improve fuel consumption (=CO_2) and to improve exhaust aftertreament systems. The efficiency increase could be achieved i.e. by variable compression, reduced wall heat etc.
The following sketch shows an example how such a variable compression ratio can be achieved:
Example: telescopic con rod:

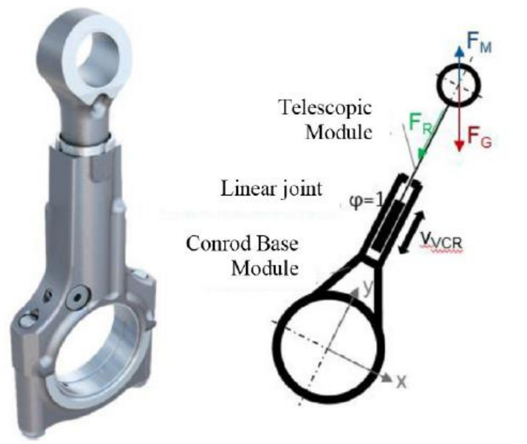

Abb. 2-1: Prinzipskizze Dual Mode VCS™ (Hüttner *et al.* 2018)

Figure 4: Telescopic con rod for enabling two compression ratio's

Emission reductions are focusing at the cold start and warm up phases where the majority of emissions are emitted. After the warm up the emissions are more or less extincted by the three-way catalyst, when the engine follows a □=1 concept.

In case of a lean burn concept, the NOx in the exhaust must be treated by the DeNOx catalyst, which stores the NOx with Barium and after being filled up, a regeneration phase with rich fuel mixture is needed. During this period the fuel consumption is bad. Hydrocarbons from oil and fuel are being treated by an oxidation catalyst.

Nowadays more and more engines use direct injection due to better efficiency/better fuel consumption. This is mainly a result of in-cylinder-cooling by the injected fuel. Due to the fact that in these engines the fuel/air mixture process is much shorter than with homogeneous charge engines, the combustion process becomes inhomogeneous and particles like in the diesel engines are produced. These particles in number and size become more and more a problem and led to the requirement of particulate filters.
So current R&D activities focus on the appropriate application of particulate filters, their regeneration and long-time stability/aging.

Diesels specific

The focus of diesel engines is on NOx emission reduction without losing the advantages in fuel consumption compared to spark ignited engines.

In general, the NOx emissions of a diesel engine can be reduced by the following measures:

- <u>Retarded injection timing</u>: disadvantage is worse fuel consumption (the center of gravity of the combustion moves to away from the thermodynamic optimum), increased soot emissions; combustion noise is improved

- <u>Exhaust gas recirculation</u>: disadvantage is increased soot (Particulate Matter) emissions and worse fuel consumption

- <u>DeNOx catalyst</u>: seldom used with diesels; stores NOx and needs regeneration with rich fuel mixture from time to time

- <u>SCR</u> (Selective Catalytic Reduction) System. This aftertreatment system allows advanced fuel injection settings (=good fuel consumption) and relative high engine out NOx emissions, which can be reduced in the subsequent SCR system by the adding of UREA (commercially sold as “adBlue”) to the exhaust gas

Focus of current developments are further optimization especially of the SCR Systems to improve dosage of adBlue and minimize the slip of ammonia (NH3).

Figure shows an advanced diesel exhaust aftertreatment system with DOC (Diesel Oxidation Catalyst), DPF (Diesel Particulate Filter), SCR Catalyst and ASC (Anti-Slip Catalyst for NH3). Furthermore, a sophisticated control system using a model based approach for the SCR is shown.

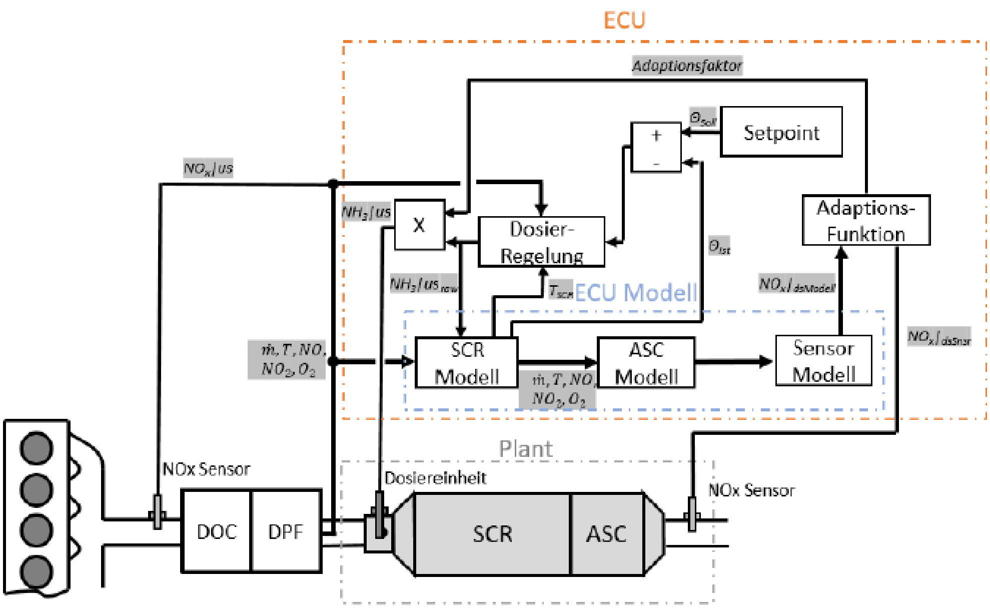

Figure 5: modern Diesel aftertreatment system with 4 catalysts and improved control measures (Source: Buchrieser/AVL)

sehr neu, BAC Arbeit? Besser etwas neutraleres

Very important to make a Diesel environmentally accepted was the introduction of particulate filters. The application of the various particulate filters seems to be rather settled at the moment, not so much development activities can be sensed. Anyhow the full diesel exhaust gas aftertreament system's complexity has reached a level which is barely manageable and explains the cost penalty of the compression ignited diesel engines compared to the spark ignited engines especially with smaller displacements, which are more cost sensitive than bigger engines like truck engines.

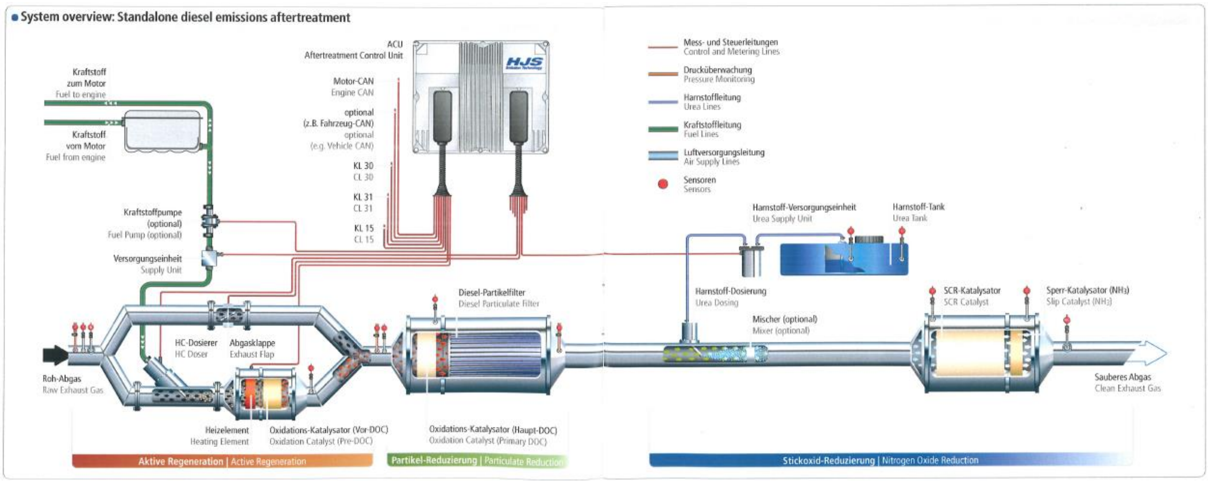

Figure 6: Full Diesel aftertreatment system from HJS (Source HJS)

Future combustion systems

In the recent years a lot of research was done for alternative combustion systems with the target to reduce to toxic engine out emissions without degrading the fuel consumption too much.

The target is to achieve extremely low engine out NOx and Soot emissions. As can be seen in Figure combustions systems aim for air/fuel ratio and temperature ranges where NOx and Soot formation is not possible. Unfortunately, these combustions systems suffer still from two shortcomings: they are not feasible across the whole engine map and they need sophisticated and expensive control, i.e. for EGR (exhaust gas recirculation).

And indeed when the local air/fuel ratio and the local flame temperatures are in a special window, NOx emissions can be drastically reduced and the emission of particulate can be avoided. Figure 6 shows this area and the location of the different combustions processes, listed besides.

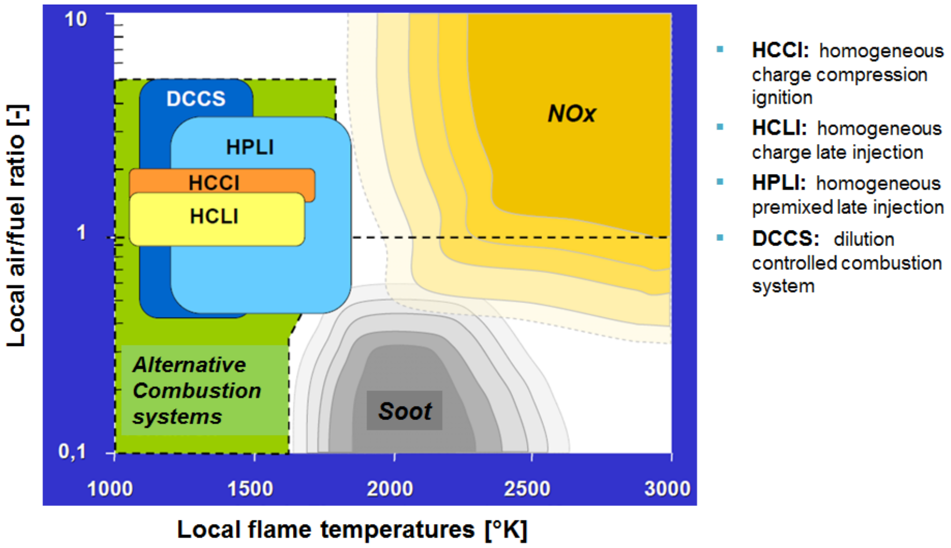

Figure 7: Area of the alternative combustion systems in the fuel ratio/flame temperature map

These combustions systems would be real advantageous; unfortunately, there are some draw-backs. So far they did not find the way into series application in internal combustion engines due to the following reasons:

- The application is only possible in part load conditions (do not work at higher loads that means the engine must return to conventional combustion system after passing a certain load threshold)
- These combustion system work with high EGR (exhaust gas recirculation) rates which require a very accurate control which is not easy for EGR
- Very accurate and expensive–closed loop- control systems are required using expensive and sensitive sensors such as pressure indication sensors at each cylinder. These sensors are suitable for laboratory use but not reliable for a whole engine life. Although intensive research work had been done on these topics so far a breakthrough did not happen and gives room for next generation of researchers.

