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# PROGRESS IN THE CONSTRUCTION OF PASSENGER CARS AS A RESULT OF $CO_2$ EMISSION LIMITATION

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***Abstract***

*Global warming is a scientifically proven fact. Much of the temperature rise on the surface of the globe has been caused by human activity. That is why several years' efforts are aimed at reducing of $CO_2$ emissions, related to the human activities. Major sources of $CO_2$ emissions include electricity production from fossil fuels, transport sector and intensive agriculture. Cutting down forests also contributes climate changes. In the field of transport, decisions are made at the level of the European Commission, and also by the wider audiences of introducing limits for $CO_2$ emissions entire fleet of new passenger cars for year 2015, 2021 and later. The actions taken by car manufacturers are diverse. Cheaper and simpler solutions are focused on the concept of micro-hybrid based on a system of 48 V. More advanced solutions are a wide range of hybrid vehicles, including PHEV, and pure electric vehicles. The use of lighter materials, improved aerodynamics and rolling resistance, more efficient internal combustion engines and gearboxes also have an impact on energy demand and, consequently, $CO_2$ emissions. An important problem to solve in many countries is the dissemination of renewable energy sources rather than fossil fuels. This article presents an outline of the issues related to eco-friendly solutions, including requirements for batteries intended for this type of vehicles. It also presents an overview of European standards in this area and progress in advanced energy sources.*

***Keywords:*** *Hybrid Electric Vehicles, Electric Vehicles, battery, capacity*

## 1. Introduction and ecological challenges

The main premise for increasing market share of ecological vehicles is $CO_2$ emissions from cars. It affects global warming. Although the share of cars in global $CO_2$ emissions is estimated at 12%, but the society can have an impact on reducing emissions by forcing ecological solutions. EU legislation stipulates that the average $CO_2$ emissions of passenger vehicles fleet per km in 2015 are limited to 130 g/km and 95 g/km in 2021. Since the development and introduction of new models to the market lasts several years, the problem is already up to date. If you measure the average specific power consumption of modern electric vehicles at 0.15 to 0.2 kWh/km, it can be estimated the actual impact of transport on $CO_2$ emissions by analysing current $CO_2$ emissions from electric energy production systems in different European countries. This implies that the introduction of eco-friendly vehicles is only a partial solution. In this case, the environmental impact is also related to the electricity production that will be used to charge the battery. As long as electricity production in some countries is based on fossil fuels, achieving the goal of limiting global warming will be difficult. Tab. 1. contains a summary of equivalent $CO_2$ emissions by a hypothetical electric vehicle with a specific energy consumption of between 0.15 kWh/km and 0.2 kWh/km. Because of the seasonal changes in $CO_2$ emissions from energy systems, two of the actual values are assumed to be respected.

## 2. Driving cycle incompatibility

The increase in the share of hybrid and electric vehicles entails the need for uniform standards for infrastructure and battery charging systems, vehicle testing, and so on. Manufacturers of

Tab. 1. Equivalent emission of $CO_2$ in some European countries [6]

| Country | Electricity production $CO_2$ emission [g/kWh] | Equivalent of $CO_2$ emission – vehicle energy consumption 0.15 [kWh/km] | Equivalent of $CO_2$ emission – vehicle energy consumption 0.20 [kWh/km] |
|---|---|---|---|
| Poland | 600 | 90.0 | 120 |
|  | 800 | 120.0 | 160 |
| Estonia | 800 | 120.0 | 160 |
|  | 1300 | 195.0 | 260 |
| Norway | 10 | 1.5 | 2.0 |
|  | 40 | 6.0 | 8.0 |
| Germany | 250 | 37.5 | 50.0 |
|  | 450 | 67.5 | 90.0 |
| Sweden | 30 | 4.5 | 6.0 |
|  | 50 | 7.5 | 10.0 |

