Diversity of Future Mobility

- Automotive Landscape 2025 –

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Summary

The text gives an overview about the automotive landscape in 2025 based on a global view. In the first section the global megatrends and the framework conditions are identified. Then it reviews the main technical developments with a special focus on electrical and hybrid vehicles. In addition the efficiency chains for propulsion systems with combustion and with electric motors are compared. It will be shown that eMobility without the use of renewable energies is not sufficient to enable an extensive green transport system. This will then be followed by exemplifications concerning the economics of Electric & Hybrid Powertrains and an outlook on the development of the market for fully or partly electrically driven vehicles.

The Market Forecast for passenger cars, based on data gathered at the CAR Center for Automotive Research, Germany, is the focus of the last part of the presentation.
1 Structure

The presentation is structured in five sections:

- It commences with a short discussion about global Megatrends which is bound to influence the development of automotive mobility in the years from now to 2025.

- It will also look at the framework conditions from various sides.

- The third part of the presentation summarizes the main technologies currently available.

- This will then be followed by remarks concerning the economics of Electric and Hybrid Powertrains and an outlook on the development of the market for fully or partly electrically driven vehicles.

- The Market Forecast for passenger cars, based on data gathered at the CAR Center for Automotive Research, is the focus of the last part of the presentation.
2 Introduction - Megatrend

We commence with a short discussion about global Megatrends which is bound to influence the development of automotive mobility in the years from now to 2025.

Looking at the various reasons for the rapid change of the global Automotive Landscape and especially the still omnipresent discussion about electrically driven vehicles, a couple of aspects can be identified.

The most important ones are

• The obvious geopolitical shift towards Asia and in particular the major role of China within the context of future mobility

• Changing global demographics,

• Sustainability and especially limited resources for fossil energies,

• A strong trend versus a much diversified use of mobility. Young people tend to refrain from buying their own car. Instead, they utilize different means for transportation very flexibly.

• And of course the rapidly changing technological possibilities
3 Framework Conditions

Looking at the various and omnipresent reasons for the drastic change of the automotive landscape, a couple of aspects can be identified.

The most important ones are

- climate protection,
- development of global demographics,
- limited resources for fossil fuels,
- legislation,
- technical and cost requirements,
- along with various obstacles on the road towards green mobility and transportation.

The most important player in this game: THE CUSTOMER.
The customer is the one who has to accept and at the end to pay for the new technologies.

The use of fossil energies for transportation purposes is due to the fact that internal combustion engines directly contribute to its consumption and is hence intricately linked to the questions

- What is the development of oil production in the short-term and long-term future?
- How can the vanishing oil be substituted?

The chart presented in Figure 3.3 shows the historical and projected figures of crude oil production from 1940 to 2050. It is obvious that starting now, give or take a few years, oil has to be substituted
continuously by other energy sources or fuels based on renewable resources.

Still, it is also obvious that, with respect to 2025, oil will continue to be available, but as we are all experiencing these days – and this is only the beginning – the price for fuels based on crude oil will continue to rise. Presently I would make no guess for fuel prices in 2025 however for the crude oil price we estimate a price of 350$ in 2025.

Another strong argument to increase efficiency and reduce \( \text{CO}_2 \) emission is owed to the fact that the world’s population is still increasing. Even more relevant than that, the per capita income is
also increasing rapidly in various countries especially in the so-called BRIC states Brazil, Russia, India and China. Figure 3.5 shows an economic model derived from historical data and the extrapolation into the future (Figure 3.6). It describes the increase of the number of vehicles in conjunction with the per capita income experienced by the US and other countries earlier. It is now assumed that all the countries shown in this chart will continue to develop along the same curve.

If we trust these figures then the number of vehicles will increase from 600 Million vehicles in 2002 to no less than 1500 Million vehicles in 2030. It can be expected that the number of cars alone in China will increase from 20 million cars in 2010 to more than 390 million cars in 2030.
Another aspect of future development of mobility is the development of global demographics.

