Transport Research Laboratory

Electric vehicles: Review of type-approval legislation and potential risks

Final report

by C Visvikis, P Morgan, P Boulter, B Hardy, B Robinson, M Edwards, M Dodd and M Pitcher

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CLIENT PROJECT REPORT

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	Electric vehicles: review of type-approval legislation and potential risks
Client:	**European Commission, DG Enterprise and Industry**
	(Ferenc Pekár)

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The views expressed are those of the author(s) and not necessarily those of the European Commission.

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Executive summary

Directive 2007/46/EC establishes a framework for the approval of motor vehicles, and of systems and components intended for such vehicles. There are currently no specific technical requirements in the framework directive to address the characteristics and risks of electric vehicles. However, TRL understands that the European Commission (EC) intends to issue a proposal for a Commission regulation to amend the framework directive by specifying requirements for electric vehicles, including the mandatory application of certain UNECE regulations.

UNECE regulations provide for the approval of vehicle systems and separate components, but not whole vehicles. Many duplicate EC directives, although it is often the case that the EC directive lags behind the corresponding UNECE regulation. For instance, several UNECE regulations have been amended to contain specific requirements for electric vehicles, while the corresponding directives have not been amended.

The Commission awarded a project to TRL to review the type-approval legislation for electric vehicles and the potential safety risks. The specific objectives of the project were:

- To provide recommendations on the completion of EC (and also UNECE) type-approval requirements for electric vehicles;
- To assess potential risks associated with electric propulsion that are not covered by legislation, including EC and UNECE regulations;
- To provide recommendations on appropriate legislative action if potential risks are identified.

The project focused on M and N category vehicles, from mild hybrids to purely-electric vehicles. There were two main strands to the project. Firstly, the type-approval directives and regulations on vehicle safety and environmental performance were reviewed by TRL experts. The review determined whether the technical requirements were compatible with electric vehicles. Wherever the approval of an electric vehicle might present a problem (due to the way the directive or regulation was written), TRL examined international standards and non-EC legislation to identify solutions. Published literature was also sought. The intention was to propose outlines for amendments to the directive or regulation that would permit the type-approval of electric vehicles. Existing proposals for amendments were also taken into account.

The second strand of the project concerned the potential safety risks of electric vehicles. Many of the hazards associated with these vehicles will be dealt with through existing EC or UNECE type-approval legislation (provided that it is compatible). However, certain aspects of electric vehicles are potentially very different from convention vehicles. There may be additional risks that are not covered by the current legislation because it was written for conventional vehicles. TRL reviewed literature to identify such hazards and performed a technical analysis of the findings. It was not the intention to imply that electric vehicles are inherently unsafe or would expose the public to greater risks than conventional vehicles. Instead, the focus was on specific hazards that might not be regulated under current EC or UNECE type-approval legislation.

During the course of the project TRL engaged with a variety of stakeholders including vehicle manufacturers and their suppliers, type-approval authorities and test laboratories. This took place on an individual basis and during a meeting in Brussels for interested stakeholders.

Review of type-approval directives and regulations on vehicle safety

The review of type-approval directives and regulations on vehicle safety covered: fuel tanks; braking; radio interference; protective steering; identification of controls; frontal impact; side impact; buses and coaches; and electrical power trains. This revealed that:

- Purely-electric vehicles should be exempt from fuel tank requirements; however, several of the tests in the fuel tanks legislation are designed to mitigate risks that a rechargeable energy storage system might also be exposed to.
- The UNECE regulation for braking has been amended to include regenerative braking systems and proposals are in discussion to set thresholds for the activation of the brake lights.
- The radio interference legislation includes performance requirements, but references various international standards for the test methods. The standards usually include procedures to deal with electric vehicles, although some potential problems were identified, such as the vehicle load conditions and antenna positions.
- Proposals have been submitted to UNECE to amend UNECE Regulations 12 (protective steering), 94 (front impact) and 95 (side impact). These proposals will detail:
    - Amendments to the test procedures to accommodate electric vehicles;
    - Post-impact requirements to protect against electric shock, retain the rechargeable energy storage system and prevent leakage of hazardous fluids (such as electrolyte).
- There are no symbols in the legislation that must be used with electric vehicle controls, tell-tales and indicators. Symbols are available in an international standard and consideration could be given to regulating some or all of these symbols in the legislation. However, research may be needed to determine whether public understanding of these symbols might be an issue.
- The bus and coach requirements are largely independent of the power train. Approving an electric vehicle using the current legislative requirements should not present any safety risks, provided that the vehicle is approved to UNECE Regulation 100.
- UNECE Regulation 100 is not mandatory for type-approval. However, an EC proposal for a Council decision to apply Regulation 100 on a compulsory basis was adopted on 15 June 2010. Mandating the application of Regulation 100 will ensure that all electric vehicles provide for the same minimum level of electrical safety. Also, excluding electric vehicles (that are within the scope of the framework directive) from the low voltage directive (2006/95/EC) would avoid potentially unnecessary testing and assessment. Excluding on-board chargers within electric vehicles from the low voltage directive might also be appropriate, but only if corresponding amendments were made to UNECE Regulation 100 (and UNECE Regulation 10).