ecological vehicles declare the vehicle range specified in laboratory conditions using standard driving cycles. Due to the large variations in the driving cycles, there are significant differences in the declared range of the electric vehicle (EV) vehicle. For example, the Tesla S90D car has a declared 557 km range in accordance with the NEDC test, but only 473 km according to the EPA test. Percentage differences in individual cases range from 15 to 30% [1]. The NEDC test overwhelms the expected performance of vehicles. Such a state has led to the introduction of a worldwide-harmonized test procedure called the Worldwide Harmonized Light Vehicles Test (WLTP). It is expected that the results of the tests carried out according to the new procedure will be closer to the real world. For comparison, simulations of hypothetical, light electric vehicle performance were performed using 3 different driving cycles. A vehicle with a total weight of 1088 kg with driver and passenger, in which the electric propulsion unit was powered by a 7.8 kWh electrochemical battery. Assuming an acceptable discharge level of the Depth of Discharge (DoD) battery = 90% and 7.0 kWh of energy is still available in each case. For comparison, 3 cycles were selected: European Urban Driving Cycle (EUDC), Urban Dynamometer Driving Schedule (UDDS) and The Manhattan Bus Cycle. *This drive cycle is provided mostly for buses. It could be used for other purposes. The cycle contains frequent stops and very low speed drive periods.* The simulation results are summarized in Tab. 2.

Tab. 2. Vehicle performance in different driving cycles

|  | EUDC drive cycle | UDDS drive cycle | Manhattan cycle |
|---|---|---|---|
| Consumed energy [kWh] | 6.70 | 6.79 | 6.91 |
| Specific energy [kWh/km] | 0.15 | 0.15 | 0.23 |
| Recuperated energy [kWh] | 0.34 | 0.54 | 0.56 |
| Test duration (0.9 DoD) [h] | 1.56 | 1.36 | 2.69 |
| Average velocity [km/h] | 29.1 | 32.6 | 11.1 |
| Vehicle range [km] | 45.4 | 44.4 | 29.9 |

Due to the low average velocity of the vehicle in the Manhattan cycle, its range is significantly lower. Worse are other parameters, such as specific energy consumption in kWh/km. Fig. 1. shows the course of the test according to the EUDC cycle and the state of the battery charge. Fig. 2 shows the course of the test according to the UDDS cycle and the state of the battery charge. Fig. 3 shows the test run according to the Manhattan cycle and the state of battery charge.