It is well known that the average age of people in the OECD countries will continue to increase and accelerate in the future. However this is also the case in other regions like China, India and even Africa. So the share of people older than 56 years in the OECD countries will increase from 14% in 2010 to 17% in 2025 and 22% in 2040.

Moreover it is forecasted that 3 out of 5 people will live in cities or urban regions called megacities in 2030.
The share of older drivers will increase globally as we could see.

But what could be said about the younger generation?

Figure 3.10 illustrates that young adults tend to decrease the percentage of their travel distances with their individual cars and increase the use of public transportation. The only exceptions are the US and Japan. From that we have to conclude that the wish to own a car will decrease.

This will lead to a much higher diversity in transportation and a trend to intermodal transport systems.
Now let us have a look at the role of the lawmaker concerning the emission of carbondioxid - CO$_2$:
The lawmakers worldwide meanwhile try to control and reduce the CO₂ and as a consequence also the fuel consumption by setting targets which are reduced every few years. This chart shows the targets for major regions. At the moment it is the EU setting the most restrictive targets.

In order to control the CO₂ emissions the use of the vehicles has to be defined in terms of velocities and other aspects. This is done very differently in different world regions. Figure 3.13 shows some examples.

![Very High Diversity in International Driving Cycles](image)

Figure 3.14: International Driving cycles

- The cycle relevant for the EU is since more than 30 years the so called New European Drive Cycle NEDC. The NEDC however only serves as a possible standard user profile for such a vehicle. It is
a synthetic drive cycle and was invented to compare different vehicles and vehicle-classes against a common standard.

This drive cycle also requires that all auxiliary aggregates be shut down. It can therefore not serve as a real load indicator. The NEDC is also not directly applicable to vehicles with electrical or hybrid drives. Therefore working groups work on the definition of new drive cycles.

Investigation at our institute showed that the difference between the fuel consumption in real applications and the NEDC is between 15 and 25% dependent on the car manufacturer and application.

It might be interesting to see the energy used by a compact class car like a Volkswagen Golf during that approximately 1200 s of travel. The energy needed is about 1,403 kWh and splits in one third for tire resistance, wind resistance and acceleration respectively.

![Figure 3.15: Energy used by a compact car](image)
One of the major obstacles of increasing the efficiency of cars is the increase of vehicle masses during the last 3 decades. During this period the unloaded masses of all cars went up on an average by 25 to 50%. Only since two years we experience a trend to a reduction of the masses and we expect the next generation of vehicles to have a weight which is reduced by around 5 to 10 percent.

Figure 3.16: Mass unloaded car – basic configuration (+ 25 ... + 50 %)

Figure 3.17 is based on approximately 350 different car models and shows the development in Europa. However it was very much the same in other world regions. This increase was mainly due to the introduction of various comfort and safety systems.
It has to be acknowledged that the average fuel consumption of European cars has been reduced by nearly 35% during the same time period. These improvements are due to improved engines, tires with reduced rolling resistance and a variety of other improvements. And there is still technical potential for another 20% reduction throughout all classes of passenger cars. This holds for gasoline as well as for Diesel driven vehicles.

One of the most important factors which influence the overall traction force is as we saw the mass of the vehicle. Except the air drag force it will have an effect to the rolling resistance, the grade resistance and also the acceleration resistance.

The resulting impact for passenger cars in Germany in 2010 is shown in the pictures below. It can be seen that the increase of the mass will result in higher fuel consumption of approximately 0.5 l per 100 km for both Diesel and Gasoline engines.
Although the mass of a typical vehicle was increased during the last 3 decades it now appears that the masses start to decrease for new car models like for instance the Golf 7 and the BMW 1 series. This is achieved by

- Downsizing of the engines while keeping their performance at the same level using supercharging or hybrid solutions.
- The use of new lighter material or common material with improved properties, like for instance steel with improved shape and hardness.

The result of these methods is exemplified with the new Golf 7 which has a mass which is 100 kg less than the Golf 6.