New fuels (CO_2 neutral)

In Europe there is an ongoing discussion how to reduce CO2 emissions until 2050. The most likely answer to this questions is to completely step out of fossil fuels usage.
An alternative to liquid fossil fuels are so called bio-fuels of the 2nd or 3rd generation, which do not use food stock (ethical concerns) but waste from agriculture. By using bio-fuels, CO2 emissions will be emitted to but there is the argument that the CO2 is going in a closed cycle – the plants need it for growth and when burnt they come back to atmosphere. So that fuels can be regarded as “zero-impact-fuels” or as “CO2-neutral” fuels. One of the pro arguments is that we and our successors can use existing infrastructure and existing and well proven internal combustion engines. The use of biofuel is very usual in Latin Americas, especially in Brasil. Some critics want to eliminate CO2 completely and accept only electricity or hydrogen from renewable sources such as hydro power, wind or solar power.

The discussion also focusses on the question whether “CO2-neutral” fuel as which the bio fuel can be regarded are a feasible or must it be “CO2-free”??

3.1.2 Trends in Electric Powertrain

Compared to thermodynamic power train technologies, electric power train technologies are characterized by a very high "tank/battery"-to-wheel efficiency (TtW)" and the potential for zero local emissions. So Battery electric vehicles are considered to be a favorable possibility to make the mobility more energy efficient and cleaner, and most of all to decarbonize the mobility. This can be true, if the electricity needed is produced by renewable sources, that is solar, wind and hydro power.

Additionally, hybrid and pure electric power train technologies enable a totally new driving experience regarding driving behavior and performance.

Although the basic technologies are developed and already available on the market, the trend goes in the direction to make these technologies affordable. This means high investments in optimization steps, especially in new development methodology, production technologies, modular design systems and application of less expensive materials. Only if these vehicles can be offered at reasonable prices, larger quantities can be sold, thus leading to a considerable environmental impact.

All components such as e-motors, battery, power electronics, cooling system, controls, charging systems are used in many different variants and the market has not yet defined the <u>one</u> concept. Also big production numbers are yet not achieved.
Taking these facts into account, further research and development work needs to be done to produce highly efficient, competitive, cost optimized and affordable products. High reliability and life time is also requested by the market.

In order to realize the full potential of BEV and PHEV and, a sufficient charging infrastructure must be available. Furthermore, due to high power demand, new PHEV and BEV need high voltage levels of up to 1000 V for peak performance.

In the field of heavy commercial vehicles and buses, the relevant power train concepts are <u>depot-bonded battery electric and hybrid vehicles</u>. Depot-bonded vehicles legitimate the pure battery-electric operation in the heavy-duty and bus sectors because the distances covered are calculable in both course and length. Depot-bonded vehicles in urban use with intensive stop and go traffic have advantages in pollutants and emissions due to the potentially higher braking energy recovery. The use of battery electric heavy vehicles has already been started, all electric battery powered trucks and buses for distances up to 800 km will be available by 2020.

Voltage levels

High voltage systems (voltages over 60V and recently going up to 800V) are required for achieving long distances with pure electric drives. Premium electric cars reach out for the highest voltage levels, such as Teslas, Porsches etc. They are the root cause for high system costs and also touch the safety issue, that means expensive isolation and touch protection system are required.
For smaller range expectations as for city cars and also of course for affordable hybrid cars, the 48 V voltage level gains importance in the last months.

e-Motors and Inverters

Large effects in terms of mitigation of pollutants and GHG emissions and generation of added value can be achieved by further developments of the electric motor.

Advanced electric motor structures like new winding types, motor materials or motor topologies as well as the motor-inverter-integration offer high potentials. The trend goes to highly integrated electric motors with higher revolution speeds (> 20.000 rpm) to provide the required performance with lower weight and less space needed. In addition, key areas of motor development are scalability, low or non-magnetic concepts, cooling concepts and thermal stability, special transmission solutions coupling electric motor and ICE and functional safety of all components.

Inverters:
Advanced motor control improves efficiency, peak power density, and peak power performance and torque accuracy (driving performance).

Regarding “Motor Control and Diagnostic Software” the aims are fast parameterization, enhanced modularization and increased safety features. Therefore, significant R&D effort is necessary for advanced, model-based modelling such as easy self-learning, and adaptive and flexible algorithms.

Of high importance is the development of highly integrated gear boxes (reduction gear) for electric power trains, which have to achieve low internal losses, optimised dynamic behaviour and optimised NVH behaviour (noise, vibration, harshness) necessary to cope with the high revolution speeds of electric motors. The R&D effort is high, as all mechanical components for automotive use (bearing, seal, magnet fastening, etc.) are at an early stage of development.

The term “Power Electronics” summarizes the converter, DC-DC converter and on-board charging unit. Short-term activities primarily relate to increased efficiency, miniaturization and new cooling concepts with special emphasis on “high temperature” cooling. New materials, “self-learning” inverters and high volume production (e.g. GaN and SiC for fast low-loss switching inverters) will minimize costs in the medium and long term and create added value. Safety circuit and passive power electronics components (fuses, resistors, capacitors, inductors) which can cope with the high energy density and automotive safety requirements are missing today and need to be developed. High R&D efforts in manufacturing processes are necessary to tap the full added value potential in Austria.

High Power Systems with up to 1,000V voltage level offer the advantage of lower electric currents necessary to achieve the required electric power throughput. Hence, the benefits are thinner cables, smaller and more efficient electric motors, lower heat generation. These benefits will be of high importance for fast charging systems. In the short to medium term high power systems will be made available in the segment of luxury class vehicles, first applications will hit the market around 2020.

Further, cost reductions are necessary in the production of the electric power train components, allowing for a high number of end users to afford and utilize the benefits of these technologies, and thereby to magnify the positive environmental impacts. Such technologies can only become widespread as the costs of these systems drop. Applied research and development in these areas, especially in the field of production technologies, continue to be required.

Batteries

The quick change in battery technology can be seen as a big challenge for all developers of battery electric vehicles. From that, big evaluation and testing effort needs to be taken to reduce risk of investment in the wrong or already obsolete technology. New skills and competence needs to be build up to understand cell chemistry, production process, cost effects and the development of optimized battery management systems. This addresses also the safe integration of new cell technologies in the battery packs, early recognition of risks, avoidance of failures and the respective quality management.

A good overview about all battery cell types delivers the so called Ragone Diagram, which shows the relationship between power capacity (W/kg) and energy capacity (Wh/kg), see Fig.

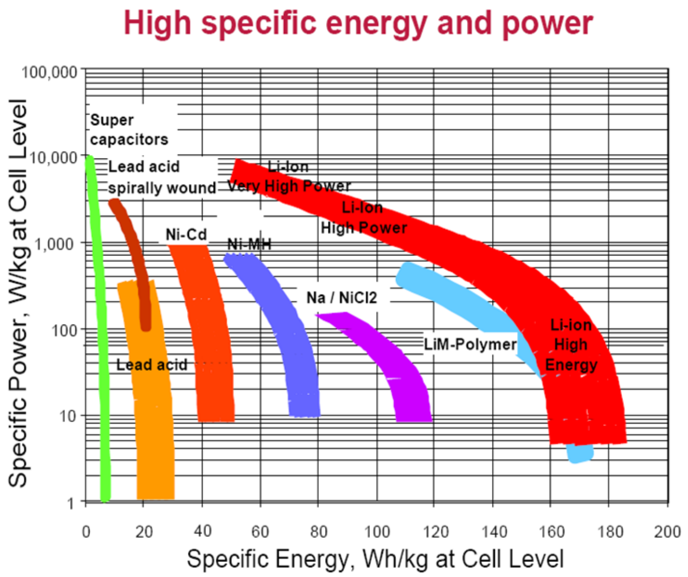

Figure 8: Ragone Diagram for electric energy storage

In the recent years the development of Li-Ion Batteries was in focus and it is said that the ongoing development is due to an enhancement of approximately 4% of cell capacity each year. Other technologies such as any types of lead acid, NiMeH batteries are still in the market (Toyota Prius used NiMeH!) but can be regarded obsolete for EV propulsion applications.

Li-ion cells can be developed in both directions, high specific energy (as needed in pure electric vehicles for longer ranges) or in the high power direction (as applied in hybrid vehicles).

The basic reaction of Li-Ion batteries can be seen in the figure below:

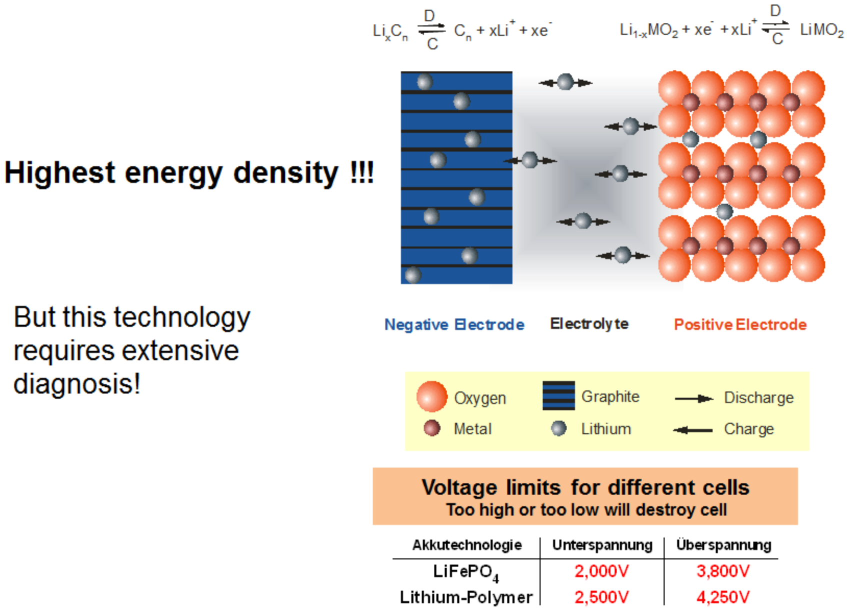

Figure 9: Basic Li-Ion cell reaction

New technologies can be seen in the horizon, as the battery cell roadmap shows:

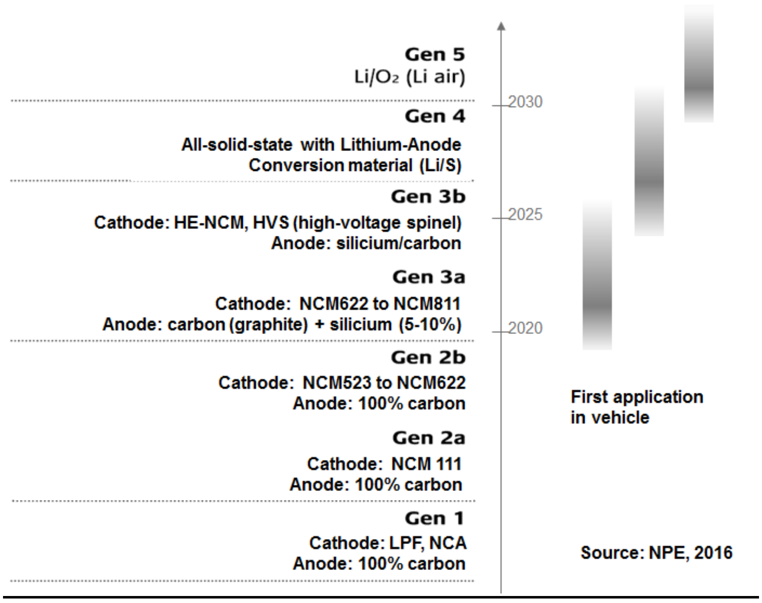

Figure 10: Battery cell technology roadmap until 2030

Current developments are at the stage 2b to 3a and their main focus is to reduce Cobalt content dramatically and to increase the cell voltage from today 3.7 to ~4.3 Volts. Cobalt is both, expensive and toxic. Next generations of batteries will be so called “solid state” batteries. In solid state batteries the electrolyte is not an organic liquid any more but either a solid polymer or even special glasses. By this design the electrolyte cannot leak anymore and so – besides higher capacities (factor 2 to 3 compared to today’s batteries) – also they cannot easily burn.