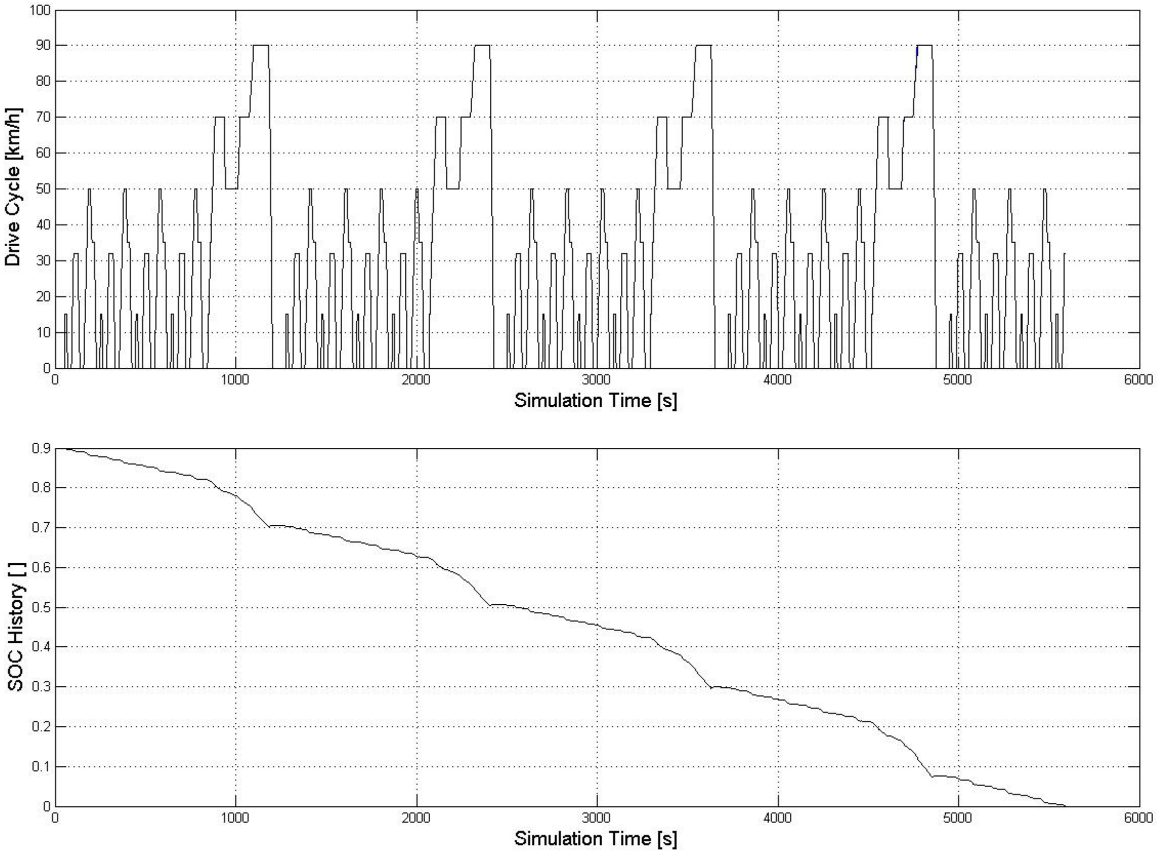

*Fig. 1. Discharge of the battery in the EUDC driving cycle (0.9 DoD)*

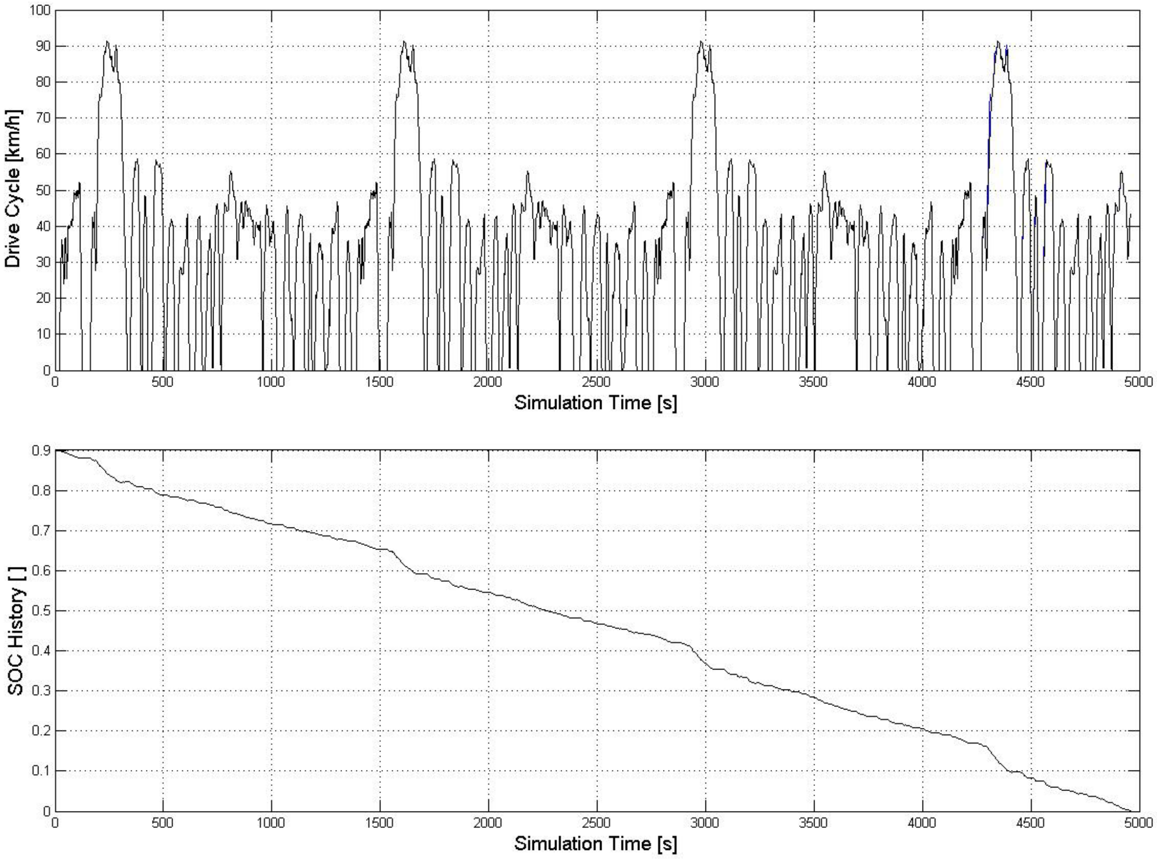

*Fig. 2. Discharge of the battery in the UDDS driving cycle (0.9 DoD)*

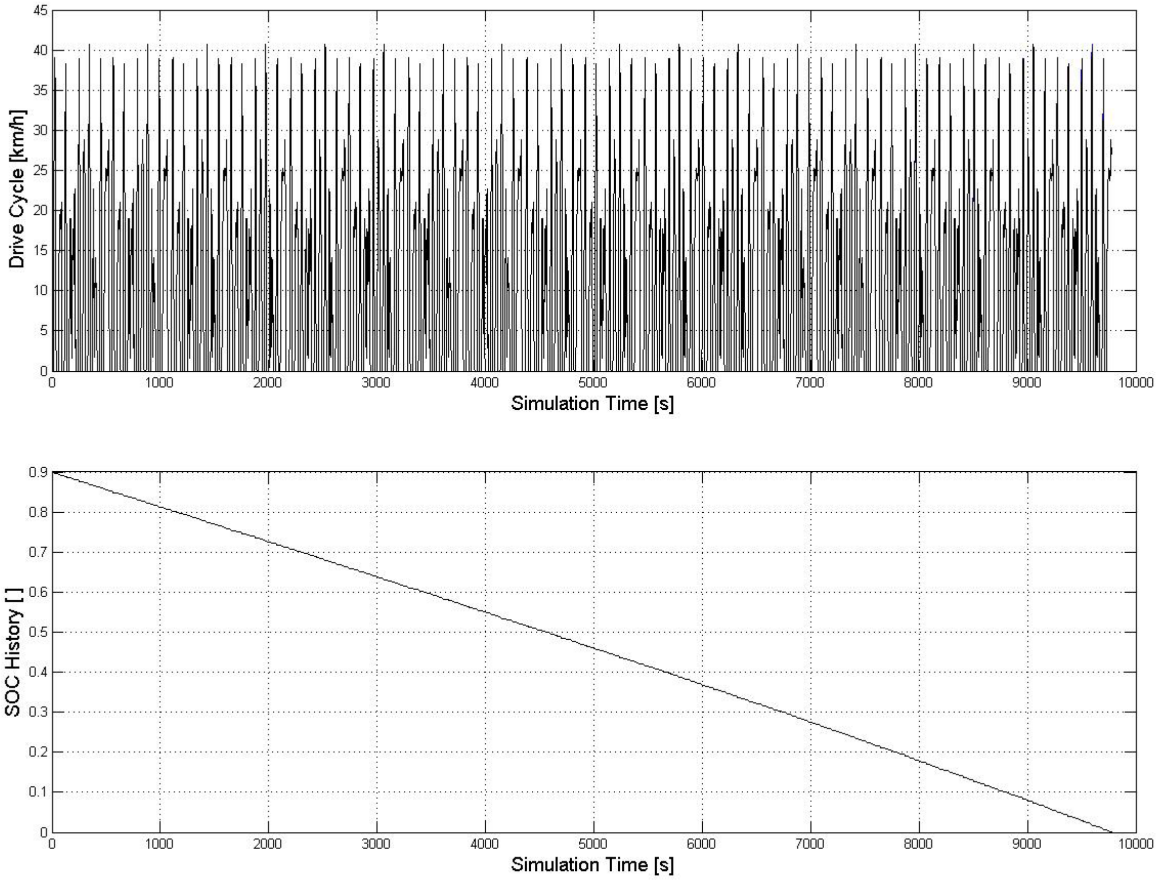

*Fig. 3. Discharge of the battery in the Manhattan driving cycle (0.9 DoD)*

## 3. Traction batteries requirements

Ecological vehicles driven entirely or partly by electric propulsion units are divided into three categories: pure EV electric vehicles, hybrid HEVs, and hybrid vehicles with battery charging capability. In addition, vehicles equipped with a 48 V system can be distinguished. Due to specific applications, each of these types of vehicles has specific requirements for power units and power stores, most commonly electrochemical batteries.

### 3.1. Battery requirements for EV vehicles

The battery for electric driven vehicle must be able to deep discharge and operate in a wide DoD range (up to 80% DoD). Operate in this area must be permissible permanently. Full power is required throughout the entire charge range (even at low load levels). Battery manufacturers for electric vehicles must provide a wide range of batteries for vehicles of different purposes. The ability to charge the battery quickly is a necessity for EVs (fast charging currents above 5C) of at least 80% Tate of Charge (SoC). Refilling energy to full capacity can take place at reduced performance. The requirement for high charging currents also applies to regenerative braking conditions. It is also possible