Other measures are the shift from passive safety which needs mass to active safety or completely new design concepts.
It has proven to be a good practice to assess the aptitude of various automotive propulsion systems by comparing the so-called “well-to-wheel” efficiency.
• If we look at the conventional combustion drive train first we have to acknowledge that even at the very beginning of the efficiency chain about 15% energy is lost, during the exploration process. Even worse: The efficiency in this field is still further decreasing.

• The biggest negative impact on the efficiency however is caused by the combustion engine with an average efficiency of less than 20%. Taking all this into consideration the conclusion is that as little as 15% of the energy originally stored in fossil resources is being used at the wheel.

• If we now assume that alternatively the energy is won from renewable sources the efficiency gain at the wheel is 65%. This is owed mainly to the outstanding efficiency of electrical drive trains with even more than 80%. This however is an idealized view which does not include the expenditure and investment necessary to establish the technical foundation for the energy generation. Nevertheless the gain is still undisputable.

• If we reconsider this process, but this time taking into account the fact that today normally electrical energy is won in power plants with an efficiency of 53%, in the best case, the total well-to-wheel efficiency decreases to 29% which is still much more than that obtained with conventional power trains. Why is there such huge a discrepancy in the efficiency of a combustion engine and a power plant? The power plant is always operated near its maximum efficiency while the combustion engine in a car only at times operates near that level, but under practical traffic conditions it is bound to be much less efficient.
As a compromise during the transition period the so-called hybrid power trains are being frequently used in contemporary cars. This can still give energy savings up to 30% depending on the degree of hybridization.

However this discussion does not adequately reflect the real usage of cars. Today’s combustion engines – along with the creation of torque – also serve to heat and cool the passenger compartment. At least for heating this means that a considerable part of the seemingly lost “heat” energy is used to heat the car. For an electrically driven powertrain these function has to be replaced by electrical energy.

![Figure 3.22: heating and cooling the passenger compartment](image)

Even after taking this into consideration one can note that an electrical powertrain is still more efficient than a combustion powertrain but the difference is now no longer as big as one might expect. Therefore the overall conclusion is:
• As long as the electrical energy for a BEV has to be produced by conventional power plants using fossil fuel there is no big advantage for an electrical powertrain

• The situation changes drastically if the electrical energy comes from renewable sources like wind or solar power plants

In Hybrid cars the electrical part of the powertrain is mainly used to enable the combustion engine to run at a higher efficiency level

The already mentioned increased number of older drivers, contributes to the introduction and roll out of driver assistance systems throughout all classes of cars.

Figure 3.23 shows an example for an automatic collision avoidance system using car to car networking techniques developed at our institute.

Figure 3.24: Automatic collision avoidance system

Talking about the introduction of new powertrains and other systems like driver assistance systems one always has to take into account the
Automotive Product cycle. Typically it takes 24-48 months to introduce a new car generation on the market. The Product Lifecycle then typically lasts for another 48 to 84 months. Having said that, we have to conclude that we can, at the most, expect only two to three car generations between now and 2025 let alone the fact that the majority of cars on the roads will still have older technical features.

![Automotive Product Cycle Diagram](image)

**Figure 3.25: Automotive Product Cycle**

As a result of the discussion about efficiency, one might question why the combustion engine has been so predominant for more than 100 years. It ruled the automotive world since Gottlieb Daimler walked into the patent office in Mannheim Germany more than 120 years ago and had his patent approved for the first combustion engine.

The answer is: At the beginning of the 20th century, cars with electrical engines initially dominated the market for a short period of time. The reason why the combustion engine finally came to
dominate the market ever since, was simply the lack of energy density in batteries.

**Example: Ford Transit BEV**

Figure 3.26: Technical Limitations

Figure 3.27 shows that in order to store the same amount of energy in an electro-chemical battery which is contained in 4,5 l of fuel one would need a Li-Ion Battery with a capacity of 40 kWh and a weight of no less than 400 kg. If we take into account the efficiency advantage of the electrical machine this battery would compete with approximately 23 l of fuel which is still way off an adequate proportion.