Long term research takes place for the so called “metal/air” batteries, which take the oxidation material from the air oxygen, by that reducing the weight dramatically. Currently the recharging is the big problem and experts expect them in the market not before 2030.

It can be stated that the cell development is still not settled and therefore may car makers are a bit confused and hesitate to choose their cell technology, as it might be obsolete in a few years.

But batteries do not only consist of cells, a complete battery for automotive application is a complex component and consists of a special housing, connect and disconnect devices, fuses, heating and cooling capability, and a complex battery management system, which is also responsible for the safe charging.

Figure 10 shows the main components of a modern automotive battery

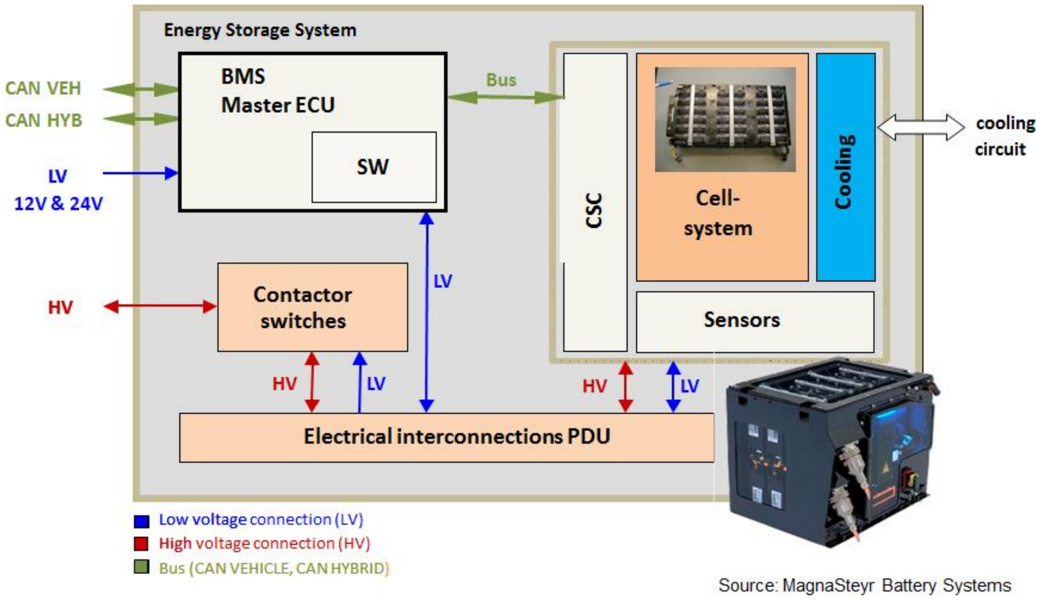

Figure 11: Automotive Battery Architecture

Figure 12: battery integration “under bonnet” in the vehicle

Summing up, battery technologies are the key drivers for the success of hybrid and pure electric vehicles. Experts predict that energy density will double and costs will fall to about 100 EUR/kWh on battery module level by 2020. Positive environmental effects of battery electric vehicles are even bigger than with hybrid electric vehicles. Lithium-ion (Li-ion) battery technologies have permeated the market but will be replaced by advanced Li-ion batteries (3rd generation) and solid state batteries (4th generation) in the long-term. R&D effort is therefore required continuously. New battery technologies such as metal-air batteries (Sulfur-Air, Mg-Air, Li-Air) with higher energy (and possibly and power density) as well as highly modular integrated batteries will not penetrate the market before 2030.

In the past years, batteries for automotive applications have been improved tremendously, however further improvement is still necessary. The aim for all battery technologies is improving the energy content at a higher voltage level, power-to-energy-ratio and integration, reducing costs whilst increasing efficiency, durability (cycle stability) and safety. Additionally, since (traction) batteries in automotive applications are quite new, there are several approaches to achieve the same objective. For example, established car manufacturers have the ambitious demand to fulfil automotive safety requirements not only on a system level but also on a cell level. On the other hand, recently established battery electric vehicle manufacturers have developed methods to obtain the same level of safety only on a systems level, using consumer electronics battery cells (with lower safety requirements).

Charging systems

The development of efficient charging technologies is critical to the success of battery electric vehicles.

Conductive charging systems (with plugs) are available and have already been partially introduced to the market.

Inductive charging is seen as a medium to long-term charging technology. Since the efficiency of such systems is still too low and the effects of magnetic fields on the human body and the environment is still unknown, further investigation and R&D effort is needed.

Battery swapping systems require a high level of standardization, which affects OEMs in their freedom of design. Two cases are necessary - one in the car chassis and - one for the battery modules, also increasing weight and complexity. Besides, they require a high number of additional standardized batteries to guarantee the constant availability of charged batteries. This is seen as a financial and logistical challenge. Cost and image are serious hurdles as long as warranty jurisdiction is not legally clarified in the EU. Consequently, it can be concluded that battery swapping systems are not worth-while for common use, at least for the moment. The situation can be judged differently in fleet operations under controlled conditions.

Fast charging (charging with high current) is another technology to shorten the charging time. However, fast charging requires sophisticated thermal management of the battery in order to prevent a reduction of the battery's durability and a loss of efficiency of the charging process itself. Besides, it presents major challenges to satisfy the high power demand and the stability of the grid. One approach to overcome grid restraints is to use buffering batteries in the charging stations – first solutions are already available at the market. However, fast charging technologies help to meet users' range anxiety, even though field tests show that users rely only to a rather small extent on fast charging because they tend to charge their vehicles at home or work.

Contact-less Charging/inductive:

Approaches have been made to improve the plug in behavior of people and to avoid the handling of sometimes dirty and wet cables. Via coils and high frequency, the energy is sent from the charging unit into the floor of the vehicles. This could be an elegant way to recharge the electric vehicles without dirty hands, but also the efficiency has to be considered. So far such systems cannot compete with standard conductive systems. The influence of high frequency energy transfers to the environment such as animals and humans need to be investigated further, to avoid any negative results.

3.1.3 Trend towards Fuel Cell Powertrain

“Green” hydrogen allows an integrated, efficient and social sustainable energy system. To achieve the climate goals which have been agreed in Paris 2015, a decarbonisation of the complete energy system is required. Green electricity and green hydrogen are the only real energy carrier for this energy change!

There are two main technologies of fuel cells for automotive applications. On the one hand the Polymer Electrolyte Membrane fuel cell (PEMFC) and on the other hand the Solid Oxide Fuel Cell (SOFC). PEMFCs distinguishing features include lower temperature/pressure ranges (e.g. 50°C to 100°C) and a special polymer electrolyte membrane.

The SOFC has a solid oxide or ceramic electrolyte and operates at high temperature levels between 500°C and 1000°C. Both technologies, PEMFC and SOFC offer a great synergy potential with their respective electrolysis technologies, the polymer electrolyte membrane electrolysis and the solid oxide electrolysis cell (SOEC). Therefore, these technologies are also discussed.

Since longer companies like Daimler, Ford, GM and especially the Asian companies Toyota, Honda and Hyundai are developing fuel cell propelled vehicles.
The market introduction of a noteworthy number of fuel cell vehicles started in selected regions in 2014 with Hyundai iX35 followed 2015 by Toyota Mirai. Before that Daimler spread out 200 A-Class F-Cell vehicles to selected customer. In this autumn Daimler starts with the selling of its first available fuel cell SUV GLC Fuel Cell or F-Cell.

The table shows that in which fields further research activities is necessary and must be further pursued.

	Short Term until 2025	Medium Term 2025–2030	Long Term 2030+
Polymer Electrolyte Membrane Fuel Cell - PEMFC	8	9	>9
Solid Oxide Fuel Cell - SOFC	<8	8	>9
Hydrogen Generation	9	9	>9
On-Board Hydrogen Storage			
Fuel Cell Vehicle Concepts	9	9	>9
Test & Validation	9	9	>9
Fuel Cell and Component Production	<8	9	9

system complete and qualified = TRL 8

actual system proven in operational environment = TRL 9

fully established in the market – R&D measures still required (TRL > 9)

Figure 13: Market readiness of advanced thermodynamic power train technologies in terms of TRL (technology readiness levels)

Current R&D activities on fuel cell components are focused on **efficiency, endurance, lifetime and cost.**

The large investments in high volume production required to lower the costs of fuel cell systems and therefore the price of the vehicles are the biggest obstacle for the introduction of fuel cell systems.

For the application in passenger vehicles, the focus is currently on the PEM Fuel Cell. Depending on the power train design, fuel cells operate at power levels from 15 to 30 kW for range extender vehicles, APU applications and Combined Heat and Power (CHP) applications up to 100 kW and more power for “pure” fuel cell vehicles.

Fuel Cell range extender vehicles are battery electric vehicles with fuel cells for maintaining charge or as a fall-back solution in case of a discharged battery. In “pure” fuel cell vehicles, the fuel cell provides the total amount of electrical drive energy. A small battery or super capacitors are required to buffer highly dynamic load changes and peak performances.
Very strong R&D effort is currently invested especially in the development of new low-cost materials with high durability under high dynamic loads for the fuel cell. With regard to the second generation of fuel cell vehicles, the focus is put on the replacement of noble metal catalysts in the fuel cell.

SOFC

In order to reduce the use of the EU-defined "critical raw materials", more R&D is required in the field of lightweight powder-metallurgical manufactured SOFC stack components, qualified catalysts and high temperature electrolysis (SOEC) - for instance via low or platinum-free resources, and through recycling, reducing or avoiding the use of rare earth elements. This is of special importance, since electrolysis is the only way to produce green hydrogen.

Hydrogen Storage

As for hydrogen storage, in the first generation of fuel cell vehicles, tanks with a pressure level of up to 700 bar are used. The tank systems have reached a reasonable level but still the technology used is expensive and its long term stability not so proven. Therefor very strong R&D effort is required for the development of hydrogen storage systems that reach high storage densities at lower levels of pressure while costs are reduced.

In the heavy-duty sector, the use of PEM fuel cells in city buses is considered an early commercial market. This helps also the buildup of hydrogen fuel stations as this fuel stations then get a reliably customer a few times a day, justifying the investment.

In the field of heavy-duty vehicles and buses, the SOFC will be ready for the market in the short term, used as an auxiliary power unit and as a range extender. Unfortunately, this kind of fuel cell cannot deliver any CO2 benefit when operated with standard fossil fuel, if operated with hydrocarbon from bio-stock the CO2 balance would be influenced.

Figure 14: Toyota “MIRAI” (=Future) vehicle and FC components

Summary Fuel Cell Vehicle Concepts

In automotive use the PEM and SOFC Fuel Cells will be used, either for range extended REX-FCV and/or "pure" FC powered Vehicles. Especially for PEMs synergies with PEM-electrolysis will take place, to enable customers to produce hydrogen in a decentralized way.