to charge with lower currents (up to 2C) at home using conventional power distribution grids. Management systems should monitoring the limits. They prevent them from exceed. It is therefore necessary to equip the vehicle with electronic management systems such as Battery Management System (BMS), Battery Thermal Management (BTM) and others. Typical battery sets voltages are above 300 V. Battery capacity for EV vehicles ranges from 20 kWh to 100 kWh. Concentrating on discharge currents, they should be between 1C for continuous operation and 3C for instantaneous operation.

### 3.2. Battery requirements for HEV vehicles

In the case of hybrid vehicles, it is necessary to distinguish between different configurations of hybrid vehicles. Other requirements will be for serial HEVs and others for parallel HEV. In the series HEV case, the internal combustion engine only drives the generator, while the mechanical power is supplied to the wheels only by the electric machine. Thus, with respect to the battery for the series HEV, the requirements are the same as for the EV, but at lower capacities and voltages. In the case of a parallel hybrid configuration, mechanical power is supplied to the vehicle wheels by both the internal combustion engine and the electric machine. The power distribution range differs in particular solutions and depends on operating conditions and design assumptions (e.g. in terms of electrical machine size selection). Battery capacity for the parallel HEV is relatively low (1.5-10.0 kWh), but batteries can be temporarily loaded with high currents (40C). The battery should be capable of full power, with a large number of deep charge/discharge cycles (up to 1000) and an unlimited number of incomplete cycles. Battery operation range is limited to SoC (20-70%). The above principle is due to the readiness of the battery to receive energy from the regenerative braking system, so the batteries for parallel HEV are not operating under extreme conditions, i.e. full discharge/full charge. This significantly affects battery life. The vehicle must be equipped with battery diagnostics and continuous battery parameters monitoring (especially the SoC level). These systems are naturally associated with the main control system of energy flow management and energy conversion in the vehicle. Typical parameters energetic capacity, from 1.5 to 10 kWh, voltage above 200 V and power up to 40 kW, depending on the size and purpose of the hybrid vehicle.

### 3.3. Battery requirements for PHEV

The rapidly evolving category of hybrid vehicles with the ability to recharge the battery creates new requirements for the batteries used in these vehicles. They are primarily related to the intended purpose of the vehicle. If the vehicle is to be used in conditions that require a high electric range (typical for city driving), the batteries should meet similar requirements as for EVs. On the other hand, if the vehicle is primarily intended for outside urban areas traffic, similar requirements apply to HEV vehicles. PHEV vehicles have limited range in pure electric driving compared to EV vehicles (up to 60 km).