Review of type-approval directives and regulations on environmental performance

The review of type-approval directives and regulations on environmental performance covered: permissible sound levels; light-duty emissions; heavy-duty emissions; engine power; end-of-lie vehicles; reusability, recyclability and recoverability; and batteries. This revealed that:

- A revised version of the UNECE regulation for permissible sound levels is being trialled which includes provisions for electric vehicles. Provided that the revision is implemented, no further action would be required to accommodate electric vehicles.
- The legislation on light–duty emissions already sets out specific provisions for electric vehicles. This includes hybrid vehicles and also purely-electric vehicles (i.e. for energy consumption and range measurement). No further amendments are needed to accommodate electric vehicles in the short term. However, the

legislation does not provide any alternative measurement to tail-pipe CO_2 emissions for electric vehicles that takes into account the generation of the electricity. Further research is needed if the optimum alternative to tail-pipe CO_2 emissions is to be identified for electric vehicles.

- The legislation relating to exhaust emissions from heavy duty vehicles is based around engine-based tests. The test procedure cannot be applied to hybrid vehicles. Research is needed to develop vehicle-based test procedures (or engine-based procedures that take the end use of the engine into account) before any amendments can be made to accommodate electric (i.e. hybrid) vehicles. An informal group on heavy-duty hybrids has been set up under the UNECE Working Party on Energy and Pollution (GRPE) to investigate this issue. The work will be completed in 2014.
- The UNECE regulation on engine power has already been amended for electric power trains.
- The end-of-life vehicles legislation (not a type-approval act) does not present any particular problems for electric vehicles; however, consideration could be given to the definition of "reuse" and the possibility of reusing automotive lithium batteries in stationary applications.
- The reusability, recyclability and recoverability legislation is a type-approval act and is intended to compliment the end-of-life vehicle legislation. There do not appear to be any particular challenges for electric vehicles.
- Traction batteries would be classified as industrial batteries by the batteries legislation (not a type-approval act). The requirements do not present any particular problems for electric vehicles.

Potential risks of electric vehicles

The review of potential safety risks of electric vehicles examined: rechargeable energy storage systems; regenerative braking systems; electromagnetic fields; crash safety and acoustic perception. This revealed that:

- As mentioned above, there is a gap in the type-approval legislation relating to the safety and integrity of the rechargeable energy storage system (RESS). A number of standards are available that include RESS-level safety and abuse tests that are similar in nature to the tests performed on fuel tanks. While the energy density of a fuel tank is much higher than that of a RESS, there are currently no regulatory tests relating to, for example, fire or extreme temperatures.
- While some potential safety problems were identified in the literature for regenerative braking systems, there was insufficient evidence for any new safety hazards that are not controlled already by UNECE Regulation 13 and 13-H.
- The effect of electromagnetic fields on human health can be controversial and questions may be raised in the future about the performance of electric vehicles. However, scientific evidence for any effect at the intensity levels typically found remains weak.
- The frontal and side impact legislation is in the process of being amended to accommodate electric vehicles. However, other potential safety issues include:
    - The possible effect on collision injury statistics if there is a greater proportion of smaller, lighter electric vehicles on the road;
    - The safety of the rechargeable energy storage system for impact angles and severities different to those of the legislative tests;
    - Rear-end collisions and the implications for the rechargeable energy storage system;
    - The risk to occupants from submersion in water.

- Concerns have been expressed about the safety of cyclists and pedestrians (particularly visually impaired people), when crossing the road. Very little research has been published on the risk presented by quiet vehicles; nevertheless, audible warning devices have started to emerge.