Summing up the detailed trends in fuel cell development:

- NVH optimization /
- improve efficiency /
- endurance/ lifetime /
- cost reduction (minimize the precious materials)/
- increase customer acceptance

Hydrogen Generation

Trends: improve cost / lifetime / safety / optimization of production process / weight reduction / packaging

3.2 Advanced Vehicle Aspects & Trends

3.2 1 Trends in body design

- **Lightweight**/Material selection for body in white
- Passive Safety developments: active safety
- New vehicle concepts for electrified and automated cars, busses, trucks
- New production methods depending on production volume

Many years the body design was dominated by the increasing challenges regarding safety and comfort, resulting in more and more weight. As an example the weight of a normal VW Golf doubled from the seventies until 2010. So it is now high time to change the direction of the weight spiral. All OEMs are now trying to reduce vehicle weight basically by introducing three measures.

Effective weight management can be achieved by:

- Design based lightweight,
- material based lightweight and
- production based lightweight.

Design based light weight consists of:

- Functional integration: one part for two or three functions, avoiding too many parts
- Multi-Material Design: using the material according it’s individual strength
- Complete Crash Management Systems with functional integration made out of aluminum die cast
- New shape oriented solutions using so called bionic optimizations to reduce materials especially for components which are in air or liquid flows
- Intensive modelling

Material based lightweight:

- Use of fiber reinforced synthetic materials, optimized light metal alloys (Al, Mg, Ti)
- Application of high strength steel sheet (TRIP, Bake hardening, multiphase steel)
- New hybrid materials with components of light alloys, steel, glass fiber, carbon fiber

- Hard metal coatings
- Increasing recycling portions in Aluminum alloys

<u>Production based lightweight</u>:

- New joining technologies (CMT- welding, electron beam welding, bonding etc)
- Development of new welding Ad-Ons for unusual welding combinations
- Development of new efficient production processes for hybrid materials
- New deformation technologies

As the car body design selection is highly dependent on projected yearly production figures, the following Figure gives an idea where which concept is currently used.

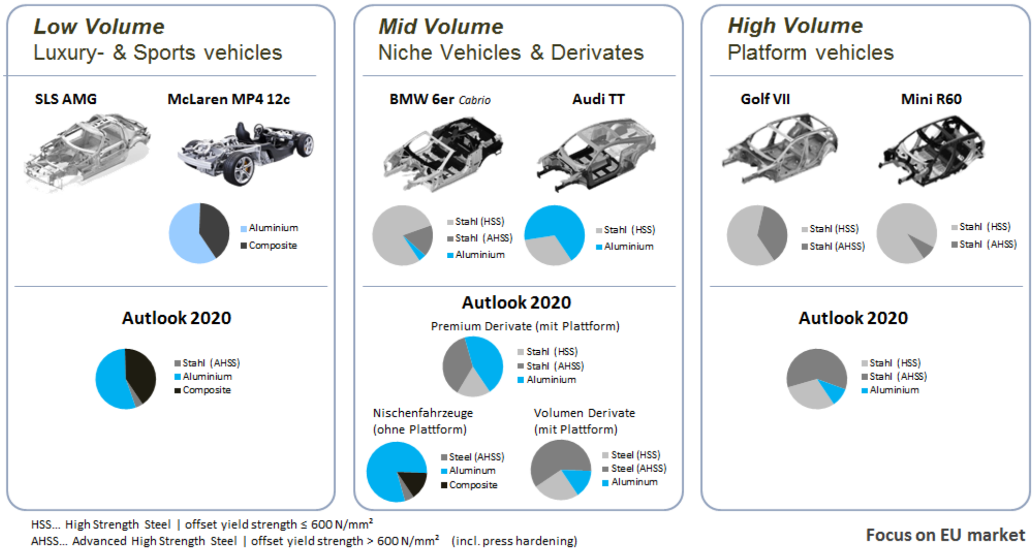

Figure 15: Automotive Body processes in production and outlook 2020

To compare the possible processes and to link them with production volume and especially to achieve reasonable costs the following graphic has been drawn.

Body in white concepts depending on annual volume and price

costs for painted body (including doors and closures)

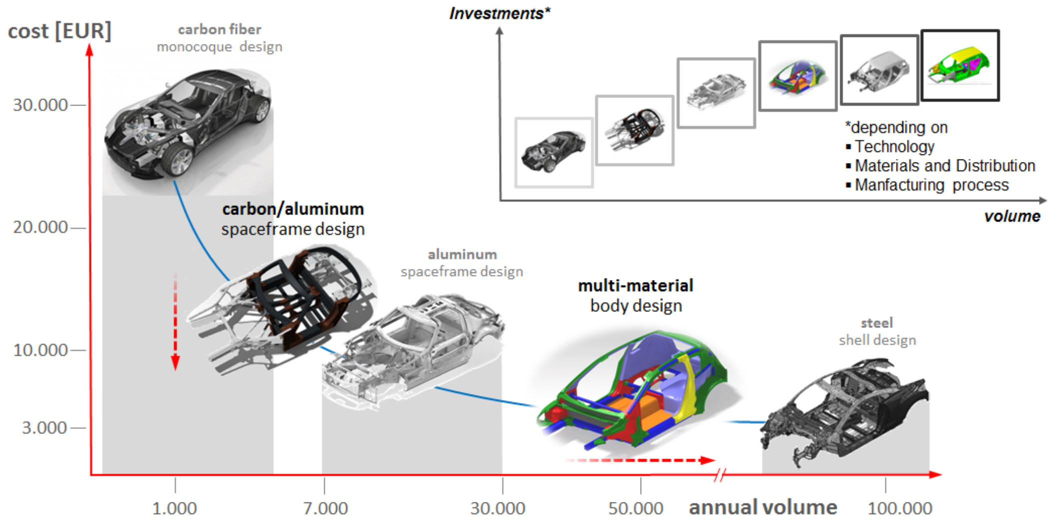

Figure 16: Costs versus Volume for different body in white concepts

A relative new trend in body in white design is the multi-material design for middle production figures around 50.000 pieces a year. This design concept tries to combine different materials and to use them where they have superior properties. Following the slogan: “the right material at the right place”, Aluminum, carbon fiber, advanced high strength steel, glass fiber and even wood materials are combined. By this understand new lightweight chassis can be designed, but especial focus shall be placed on recyclability of the different materials.

Passive Safety versus Active Safety

As mentioned in the beginning of this chapter, one reason why the weight of the vehicles increased tremendously in the recent decades were the stringent and continuously increased safety standards, which could be only matched by stronger and heavier designs. So the vehicle’s passive safety including the occupant restraint systems reached a very high level.

New vehicle concepts for electrified and automated cars, and busses offer the chance to go in a different direction, because they will offer a high degree on active safety. Hopefully these developments will lead to avoid collisions completely and then the vehicles could rebuild their passive safety to a minimum which would make them lighter again.

Figure 17: New vehicle concepts with high active safety but reduced passive safety

Further new automated vehicle concepts so called “People Mover” will be developed.

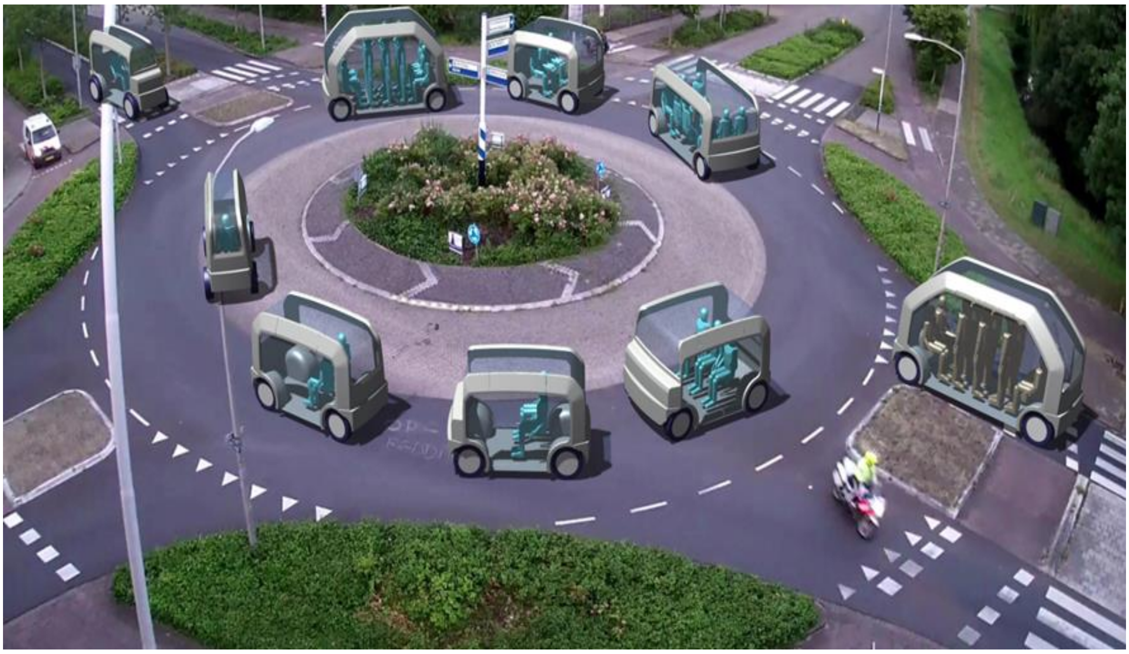

Figure 18: New Mobility concepts with make up the city transportation of the future

It is more and more recognized that even premium sports cars, commercial vehicles (delivery vans and trucks), trains, ships are being electrified.

3.2.2 Hybrid Architectures

Choice of ice engine

Since the ICE is operated in a substantially different way (peak shaving, load point shifting, start/stop…) in a hybrid compared to a pure thermodynamic power train, the special adaptation of existing combustion engines or the use of alternative combustion engines allows for a further reduction of emissions and fuel consumption. Conventional gasoline or diesel engines are only the short-term choice. Alternative approaches (modified combustion processes such as Miller/Atkinson) or even alternative engine concepts with small displacement for use in range extender applications, are promising options.

In the field of commercial vehicles, the R&D focus is on diesel and natural gas engine concepts, some of which have already been launched and will permeate the market in the medium term.

48V-Systems

A special role in HEV can be predicted for 48V systems, especially in passenger cars which are produced in high numbers under extraordinary price pressure. Cost efficient hybrid systems based on 48V will be an attractive solution in this segment. 48V systems will be applied as part of the power train as well as for auxiliary systems (brakes, steering, AC system etc.). It is anticipated that, in the near future, luxury cars will use a 48V board net voltage since auxiliary comfort systems are reaching their limits with 12V systems.

Micro hybrid systems using 12V systems cannot provide sufficiently effective environmental benefits, as the achieved power levels up to 3-4 kW are not sufficient for electrical cruising or regenerative braking. So 48V systems which provide power levels up to 8 to 10 kW – recently reported up to 30 kW, thus already reaching the mildly hybrid area – promise to provide remarkable fuel consumption or CO_2 reductions in functions such as regenerative braking, ICE assist via electric supercharge technologies or even the so-called “sailing” which becomes possible at these power levels.

A cost-effective solution is to implement a Belt-Starter-Generator (BSG). A further benefit can be created by “phlegmatizing” the ICE dynamics, the so-called “peak shaving”.