On the other hand there are various investigations on the distances actually traveled under daily conditions. The chart in Figure 3.28 shows the number of cars in Germany driven over a certain distance.
on a daily basis. It shows that a potential travel range of 100 km would basically be sufficient for more than 90% of all journeys. This result might of course be different in other countries. However it also shows that an alternative use of cars as for instance in car-sharing systems might be a solution for the future.

Figure 3.29: Daily travel distance of passenger cars in Germany
4 Technology of Electric & Hybrid Vehicles

As we all know there will be many efforts to realize electric or electrified powertrains. In the next section I will give a brief overview over the basic principles of those powertrains and the different technologies.

![Diagram of Degree of Hybridization](image)

The trend is in the direction to eventually purely electrically driven vehicles in the distant future. It will be paved by various types of, more or less complex structured, hybrid drive trains. We will look at that nomenclature of the terms Micro Hybrids, Mild Hybrids and so on. There are basically two different ways of structuring. The first one refers to the Degree of Hybridization.

- A very basic **first step** is the Micro-Hybrid. This type of Hybrid is simply characterized by the presence of a start-stop system,
which means that the engine is switched off during standstill of the vehicle but also some of the auxiliary aggregates are driven electrically, instead of hydraulically or directly by the combustion engine. An example for this is the BMW 1 series.

- In a second step, the Mild Hybrid, the electrical motor is used to reduce the dynamics of the combustion engine by providing additional power to boost the drive train. Normally this system also offers the feature to save energy by recuperating the kinetic energy into the electrical system of the car. As modern cars often have an electrical power consumption of more than 1 kW, this can be an effective method to reduce the fuel consumption. However even this system does not allow for pure electric driving. One of the cars with this functionality is the Mercedes S400.

- Pure Electric Driving comes with the Full Hybrid System. The most famous vehicle of this kind is the Toyota Prius which offers the feature to drive at least small distances purely electrically.

- Finally the Plug-In-Hybrid offers the opportunity to drive electrically over greater distances. The combustion engine is only used to provide, via the generator, electrical energy for the electric motor in order to increase the potential driving range. This type of Hybrid is sometimes called Hybrid with range extender. The most current vehicle with this feature is the Opel Ampera or the GM Volt.

- The general targets of all these technologies are
  - Optimization of the efficiency of the combustion engine by intelligent operation strategies and recuperation of braking energy
o The classification follows the degree of hybridization and topology
5 Economics of Electric & Hybrid Vehicles

But the technical point of view is not the only one! Electrified powertrains have to be competitive with the conventional cars with a combustion engine. Especially the required battery drives the price of an electrified car.

A frequently asked question is related to the additional cost necessary for electrical and hybrid vehicles. This additional cost is in both cases mostly related to the battery. Let us look at a rather simple calculation for an electrical power train for a purely electrically driven vehicle. The basis is set by a compact European car with a cost of around 20000€.

- The removal of the combustion engine along with the gearbox and the fuel tank reduces the total cost by approximately 4000€.
- The electrical power train without the battery adds approximately 2000€.
- If we assume the car to be operational for about 5 years and with a running distance of around 100,000km the operating cost could be reduced by 5000 € which leaves in this very optimistic scenario a cost margin of 7000 € for the battery.
- If we were to further target at a range of 150 km then a battery with at least 30 kWh is required.
- This restricts the cost for the battery to 233€/kWh. For comparison the most optimistic estimated cost is 500€/kWh today.
Furthermore private people might not calculate like this. As a result from interviews of potential customers conducted during our investigations we have come to acknowledge that the selling price plays the key role.

![Figure 5.1: Economics of Powertrains – First Approach BEV](image)

Figures 5.2– 5.3 show the development of cost and reduction of CO₂ emission on a medium timescale.