1 Introduction

The European Commission (EC) awarded a project to TRL to review the type-approval legislation for electric vehicles and the potential safety risks. The specific objectives of the project were:

- To provide recommendations on the completion of EC (and UNECE) type-approval requirements for electric vehicles;
- To assess potential risks associated with electric propulsion that are not covered by legislation, including EC and UNECE regulations;
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The project focused on M and N category vehicles, from mild hybrids to purely-electric vehicles. There were two main strands to the project. Firstly, the type-approval directives and regulations on vehicle safety and environmental performance were reviewed by TRL experts. The review determined whether the technical requirements were compatible with electric vehicles. Wherever the approval of an electric vehicle might present a problem (due to the way the directive or regulation was written), TRL examined international standards and non-EC legislation to identify possible solutions. Published literature was also sought. The intention was to propose outlines for amendments to the directive or regulation that would permit the type-approval of electric vehicles. Existing proposals for amendments were also taken into account.

The second strand of the project concerned the potential safety risks of electric vehicles. Many of the hazards associated with these vehicles will be dealt with through existing EC or UNECE type-approval legislation (provided that it is compatible). However, certain aspects of electric vehicles are potentially very different from conventional vehicles. There may be additional risks that are not covered by the current legislation because it was written for conventional vehicles. TRL reviewed literature to identify such hazards and performed a technical analysis of the findings. It was not the intention to imply that electric vehicles are inherently unsafe or would expose the public to greater risks than conventional vehicles. Instead, the focus was on specific hazards that might not be regulated under current EC or UNECE type-approval legislation.

During the course of the project TRL engaged with a variety of stakeholders including vehicle manufacturers and their suppliers, type-approval authorities and test laboratories. This took place on an individual basis through telephone discussions and face-to-face meetings. In addition, a group stakeholder meeting was held in Brussels to present the findings of the interim report and to obtain feedback from the stakeholders.

1.1 Background on electric vehicles

Electric vehicles have the potential to contribute to significant reductions in both carbon emissions and the world's dependence on oil as its prime transport fuel. Even when the electricity itself is far from low carbon, such as when the generation mix contains a large proportion of unabated coal-fired power stations, the greater energy conversion efficiency of the electric motors mean overall life cycle emissions (known as "well-to-wheel") are often lower than conventional petrol and diesel alternatives. As electricity generation across the EU becomes lower carbon (in line with policies such as the EU Emissions Trading Scheme and the Renewable Energy Directive), the potential for electric vehicles becomes even greater. Decarbonisation of the electricity sector is possible by various measures, many well-established and others under development, including through end-use efficiency gains, the expansion of renewable and nuclear sources, carbon capture and storage, and switching from coal to natural gas. The UK Government's King Review (King, 2007), for example, suggested that electric vehicles (passenger cars) could achieve CO_2 emissions as low as 30 g/km by 2030 (from 80 g/km now). Average new car emissions in 2008 across the EU were over 150 g/km, based mainly on conventional internal combustion engines using (largely fossil) petrol or diesel.

For this potential to be realised, however, electric vehicle manufacturers must be able to produce and sell their vehicles to the mass market. To do so, the vehicles will have to meet a wide range of legislative requirements, covering both their safety and environmental performance, just as mass-produced internal combustion engine vehicles do today.

For the purposes of this study, "electric vehicle" includes both hybrids and purely-electric vehicles. Hybrid vehicles combine electric power from an on-board battery with an internal combustion engine. Different degrees of hybridisation are possible.

- A "mild hybrid" switches the engine off when the vehicle is stationary and then restarts when the accelerator is pressed. Energy from braking is stored and can be used to support the internal combustion engine during acceleration.
- A "full hybrid" is capable of running on battery power alone, although usually for short distances only. The vehicle runs on electric power at low speeds and under low loads and switches to the internal combustion engine for higher speeds and hard acceleration. This maximises the overall efficiency.
- A "plug-in hybrid" can be charged directly from the grid and can run on electric power for longer distances. This requires greater battery capacity than other hybrids.
- An "extended range hybrid" uses a small internal combustion engine to charge the battery rather than drive the wheels.

Purely-electric vehicles run on battery power only and do not use an internal combustion engine or liquid fuel. The current generation tend to be smaller vehicles with a limited range and performance, and the battery often takes as much as 7 hours to recharge. However, recent developments in battery technology suggest that batteries could offer acceptable range, performance and charging time in the longer term.