An important aspect of 48V systems is that they do not require touch protection measures which are prescribed by law for systems over 60V. As a consequence, special training and safety equipment for high voltage handling in garages will not be needed in the short term. The introduction of 48V systems requires extensive research in the development of 48V components such as electric motors and inverters. Especially the fusing and switching technology of high currents is a big challenge. The development of 48V system components as bridge technology for large electric vehicles offers a good business opportunity in the future.

Series-/ Parallel / Power Split Architectures

The functionality and efficiency of hybrid powertrains also strongly depends on the selected architecture or topology.

Series:

In the series architecture all components of the powertrain are arranged in series, that means the energy flow follows: ice – generator - inverter – dc-link - (battery) – inverter – e-motor. In this configuration the ice has no direct connection to the wheels. If such a powertrain should deliver full vehicle performance all the machines mentioned before need to have approximately the identical high power rating, which leads to 3 big engines. These three main engines are then usually too big and expensive (two electric machines, two inverters) especially for passenger car application in predominantly city driving, therefore this kind of hybrid is seldom realized, but mainly in busses, trains, ships or other big machinery.

In general, the efficiency of series hybrid powertrain is low due to the high number of energy conversions. So the chemical power of the fuel is converted into mechanical power with relative low efficiency, then in the generator this mechanical power is transferred into electric power and so forth. Finally, the electric power has been reconverted in the e-motor to mechanical power. So up to 11 efficiencies need to be passed until the power is at wheels. Considering this fact, these kind of hybrids could be also called an "energy conversion machine".

One variant of the series arrangement is the so called "Range Extender" (REX), where the power dimensioning of the ice-generator set is significantly lower than the e-drive system at the wheels. A big battery supplies the energy for "normal" use. As the name says in this arrangement the gen set helps to prolong the range of the dominantly electric drive and recharges the battery in case the distance to be driven is significantly longer than usual. The power of the gen set can be chosen in the range between 5 to 15 kW – but then it is obvious, that when the batter is flat (which might occur more often than expected), the vehicle will "limp home" only with that power – becoming an obstacle in the traffic especially in hilly or even mountainous environment. So it is better to choose a power between 30 to 40 kW, so that the performance of the vehicle does not deteriorate so much when only depending on the gen-set. Transferring higher power through the complete chain also means that the efficiencies involved lead to suboptimal overall result – in this case a direct connection of the ice engine to the wheel would save about 10 to 15% fuel consumption – a real considerable amount. But introducing this possibility will make a parallel hybrid out of the series hybrid.

It can be stated that the trend goes away from series hybrid powertrains – on one hand because the batteries improved significantly in recent years – the capacity was raised and cost came down – and therefore the need even for range extenders became less urgent. On the other hand, the mentioned low efficiency of such an arrangement is not suitable in times when CO2 targets are becoming more and more stringent.

Parallel

This architecture is the most common due to its mechanical and cost efficiency. Only one electric motor/inverter is necessary, can be dimensioned in the lower power range as the full size ice engine will take over for high power demand. And there is no range limitation as the range is determined by the tank capacity of the vehicle as usual.

Most companies such as VW, Audi, Daimler etc. trust in this concept. Daimler "invented" a nomenclature and called the subversions of this architecture Px, as shown in the following illustration: Figure

The trend indicates that P2 offers the most flexibility and advantages. With P1 pure electric driving is not meaningful as in electric mode the ice engine must be motored and by that causing severe losses. P2 with the two separation devices before and after the e-motor provides pure electric driving as well as all other hybrid modes in an efficient way.

P3 with the e-motor after the transmission is more disliked as the e-motor is operated with lower speed and higher torque for the same power level, resulting in a more bulky and heavier machine.

- Key characteristics:
- Direct, mechanical connection between ICE, electric motor and final drive
- ICE and electric motor(s) can provide traction torque at the same time („parallel")
- Different variants, depending on arrangement of EM to other components

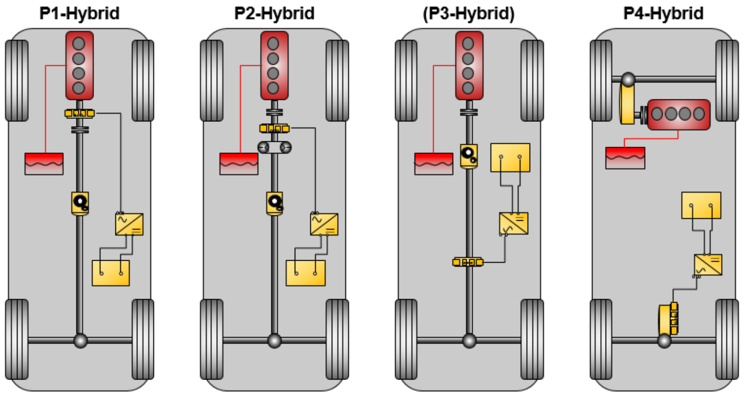

Figure 19: Different parallel hybrid arrangements according Daimler

P4 is the "ad-on" parallel system using a second electric axel in addition to the conventional driven axle. As shown in Figure the electric axle is in the rear, some super sports car put the electric axle in front. A kind of shortcoming exists with P4 and that is charging of the battery. On first sight only brake energy recuperation and generating electricity via the road, i.e. the front axle delivers more and the rear axle is braking the surplus energy in, is possible. The amount brake energy recuperation from a rear axle is limited, charging via the road is not advisable due to driving dynamics. Therefore, it is recommended to use a high voltage generator at the ice or the increase the battery to a plug-in size and charge the battery from the gridele.

It is used for instance by Peugeot.

Power Split / structural variable

This architecture has been introduced by the Toyota Prius to the market in 1996 and this car has been the most successful hybrid car since then. More than 10 Mio pcs have been produced.

Technically the THS (Toyota Hybrid System) consist of 2 electric machines, the ice and a power split device (planetary gear set):

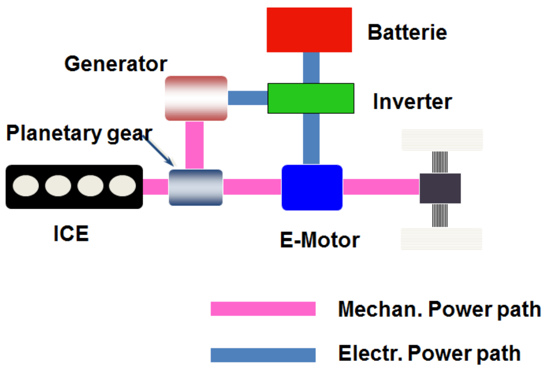

Figure 20: THS hybrid arrangements - Toyota Prius

The idea is, that most of the power shall reach the wheels via a mechanical path, while a smaller amount of power is used to control the speed of the drive shaft. This arrangement allows CVT like operation and most customers appreciate that comfortable operation.

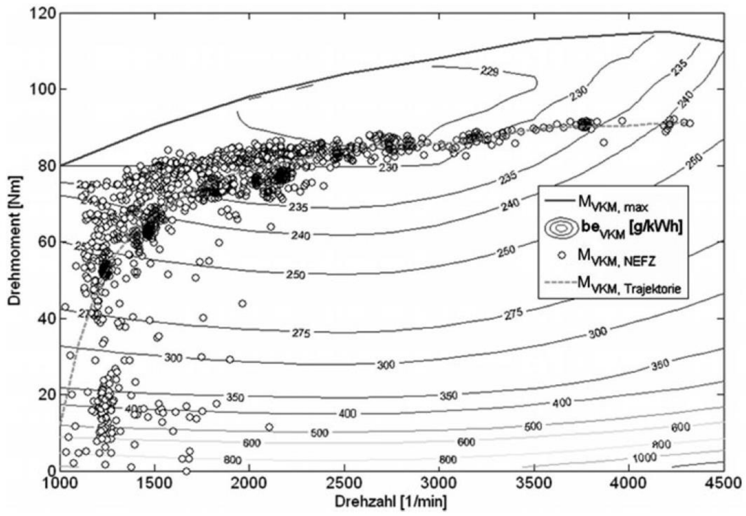

Abb. 6.9. Betriebspunkte des Verbrennungsmotors im NEFZ und die daraus ermittelte Trajektorie [106]

Figure 21: Operating points of the Prius ice in the ice map following a CVT strategy to achieve low fuel consumption

Trend of hybrid architectures: > PHEV (plug-in hybrids)

In Europe usually the legislation does not care about the technology under the engine cover, only in case of Plug-In hybrids it makes an exception. Depending on the pure electrical range CO2 emissions can be subtracted from the WLTP cycle result, by thus making the PHEVs a very attractive concept to bring down the CO2 fleet emissions.

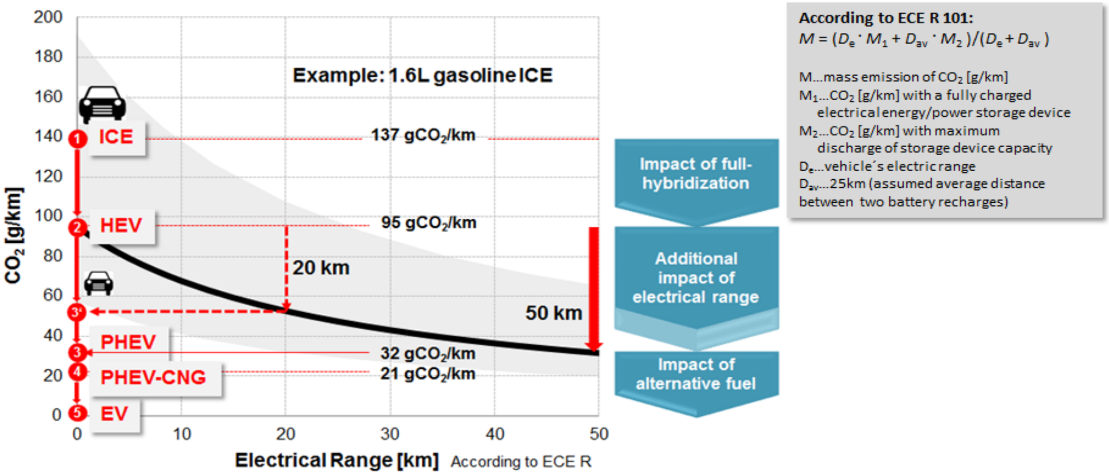

Figure 22: Saving CO2 by a pure electric range according ECE R101

Example: VW GTE or Passat GTE

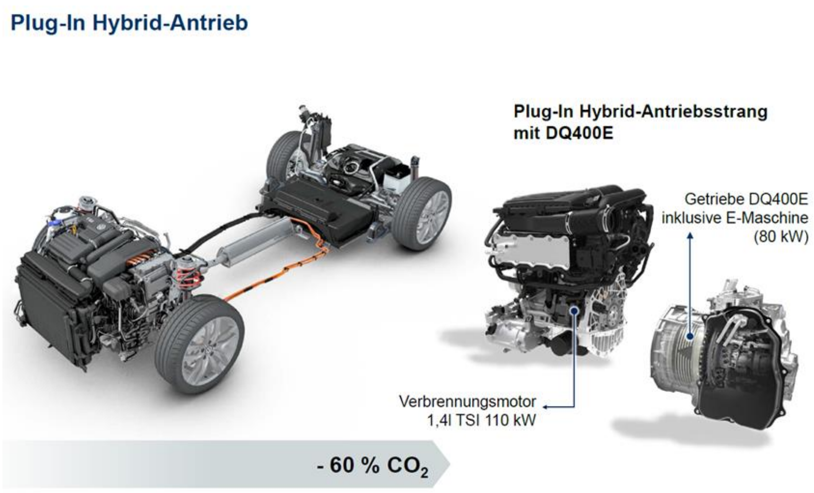

Figure 23: Hybrid powertrain components of a VW Golf GTE vehicle

Transmission

The transmission is becoming more important with the increasing electrification of the power train than ever before. Full integration of all electric components into the transmission (hybrid transmission) is a trend. Since the electric motor must be operated at high speeds (= high power density), new efficient and silent reduction gearing to the axle is required. A so-called hybrid transmission fulfils the function of an actuator to operate the ICE and electric motor in parallel and/or serially. The R&D effort and the added value in mass production are high. Fuel consumption can be reduced by up to 15% by optimizing the inter-action between transmission and the overall power train.