### 3.4. Vehicles with 48 V system

The use of 48 V technology can achieve the goal of reducing $CO_2$ emissions at acceptable costs and using low and safe system voltages. The 48 V level does not require the use of special safety features required in higher-voltage vehicles (EV, HEV, PHEV). Tab. 3 lists the main traction batteries for different vehicle categories. This solution has functionality: Stop & Go, regenerative braking, boosting and coasting. Emission of such vehicles is below 95 g $CO_2$/km.

*Tab. 3. Traction batteries parameters*

| | EV | HEV | PHEV | 48 V |
|---|---|---|---|---|
| Energy capacity [kWh] | Up to 100 [kWh] | 1.5-0.0 | Up to 50 | 0.2-3.0 |
| Operating current [A] | 1C permanent<br>3C temporary | 10C permanent<br>40C temporary | 3C permanent<br>20C temporary | 100 A<br>up to 200 A |
| SoC operating range [%] | 20-90 | 20-70 | 20-90 | 20-90 |
| *where C is nominal energetic capacity [kWh]* | | | | |

Figure 4 shows the course of Li-ion battery voltage changes as a function of charge reduction. The course of changes in this curve makes it easy to monitor the battery and to indicate the remaining battery charge.

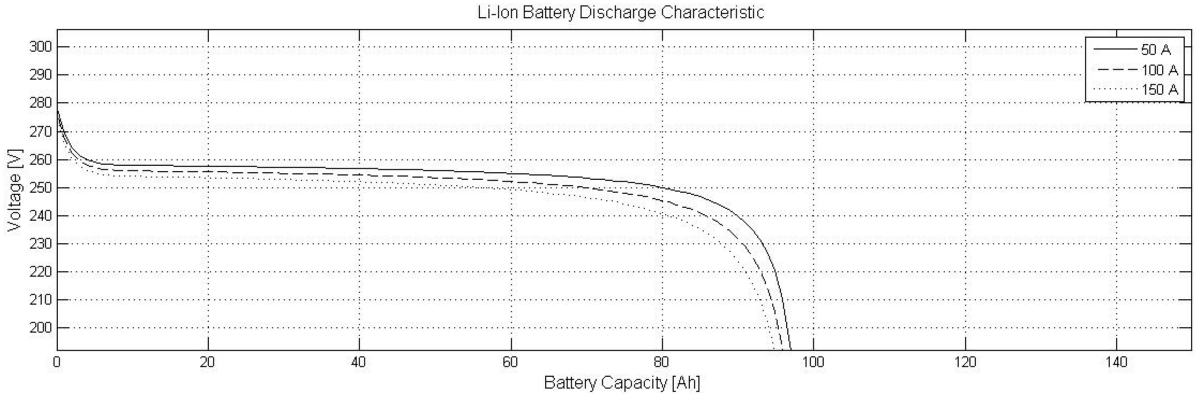

*Fig. 4. Li-Ion battery voltage vs State of Charge*

## 4. European standards

IEC 62196-1 (PN EN 62196) *Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles – Part 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers* [2].

The standard is applicable to vehicle computer, plugs, socket-outlets, connectors, inlets and cable assemblies for electric vehicles, charged via conductive connection. The operating voltage of such a systems cannot exceed 690 V AC and current to 250 A and 600 V DC and current to 400 A.

IEC 62851 (PN EN 61851) *Plugs, socket-outlets, vehicle couplers and vehicle inlets – Conductive charging of electric vehicles* [3]. The standard defines four modes of charging batteries: *Mode 1:* Slow charging from a household-type socket-outlet. In Europe, this means single-phase 16 A 230 V, 3 kW socket. EV can be equipped with a cable for connecting the socket and the vehicle. *Mode 2:* Slow charging from a household-type socket-outlet with an in-cable protection device. *Mode 3:* Slow or fast charging using a specific EV socket-outlet with control and protection function installed. *Mode 4:* Fast charging using an external charger.