1.2 Energy storage technology development

Up until about 15-20 years ago, the only available automotive battery technology was lead-acid, i.e. simply having several conventional car batteries connected in series. Although mass-produced and relatively cheap, they were big, heavy and short-lived, and electric vehicles using them had very limited range. Alongside the development of laptop computers, mobile telecommunications systems and other portable electronic devices, other rechargeable battery chemistries were developed to such a degree that they could be scaled up to automotive applications. Nickel-cadmium (Ni-Cd) batteries were developed first, but were superseded by nickel-metal hydride (Ni-MH) and sodium nickel chloride (NaNiCl) batteries.

Most recently, lithium-based technologies have been developed and are now on the verge of mass-market use. Lithium-ion (Li-ion) batteries are planned for several electric vehicles due to become available in 2010, including those from Citroen, Mitsubishi, Opel and the plug-in version of the Toyota Prius. They already feature in the Tesla Roadster sports car. Li-ion batteries have better energy storage capabilities (Watt-hours per kg) than both lead-acid (by a factor of >3) and Ni-MH (factor of 2) and have better energy efficiency (c. 90%), which make them suitable for electric vehicles. They also have very high specific power (Watts per kg) which makes them suitable for plug-in hybrid vehicles (Matheys *et al.*, 2008). Given that projections of costs are likely to fall from circa $1000/KWh today to about $300/KWh by 2015; Li-ion batteries are assumed to be the technology of choice for electric vehicles in the short to medium term.

Longer term developments may include lithium-air batteries such as that being developed by the University of St Andrews and others (EPSRC, 2009) and the zinc-air battery being developed by ReVolt Technology (ReVolt Technology, 2009), both of which have the potential to increase energy density by factors of 2 or 3 over Li-ion designs, and be cheaper and inherently safer. With the world-wide development of environmental standards and legislation using the "polluter pays" and "producer responsibility" principles, the need to drive electric vehicle energy storage system costs down has tended to be synonymous with a trend towards the use of naturally abundant and environmentally benign materials. This trend looks set to continue as new technologies emerge.

Ultra-capacitors are also in development and are capable of storing and releasing energy very quickly across a very broad temperature range. There are potentially useful, therefore, for quick acceleration, cold starting and regenerative braking and as a lightweight supplement to electric vehicle range and battery life. Using the electrical properties of activated carbon, they are also able to cycle many millions of times without noticeable degradation in performance, and hence have long life-times (Maher, 2005).

1.3 Overview of the legislation for electric vehicles

1.3.1 EC type-approval of electric vehicles

EC Whole Vehicle Type-Approval is based around EC directives and provides for the approval of whole vehicles, in addition to systems and components. A framework directive lists a number of separate technical directives that the vehicle must comply with in order to gain type-approval. The framework directive also lists United Nations Economic Commission for Europe (UNECE) regulations that are considered to be acceptable alternatives to certain EC directives. The whole vehicle type-approval scheme was introduced in the 1970s through Directive 70/156/EEC and it became mandatory for M_1 category vehicles (i.e. passenger cars) in 1998. The recast new framework directive 2007/46/EC, has since been published and extends the scheme to larger passenger (M_2 and M_3 category) and goods vehicles (N category).

Directive 70/156/EEC contained an exemption clause (within Article 8) for vehicles incorporating technologies or concepts which could not, due to their nature, comply with the separate directives or regulations[1]. This clause effectively restricted approvals for such vehicles to national schemes. However, Member States were obliged to send a request to the Commission to grant whole vehicle type-approval, accompanied by a file containing certain technical information. This included a requirement for a description of tests and their results that demonstrated at least an equivalent level of safety and environmental protection as that provided in the directives and regulations.

Directive 2007/46/EC lifted this restriction and (within Article 20) allowed Member States to grant EC type-approval to vehicles incorporating new technologies, subject to authorisation being granted by the Commission. Nevertheless, there are currently no specific technical requirements in the framework directive to address the characteristics and risks of electric vehicles. However, TRL understands that the Commission intends to issue a proposal for a Commission regulation to amend the framework directive by specifying requirements for electric vehicles, including the mandatory application of certain UNECE regulations.

Furthermore, in 2014 around 50 base directives covering vehicle safety issues will be repealed. Their requirements will be carried over to Regulation (EC) No. 661/2009 (on the general safety of motor vehicles) and replaced, where appropriate, with reference to the corresponding UNECE regulations. This is intended to simplify type-approval legislation in line with the recommendations contained in the final report of the CARS 21 High Level Group (European Commission, 2006).