Increasingly the electric motor is integrated into the transmission, making the transmission supplier a supplier of the whole hybrid system.

Figure 24: Example VW DQ400E "Hybrid"Transmission

To reduce noise emissions from the ICE (in hybrid electric vehicles) and transmission, acoustics R&D continues to play an important role.

Due to their heavy weight, truck transmissions need to deal with much higher torques in both directions at higher numbers of transmission steps compared with passenger cars, making the integration of an electric motor more difficult. The R&D effort is particularly high, since durability and reliability expectations require more extensive testing than in passenger car applications. Austria's added value in this area mainly lies in the development of complete transmission systems (transmission, electric motor, inverter, clutch) with associated actuators and operating strategy.

Thermal management

Thermal management affects both the operating conditions for individual components and the comfort in the cabin. Cabin heating and cooling under extreme environmental temperatures can significantly reduce a (electric) vehicle's range. In some cases, for example in city traffic, the energy demand for heating can exceed the demand required for propulsion. New solutions for heat storage systems are of particular interest. Unused heat can be stored and effectively used at a later time (e.g. waste heat of power train components for interior heating the next day). Chemical heat storage systems (with no insulation requirements and indefinite storage duration) offer high potential for this purpose. Such storage systems are available at a basic level, but a lot of R&D effort is still required. The behaviour of the electric components such as batteries, inverters and electric motors are of special interest with regard to the vehicle components.

In **Fuel Cell Vehicle Concepts** the development trend goes to **NVH optimization** and targets to increase customer acceptance (also for accepting the insufficient infrastructure at the moment). Governmental incentives are also required to boos this technology, especially in China the government is supporting fuel cell vehicles with high subsidies.

3.3 Production Systems

In following chapters, the focus switch from the product to the production view. The historical development of production systems (see Figure 25) starts with Ford and Tylor who worked out a line concept and have managed to bring the average time of production for a Model T down to 93 minutes. Mass production was supplemented by **technology-oriented concepts** such

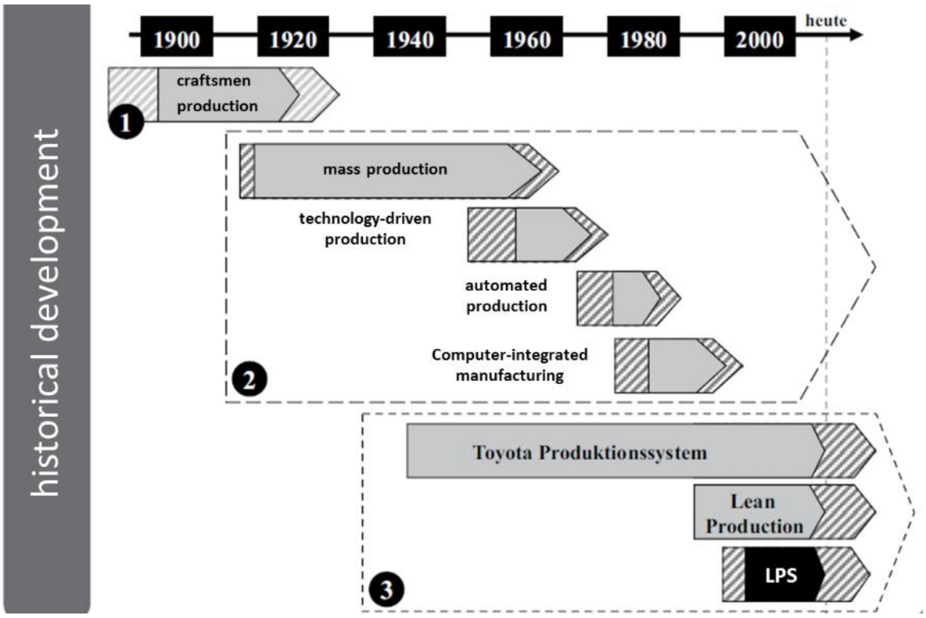

Figure 25: Source: Dombrowski, U.; Mielke T.: Ganzheitliche Produktionssysteme, 2015

as numerically controlled machine tools. Later came approaches such as rationalization through automation or the **computer integrated manufacturing**. However, the so-called second revolution in the automotive industry is introduced by the introduction of Lean Production by Taiichi Ohno. He assumed that a German worker was three times as productive as a Japanese was and an American worker three times more productive than a German worker. Therefore, Toyota planned to boost productivity ninefold in three years. **Lean Production** is an approach of continuous process optimization and involves the efficient design of the entire value chain. With the help of various methods, procedures and principles, the aim is to harmonize processes and to create a holistic production system without waste. Key aspects of the approach include customer focus and cost reduction. Waste potentials should be identified and eliminated, so that values can be created and maintained without wastage. With extension to a system, all business areas are included.

As shown in figure 25, the car industry were a pioneer in adapting the lean production system, whereby the German automotive industry were relatively late. It can also be seen that there was an adaptation across sectors. Today, LPS is one of the common methods (Dombrowski und Mielke 2015, 4 ff.).

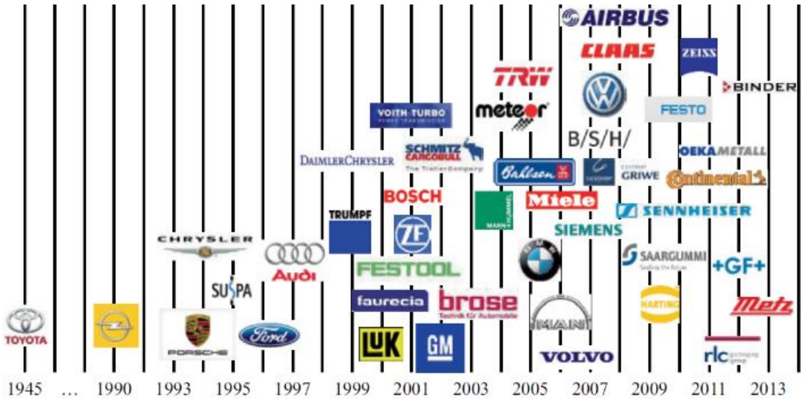

Figure 26:

For more than 100 years, the assembly line in the automotive industry has set the pace. A new approach are the **modular assembly**, it enables companies to handle the increasing complexity and diversity of variants better, more flexibly and more efficiently. The idea behind it is a production without an assembly line, dissolved into its individual working steps. The new production stations are staffed by one or two workers. Unlike today, they work evenly in a continuous rhythm because they no longer have to adjust their activities to the belt speed. In addition, they no longer move with the band. Automated guided vehicles (AGV) carry out the transport of the bodies and the parts between the stations. New types of AGVs that can orient themselves and their centimeter-accurate positioning is via a wireless network, a central computer controls them as needed. AUDI calculate with productivity advantage of about 20 percent plus x, through modular assembly. The "x" increases the more the variety of variants grows (Basic 2016).

3.3.1 The German automobile industry:

Now we move from the organizational to more technical driven approaches. In here, new business models and digitization are the biggest impetus, concern to production and research & development (see figure 26) (PWC 2018).

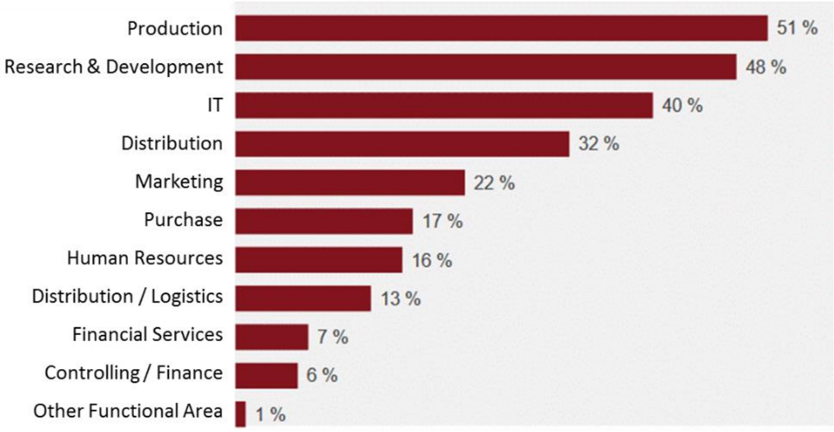

Figure 27: Functional areas with biggest changes due to new business models / digitization (Source: PWC, B2B-Survey "Stimmungsbarometer Automotive", Februar 2017)

The look at the efforts of the automotive industry shows a more detailed view. As an example, BMW and Daimler are taken. The objectives are refer to the outputs, the companies hope to archive due to the areas of activity (Dunckern 2014).

BMW (Ebner 2014):

Objectives:

- R&D for further improvement in lightweight construction
- mass production: intelligent networking, improve quality by reducing cost
- support projects or new production structures with digital factory approaches.

Areas of activity:

- simulation in production
- assistance systems in production
- robotics and autonomous systems
- networked value chain
- digital factory
- human-robot systems
- mobile assistance systems
- sustainability

Daimler (Kienzle 2014):

Objectives:

- shortening of start-up times through digital security,
- horizontal and vertical integration,
- reduced procurement times for production facilities,
- optimization of production and assembly,
- Increasing automation through human-robot interaction
- flexibilization of production through adaptable production,
- global optimization of processes.

Areas of activity:

- digital life at work,
- integrated IT processes (PLM, ERP, CAD, MES),
- digital factory and virtual commissioning,
- versatile factory,
- sensitive robots.

For categorization, the areas of activity can be clustered by activity type. One the one hand a high manual activity level and on the other a high degree of automation. In fact, there are several commonalities fit to both. The trends are explained in the next paragraph. The high manual activity level stands out for a small amount of robots, recurring activities for employees, high flexibility in production, high staff costs and low machine costs. Due to that, trends turn into sensitive industrial robots, assistance systems, high quality in production and augmented reality. High degree of automation is defined by high machine costs, low flexibility, high degree of standardization and a high robot application. This leads to more predictive maintenance, big data, M2M communication and sustainability issues. Commonalities are autonomous transport units, digital factory (planning and simulation), smart Data for predictive quality, data lifecycle, KPIs via mobile dash boards, horizontal and vertical integration, OPC UA (as a synonym for standards) for communication, transparency in production with RFID, clouds and IT security.