If we consider the local CO₂ emissions only, the situation is shown in figure 5.4 and figure 5.5.
• However if we also consider the emissions generated during the production of electrical energy the situation is worse.

Of course there will be major improvements and a steep learning curve during the next 15 years. This leads to the situation shown in Figure 5.8. It can be seen that we look forward to significant
improvements for all types of concepts, even for the optimized combustion engine. At the same time the additional cost for electrification will go down in all segments. This is due to the well-known learning curve in automotive industry which drives cost down within very short times.

![Figure 5.9: CO₂ Reduction Potential vs. Cost 2025(EU-Fuel Mix)](image-url)
6 Market Forecast 2012 – 2025

The question to be asked next is: How will technical and economical advances influence the development of global car production figures. This is like looking into a crystal sphere. However let’s give it a try.

![Figure 6.1: Passenger Car Registrations](image)

Translating the tendencies mentioned in terms of market shares, we estimated in our CAR institute the global number of car registrations. The result based on an aggressive yet realistic assumption of an crude oil price of 350$ per barrel in 2025 that
• only 30% pure combustion cars will be left in 2025
• but around 35% of mild and full Hybrids
• still less than 20% of Plug-In-Hybrids
• and still less than 5% battery electrical vehicles
• Small but from then on increasing numbers of fuel cell vehicles.

Moreover we expect massive development of eMobility in China and significant total growth only in the BRIC states.

The battery is one of the most important factors for the performance (range) and the prize of an electric car. Due to the technical restrictions, the costs and maybe the “fears” of the costumer there will be various possibilities to “provide” mobility.

• E.g. Renault sells a car w/o a battery. The energy storage will be leased. In this case the customer doesn’t have to pay for the battery and will not have the risk of a costly damage of the energy storage.

• The second possibility is the conventional one. Here the customer will buy the whole car including the battery.

• A new approach would be to sell a package containing the energy needed.
If we recall that there is a strong trend especially in the group of young people to switch between several transportation systems we talk about integrated mobility. Let’s dig a little bit deeper into this topic.

As a consequence various models for integrated mobility models are being created. An example is shown in figure 6.3. Ruhrauto is an integrated mobility concept which will be realized during the next years in the Ruhr area in Germany. We are working as the scientific coordinator of the concept. Other partners are

- A car-sharing company.
- OEMs providing the cars.
- Local housing associations providing contracts for flats including a tailored mobility concept.
- And public transport systems.
There will be a transition from vehicles with combustion engines to E-Mobility. However this path will be paved by a variety of other solutions mainly dedicated to alternative fuels preferably from renewable sources. As of today combustion engines are mainly driven by oil-based fuels with other fossil fuels like CNG and LPG being used in minor quantities.

- In 2015 we will see more Biofuels along with a strong growing number of Hybrid and Hybrid plug-In cars.
- In 2020 the Hybrid car will grow further along with an increasing share of electrical energy supply.

From 2025 we will see the first considerable share of electrically driven vehicles and the first fuel-cell vehicles.
This forecast is also reflected by major OEMs with their product strategy like for instance Volkswagen. This chart shows the propulsion systems planned to be introduced along with the new MQB –System. MQB stands for “Modularer Querbaukasten”. Loosely translated this means Modular Packaging Matrix. They are preparing for combustion engines, electric powertrains as well as for alternative fuels.
Figure 6.6: OEMs plan for diverse propulsion systems
[Example: Volkswagen (+ Audi, Skoda, Seat), Source: Volkswagen AG]
7 Final Statements

• The era of fossil fuels is still far from being over
  o BUT the era of cheap oil is definitively over
  o Alternative Fuel will support the transition

• Driver Assistance Systems will become commodities
  o Trend from comfort to safety applications

• Hybrid Vehicles will offer the best value to customers
  o Market Share for Hybrid Propulsion Systems > 75%
  o Market Share for BEV still less than 5%
  o Fuel Cell still no breakthrough

• New Business Models
  o Car Sharing Programs mainly in cities