[1] The clause included vehicles, components or separate technical units.

1.3.2 UNECE regulations

UNECE regulations provide for the approval of vehicle systems and separate components, but not whole vehicles. Many duplicate EC directives, while others are ahead of the directive (i.e. the EC directive lags behind in terms of a key amendment or development). Several UNECE regulations have been amended to contain specific requirements for electric vehicles. These include: UNECE Regulation 12 (protective steering), UNECE Regulation 13 (braking), UNECE Regulation 51 (noise), UNECE Regulation 83 (emissions), UNECE Regulation 85 (engine power) and UNECE Regulation 101 (CO_2 emissions). In addition, efforts are underway to amend UNECE Regulation 94 (frontal impact) and UNECE Regulation 95 (side impact).

There is also UNECE Regulation 100 which sets out specific provisions for electrical power trains. The requirements cover the protection of users against electric shock, rechargeable energy storage systems, functional safety and hydrogen emissions. A proposal to amend Regulation 100 was adopted by the World Forum for Harmonisation of Vehicle Regulations (WP.29) in March 2010. The 01 series of amendments were developed by an informal working group on electrical safety (ELSA), which was set up under the Passive Safety Working Party (GRSP) of UNECE. These amendments included an extension of the scope from purely-electric vehicles to hybrid vehicles (and in fact all kinds of power train systems above a certain working voltage level).

UNECE Regulation 100 is not mandatory for type-approval in the European Union. Furthermore, it is left to the discretion of the type-approval authorities to require compliance with the UNECE regulations that include specific provisions for electric vehicles. However, an EC proposal for a Council decision to apply Regulation 100 on a compulsory basis was adopted on 15 June 2010 (European Commission, 2010). Once this proposal is adopted by the Council, UNECE Regulation 100 will therefore be incorporated into the EC type-approval system.

2 Review of type-approval directives and regulations on vehicle safety

This section focuses on the type-approval legislation for vehicle safety. It includes EC directives and the corresponding UNECE regulations, although it is understood that each of the directives will be repealed in 2014 when Regulation (EC) No. 661/2009 (on the general safety of motor vehicles) takes effect.

2.1 Fuel tanks and rear under-run: Directive 70/221/EEC and UNECE Regulation 34

2.1.1 Overview

Directive 70/221/EEC (as amended) comprises two separate parts. The first part relates to tanks for liquid fuel (where the fuel is liquid at ambient temperatures) and applies to all M and N category vehicles. It outlines a number of general design and installation requirements and assesses the performance of the tank in a series of tests. The general requirements cover a range of issues such as corrosion resistance, (excess) pressure management and the location and protection of the tank in a vehicle. The types of tests that are carried out depend on the construction of the tank. Metal fuel tanks are subjected to the following tests:

- Hydraulic internal pressure test

  An isolated unit complete with all its accessories is filled with a non-flammable liquid (for example, water). The pressure is increased gradually through the fuel feed pipe to double the working pressure (or at least 0.3 bar). The pressure is maintained for one minute. The tank must not crack or leak during the test, but permanent deformation is allowed.

- Overturning test

  The tank with all its accessories is mounted on to a test fixture that can rotate about an axis parallel to the longitudinal axis of a vehicle. Tests are carried out with the tank filled to 90% of its capacity, and also to 30% of its capacity, with a non-flammable liquid having a density and viscosity similar to fuel (water may be accepted). The tank is rotated through 90° to the left and held for five minutes before being rotated through a further 90°. The tank is held in this inverted position for at least another five minutes before being rotated back to its original position. The procedure is then repeated in the opposite (i.e. left) direction. Any leakage of fuel must not exceed 30 g/min during the test.

Further tests are performed on plastic fuel tanks:

- Impact resistance

  The tank is filled to its capacity with a water-glycol mixture or another liquid with a low freezing point. A pendulum impact test is carried out with the tank temperature at 233K ± 2 K (-40 °C ± 2 °C). The tank must not leak as a result of the test.

- Mechanical strength

  This test is similar to the hydraulic internal pressure test, but in this case the tank is filled with water at 326 K (53 °C) and the test period is five hours. The tank must not crack or leak, but permanent deformation is allowed.

- Fuel permeability

  The tank is filled with fuel to 50% of its capacity and stored at 40 °C for eight weeks. The average loss of fuel must not be more than 20 g per 24 hours.