3.3.2 Trends in production

Industry 4.0

Industry 4.0 means the digital linkage between humans, machines and products and the digitalization of the industrial production. (Bundesministerium für Wirtschaft und Energie) One important part of that is the so called "internet of things" [IoT], which describes the connection of products and devices, the collection of data from them, and finally the internet- and cloud-based communication with the connected devices among each other and with us. Many of the connected things will be sensors, which will be easier and cheaper to produce in the near future. By that, new levels of networks and connectivity between machines and people and also between the real and the virtual world will be possible. (Desjardins 2015)

Industry 4.0 leads to transparency and controllability of processes, machines and plants through intelligent networking, targeted digitalization and value-oriented reorganization of processes. Three trends can be highlighted:

Smart Factory: The networking of embedded production systems, based on cyber-physical systems, as well as agile processes enable a profitable production of products even with a high degree of customization up to lot size one.

Data management: Through the data management and analysis of the huge amount of data, in result of the connected system. It is possible to create a high transparency and transfer the information by AI directly into the improvement algorithm

Component identification and tracking: Another advantage of the data-driven production is the transparent in the traceability of each piece. For example, the piece can be represented virtually based on digital twins and processes can be reproduced. As a result, information from the entire supply chain can also be used in the feedback flow for improvement.

Resource-efficient production

Supporting energy and resource efficient value creation through individual planning approaches, innovative process control and integrated management.

Several factors play a role in energy efficiency, such as legislation and cost savings. Material and energy flow simulations can be used to model manufacturing processes and to make challenges such as stochastic influences and complex interactions manageable.

Human integration

Promote efficiency and ergonomics for the workplace, with established deployment methods, lean organizational structures and intuitive mobile IT-assistance systems.

Proper workspace design based on digitization as a "digital workstation" can increase productivity by up to 30%. In manufacturing processes, above all, the necessary data availability and an optimal working condition are important.

Through stochastic evaluation of the order data, not only process planning but also factories can be optimally planned in order to have the best possible utilization. Due to the complexity of the processes, human support is essential. For example, sensitive robotics or exoskeletons are used here (IWU 2016).

3.4 Quality Management and Innovation Methods & Trends

3.4.1 Quality Management

Technological innovations, new and financially strong competitors as well as platform-based business models are the most important factors, the automotive industry has to deal with. To cope with these many changes, the automotive industry needs efficient processes and competent employees. To give an easy introduction to quality management, Figure 28 offers a good approach.

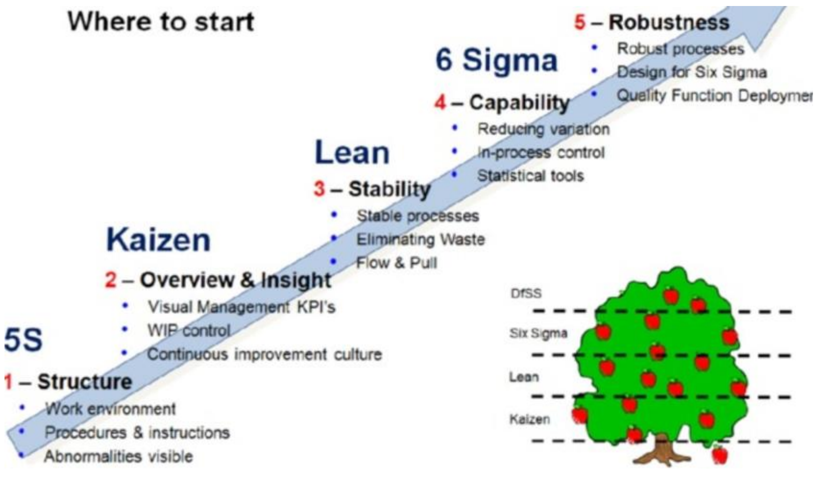

Figure 28: generalized overview of quality management procedures (Source: pharmamirror 2013)

The figure shows the procedure for the introduction or use of QM. The **5S method** is easy to implement and therefore stands at the beginning. The aim of a 5S method is to design the workplaces in a way that the work can proceed smoothly, searches as well as long transport routes and waiting times can be avoided, thus waste-free work can be done. A clean and orderly working environment is also considered the basis for high quality work. 5S stands for:

sort (Seiri), set in order (Seiton), shine (Seiso), standardize (Seiketsu) and sustain / self-discipline (Shitsuke).

The 5S method can be assigned to the **Kaizen** working philosophy. The methodical concept is centered on the pursuit of continuous and infinite improvement and contains five central foundations: process orientation, customer orientation, quality orientation, criticism and standardization. Kaizen pursues several goals. The main goal is a higher customer satisfaction, since customer acquisition is more expensive than customer loyalty. To ensure customer satisfaction, three factors are at the forefront: cost reduction, quality assurance and time efficiency.

The next step is **Lean**, mentioned bevor in the overview of production systems (see chapter 3.3). The term refers to the entirety of the principles of thought, methods and procedures for the efficient design of the entire value chain of industrial goods. The customer is at the center of the activity: Focusing on his wishes and requirements, this is the basis for the right orientation of a process. The identification of the value stream: This is the decomposition of the processes into subareas. All processes within the value chain must ultimately be aligned with this value stream. The flow principle: This value stream should run as possible without interruptions and delays in a steady flow. The pull principle: This harmonic chain runs backwards, since every activity originates from the customer's starting point, which is from its order. Ideally, there is no storage, no delays and no waiting time, because every single piece that is needed in a steady flow, is harmoniously in the exact place where it is needed. The continuous improvement process: The basic idea of Lean Management is constant improvement, new methods, ideas and learning processes. You are not satisfied with the existing one. In this respect, there will never be an optimal state but the path is constantly being taken.

The combination of the Japanese lean approach and the American Six Sigma method resulted in Lean Six Sigma, a quality management method enriched with lean tools. The name Six Sigma comes from the mathematical sigma (σ) for the standard deviation and thus gives six times the standard deviation. It follows the philosophy to fulfill the requirements of the customer holistically and profitably. The lean philosophy mentioned bevor, systematically identifies and eliminates waste in the company and thus streamlines the processes. More specifically, Lean Six Sigma is a strategy to improve quality and increase productivity by reducing confounders and errors in processes. The Six Sigma qualifications are given in so-called "Belts". The classic ones are Green Belts, Black Belts and Champions.

Figure 29 The Six Sigma DMAIC cycle (Source: https://iancos.files.wordpress.com)

The Six Sigma method is based on the DMAIC cycle, which consists of the first letters of the respective phases: Define, Measure, Analyze, Improve and Control. As shown in Figure Figure 29, the phases build on each other and are connected to each other. For each phase there are tools that can be used. The cyclical design ensures continuous improvement (Melzer 2015, S. 4).

The **define phase** considers the task of the project to be processed, describes the current situation and defines the goals (Melzer 2015, V). In addition, the project organization and scheduling are defined. The goal is to generate a general understanding of the project as a team. For this purpose, the project is defined in this workshop, a project contract is presented, a SIPOC is created and first quick improvements are implemented.

The goal of the **measure phase** is to see how big the problem is and how far customer requirements are met (Meran et al. 2014, S. 77). For this measurable quantities are required, which are processed and evaluated with the help of statistical methods (Toutenburg und Knöfel 2009, S. 70). The procedure here is first to select the most important output measurement criteria, to plan and perform the data acquisition and to calculate the current process performance. The result of the measure phase is the actual sigma level (Benes und Groh 2017, S. 201).

The **analyze phase** is the third phase of the DMAIC process. Their main task is to present the cause-and-effect relationships of the various inputs and outputs. For this purpose, the previously collected data and results are checked against why the performance goals of the customer are not met and how these influences are related. Many different factors can influence the result of the process. Therefore, with the help of various tools, the influencing factors are revealed and thus the key factors are highlighted in order to discover the potential for improvement in the next step, based on the analysis (Meran et al. 2014, S. 163).

The **improve phase** describes the actions, which are be taken based on data analysis and the implementation are planned and carried out.

For each significant input from the results of the analysis phase, a measure is derived. These measures can be obvious, but sometimes they have to be worked out first with. Creativity techniques can then help (Melzer 2015, 63 ff.).

The **control phase** is the last one in a Six Sigma project. This phase is intended to prevent the improvements achieved from decreasing again after completion, thus ensuring their long-term survival (Toutenburg und Knöfel 2009, S. 281). Responsibilities are clarified and a process management plan based on Deming's PDCA cycle is introduced. Again, the name is composed of the initial letters of the phases; Plan, Do, Check and Act. In the plan and do phase, the process is mapped using a detailed process map with those responsible. In the check phase, control points are determined for this process, where fluctuations are measured by means of target / actual comparisons. If these measurements are out of control, actions intended in the act phase will be taken (Six Sigma Deutschland GmbH).

3.4.2 Trends in Innovation

The megatrends are combinations of technological advances and upheavals in global society and the environment that will change the economy, businesses and lifestyles. For example, environmental and population pressures require cleaner energy and better functioning cities. These forces are driving demand for renewable energy and intelligent transport systems to reduce congestion. Technological answers include an increase in energy storage capacity that will improve the range of electric vehicles and facilitate the supply of renewable energy in the event of weather changes. In general, intelligent products will bring digital intelligence to new locations, as sensor-based machines are becoming increasingly autonomous thanks to decision-making software. In companies, functions that seemingly have little to do with numerical processing - such as sales and human resources - are supported or adopted by robotics and artificial intelligence.

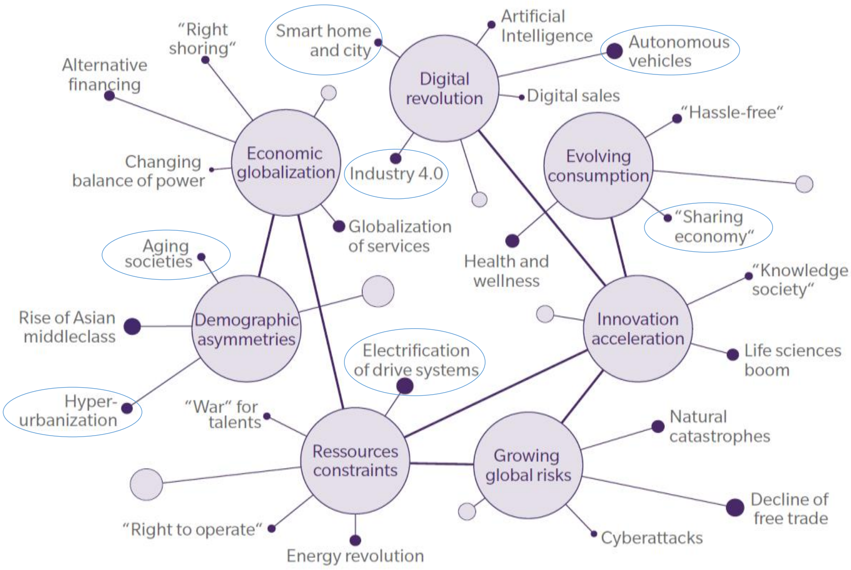

Figure 30: Megatrends in Innovation (Source: Oliver Wyman, Megatrends And The Future Of Industry, 2018)