IEC 61851-1 also describes the pilot signal, which communicates the charging requirements by means of PWM method [5]. Tab. 4 lists the standard charging parameters.

*Tab. 4. Details of charging modes*

| Charging Mode | AC grid type (phases) | Maximum current [A] | Maximum power [kW] | Estimated charging time [h] | EV connector type |
|---|---|---|---|---|---|
| Mode 1 | 1 or 3 | 16 | 3.7 | 5.5 | A, B |
| Mode 2 | 1 or 3 | 32 | 22 | 1.0 | A, B |
| Mode 3 | 1 or 3 | 63 | 44 | 0.5 | A, B, C |
| Mode 4 | DC | 400 | up to 200 | 0.1 (CC phase only) | C |

IEC 61980 *Electric vehicle wireless power transfer (WPT) systems - Part 1: General requirements.*

The regulations included in IEC 61980 standard apply to equipment the wireless electric power transfer (WPT) to the Electric Vehicle energy storage. The technologies considered here include:

- inductive power transfer (MF-WPT, electric energy transferred through the magnetic field),
- capacitive power transfer (EF-WPT, electric energy transferred through the electric field),
- microwave power transfer (MW-WPT, electric energy transferred through electromagnetic waves in range 1 GHz to 300 GHz),
- infrared power transfer, (IR-WPT, energy is transferred through electromagnetic waves in range 300 GHz – 400 THz).

The standard describes the following issues:

- the characteristics and operating conditions,
- the specification for the required level of electrical safety,
- requirements regarding basic communication for safety and process matters if required by a WPT system,
- requirements for basic positioning of the primary and secondary devices, efficiency and process matters – if required by a WPT system,
- specific EMC requirements for WPT systems.

Directive 2006/66/EC – *after making changes, the directive creates uniform system for collecting and recycling worn out batteries.* Directive applies to all kind of batteries because any battery contains harmful substances. Some materials can be recycled and reused in future production process.

EU Regulation No 333/2014 of the European Parliament and of the Council *amending Regulation (EC) No 443/2009 to define the modalities for reaching the 2020 target to reduce $CO_2$ emissions from new passenger cars.* Regulation stipulates that fleet average $CO_2$ emissions per km in 2015 are limited to 130 g/km and 95 g/km in 2021. After 2050, new passenger cars should be zero-emission.

## 5. Materials for electrodes and electrolytes

The research and development of lithium based traction batteries focuses primarily on the introduction of new materials. In a typical lithium-ion battery, the main material used for negative electrodes is graphite. An important factor affecting the parameters of the battery is the active surface of the electrodes. For graphite, the active area is about 3 $m^2$/g while for Lithium-Titanate is much higher and is about 100 $m^2$/g. Lithium-Titanate [4] batteries could be characterized by very high values of specific energy and often they are consider as combination battery-supercapacitor. This means, that such kind of battery could accept high currents (charging) as well as deliver high currents (discharging). Therefore, fast charging mode using high power charging stations for such batteries is possible. This gives possibility to reduce recharging time. In this technology, such features have been obtained as a result of decreasing of battery internal resistance. Solid Electrolyte Interface (SEI) layer, which reduce battery capacity, was eliminated and negative graphite electrode was replaced with Lithium-Titanate compounds electrode. Much promising is the SnO compound, which is characterized by even greater porosity and active surface. In Lithium-based batteries, two types of electrolyte are used: liquid and solid. In automotive applications, safety systems must be used to prevent fires or explosions. Searching for new materials for electrolytes that will provide safety is one of the main areas of research.

## 6. Conclusions

Reduction of $CO_2$ emissions by the transport sector requires the introduction of solutions that rely more or less on the electrification of car drives. Depending on the purpose of the vehicle, there may be different requirements for the used traction batteries. The current state indicates the dominance of lithium-based batteries. Batteries of this type are characterized by good power and energy density values, but require careful operation during operation, as exceeding certain limits may result in the ignition of the battery.

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