As a part of the autonomous driving, the "car connectivity" must be mentioned. The process of getting everything connected to the internet has already started, not only cars or industrial things like machines or robots, but also a lot of everyday objects, private ones as well as public ones. The three components of the IoT are things with networked sensors, data stores and analytic engines. Sensors, hardware modules, data transmitters and control units to track performance, health and damage factors in real time are implemented more and more. For cars, that consists in diagnostic and analytical tolls, enhanced safety features and info-tainment. Furthermore, the car will be equipped with internet access and WLAN and can share that internet access with other devices inside and outside the vehicle. The conditions, that must be fulfilled for really talking about car connectivity are interconnectedness, assistance and safety systems, operating and display concepts and a focus on personal experience. (Desjardins 2018) For the user in general that means a personalized driver and passenger experience, where the person can interact with the product. (Hegde 2017) Another important factor about the data collection within that topic is that the owner of the car as well as the manufacturers can learn a lot about the driving behavior and preferences and that it can be evaluated how the car could be used in the most optimal way. (Medium Corporations 2017) The most innovative strength on that topic of car connectivity is currently in Germany, closely followed by Japan, China and the USA. Within Germany especially the VW Group, BMW and Daimler innovate a lot. (Statista 2017) Another trend which could help here a lot is the trend of “coopetition”, where companies cooperate to find new solutions together. At the moment, risks and threats consist in the high amount of data, on the one hand for the handling of that but on the other hand also about legislation and security topics. Privacy is an important aspect there, which we also discussed during the workshop. Security concerns of public must be prioritized in the companies! Unfortunately, the potential number of hackers grow at the same rate as the number of possibly connectable items does, which means a potential security risk. (Medium Corporations 2017)

A lot of data is also necessary for self-driving cars, which are kind of “the next step” after connecting. The characteristics of self-driving cars consist in scanning the environment with the help of sensors, navigation without human invention, communication with other traffic and making safety-relevant decisions. There are six levels of automation, from zero to five, which define the capability of the car to operate without human invention. The critical step, where we are right now, is between level two and three. There it changes from “the human driver monitors the driving environment” to “the automated driving system monitors the driving environment”. The main engineering challenges of that topic can be summed up as sensing, processing and reacting. Therefore, a lot of different types of sensors are necessary around the whole car. The greatest advantage of self-driving cars is the avoidance of car crashes; 94% of the car crashes today are caused by human error. Also, traffic jams should be avoided as well, by always calculating the most efficient routes and “knowing” where the jams are in real-time. Besides, those self-driving cars can be a great chance for elderly and disabled people. Current difficulties consist in the human interaction, the weather, especially heavy rain or snowy roads, morality and ethics, security and driver safety and cost and affordability. (Desjardins 2014) As discussion base in the workshop we used “The moral machine”, which gives you two options to choose about saving lives or not. (MIT media lab)

Many of the automotive trends were discussed during this workshop. What remains are the consumption trends, which are reflected in human machine interfacing, changing customer structure and new distribution channels (see figureFigure 31)

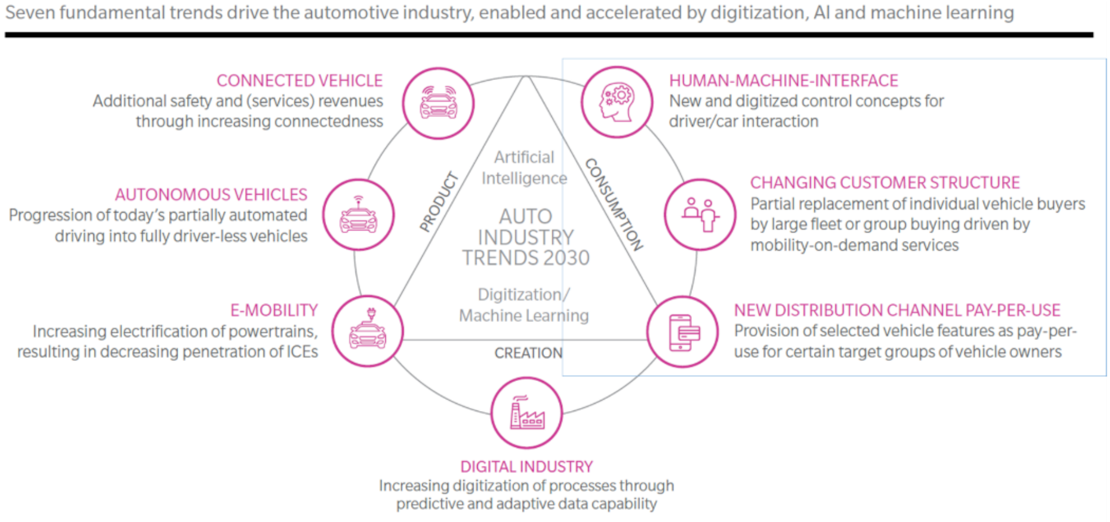

Figure 31: Automotive Trends through 2030 (Source: Oliver Wyman, Automotive Manager, 2018)

In order to unite all needs of the customer in a car, more and more services have to be integrated, which makes the interface to the driver more extensive. figure Figure 32 shows different solutions that are implemented in cars. Here, for example, the work with haptic feedbacks.

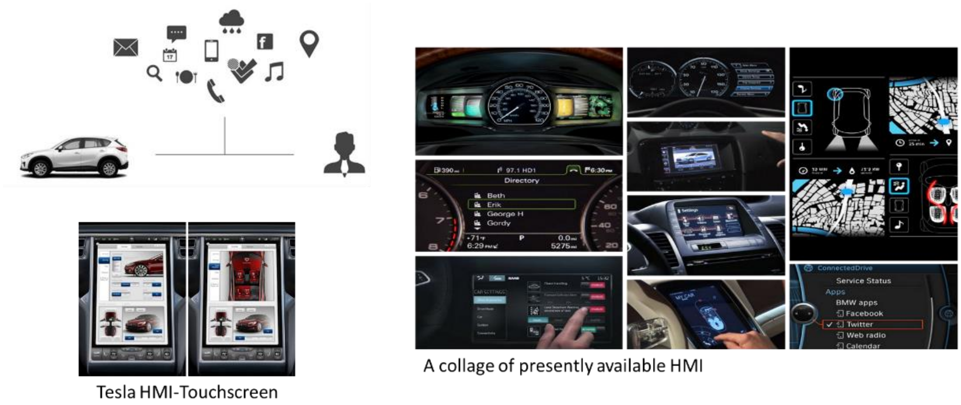

Figure 32: Human Machine Interface in cars

Above all, the **Changing Customer Structure** means dissociating the idea of the own car. More and more sharing concepts become attractive and even pure mobility concepts possible.

Here the customer of OEMs changed from B2C to B2B business. As a result, OEMs have to adapt to the changing of customer needs.

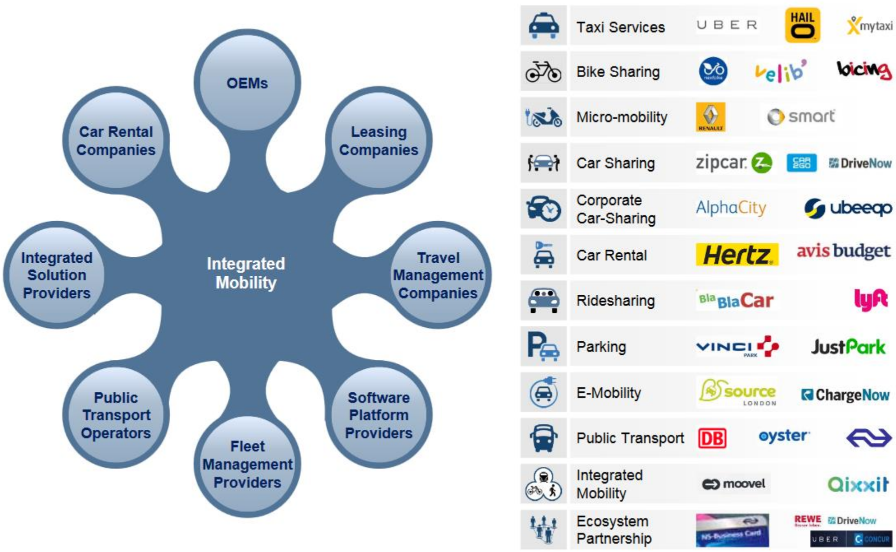

Figure 33: Changing Customer Structure (Source: Martyn Briggs, Frost & Sullivan, Future of Mobility: Slide 4)

As an addition to the customer structure and as a result, the **distribution channels** and the associated services that can be offered change. The figure below shows some concepts and services for each level.

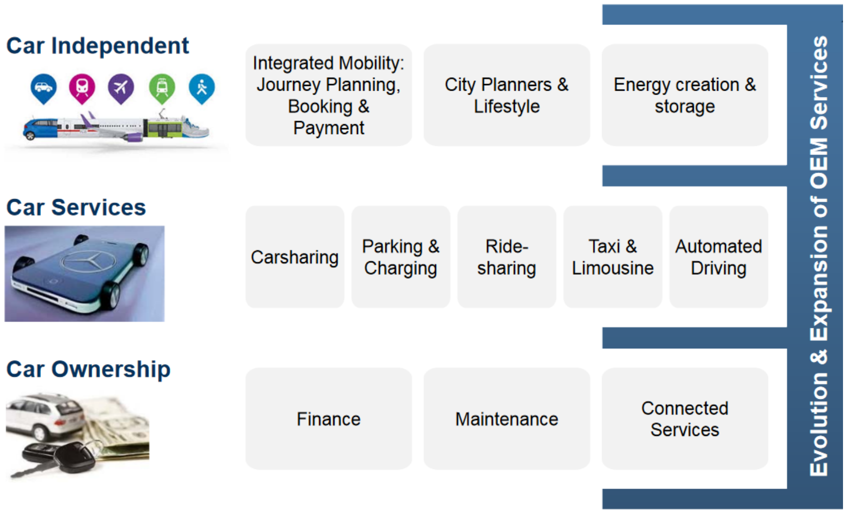

Figure 34: New distribution channels (Source: Martyn Briggs, Frost & Sullivan, Future of Mobility: Slide 9)

4 Activities

- Design thinking

- Best-practice from the industry
- Mind-map
- Discussion
- Q&A

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List of Figures

Glossary

- “Smart” Technologies, Factory, Service
  The descriptive term "smart" is used in multiple combinations, for example in connection with products (Smart Products), with service (Smart Service) or with factories (Smart Factory). Smart can be almost translated into "intelligent". These "intelligent objects" are connected to cyberspace through their information and communication technology. This enables them to perceive their context through sensors and to network and interact with each other, as well as with the Internet and humans. The physical function is complemented by the capabilities of digital objects, creating added value
- Lean Production LPS:
  Lean Production is an approach of continuous process optimization and involves the efficient design of the entire value chain. With the help of various methods, procedures and principles, the aim is to harmonize processes and to create a holistic production system without waste. Key aspects of the approach include customer focus and cost reduction. Waste potentials should be identified and eliminated, so that values can be created and maintained without wastage. With extension to a system, all business areas are included.
- Six Sigma
  Six Sigma is a quality management method based on the DMAIC cycle, which consists of the first letters of the respective phases: Define, Measure, Analyze, Improve and Control. For each phase, there are tools that can be used. The cyclical design ensures continuous improvement
- Automatization
  Something is automatic, when the behavior is defined, by programmers developed and happens without human intervention
- Autonomization
  Something is autonomous when decisions and independent reactions are made in individual situations and to a changing environment
- Industry 4.0
  Industry 4.0 means the digital linkage between humans, machines and products and the digitalization of the industrial production
- Internet of Things
  The Internet of Things [IoT] describes the connection of products and devices, the collection of data from them, and finally the internet- and cloud-based communication with the connected devices among each other and with the humans
- Industrial Internet of Things
  The Industrial Internet of Things [IIoT] means the use of the IoT especially in the context of industry