- Resistance to fuel

  After the fuel permeability test, the tank must still be capable of passing the impact resistance and mechanical strength tests (described above).

- Resistance to fire

  The tank is filled to 50% of its capacity with fuel and exposed to defined periods of direct and indirect exposure to flame. There must be no leakage of fuel from the tank.

- Resistance to high temperature

  The tank is filled to 50% of its capacity with water at 293 K (20°C). It is then subjected for one hour to an ambient temperature of 368 K ± 2 K (95 °C ± 2 °C). The tank must not be leaking or seriously deformed after the test.

- Markings on the fuel tank

  The trade name or mark must be present on the tank, including when it is installed on the vehicle.

The second part of the directive sets out sets out requirements to provide rear under-run protection for large vehicles. It is intended to prevent smaller vehicles from under-running them in the event of a collision. The directive applies to all vehicles unless they have less than 55 cm ground clearance. The rear of the vehicle must provide effective protection against M1 or N1 vehicles under-running from the rear, typically using a metal box section structure. The under-run protection is validated by a test that applies a horizontal force to the structure to simulate a vehicle impact.

The EC recognises UNECE Regulation 34 as an alternative to the fuel tanks part of Directive 70/221/EEC. The main purpose of the regulation is to prevent fire risks by establishing design and performance requirements for liquid fuel systems. The regulation comprises four main parts:

- Part 1 Approval of vehicles with regard to their fuel tanks

  This part applies to all M and N category vehicles and is practically identical to the fuel tanks part of Directive 70/221/EEC.

- Part 2 Approval of vehicles with regard to the prevention of fire risks in frontal and/or lateral and/or rear collision

  This part applies at the request of the manufacturer to all M and N category vehicles that are approved to parts 1 and 4 of the regulation. It contains requirements for the installation of liquid fuel tanks that cover both the fuel installation and the electrical installation. The fuel installation requirements cover the protection of components from obstacles on the ground and from abnormal stress brought about by twisting and bending movements, and vibrations of the vehicle's structure. The components must also remain leak-proof under the various conditions of use of the vehicle. The electrical installation requirements are intended to protect the wiring insulation from damage (at points where electrical wires pass through walls or partitions) and from corrosion.

  This part of the regulation also contains frontal, lateral and rear-end impact tests and associated post-collision leakage requirements. The frontal impact test procedure comprises a full-width test against a rigid barrier from 48.3 to 53.1 km/h. However, the test procedure in annex 3 of UNECE Regulation 94 can be used instead. The lateral impact test is performed according to annex 4 of Regulation 95 (i.e. there is no test procedure in UNECE Regulation 34). Finally, the rear-end impact test procedure involves the vehicle being struck by a rigid impacting surface from 35 to 38 km/h. This can take the form of a moving barrier or a pendulum test. In each case, no more than "a slight leakage of liquid in the fuel installation" is permitted, and if there is a continuous leakage after the collision, it must not exceed 30 g/min. In addition, the (auxiliary) battery must be kept in position by its securing device.

- Part 3 Approval of tanks for liquid fuel as technical units

This part lists the requirements of part 1 of the regulation that must be met when approving liquid fuel tanks as separate units.

- Part 4 Approval of vehicles with regard to the installation of approved tanks

This part lists the requirements of part 1 that must be met when installing an approved fuel tank.

2.1.2 Compatibility with electric vehicles

Fuel tank requirements are clearly inappropriate for fully electric vehicles; they do not use liquid fuel and therefore have no fuel tank. The first part of Directive 70/221/EEC (or any part of UNECE Regulation 34) cannot be applied to these vehicles. In contrast, hybrid vehicles (from mild hybrids to range-extended electric vehicles) are fitted with conventional fuel tanks and they will need to meet the requirements of the directive or the regulation.

The legislative requirements are compatible with hybrid electric vehicles because they relate to the fuel tank and its accessories only. However, hybrid vehicles could present a new hazard due to their high voltage components, which can generate enough energy to create a spark. This could potentially ignite any fuel vapour present resulting in a fire. The overturning test described in Section 2.1.1 permits 30 grams of fuel to leak per minute. This implies that an overturned vehicle could leak at least 150 grams, depending on the time taken for the emergency services to arrive. Adopting more stringent requirements for fuel tanks intended for hybrid electric vehicles would overcome this potential problem. Nevertheless (at the present time) there is no evidence that current hybrid vehicles pose a greater risk of fire. It might be the case that, although a limited amount of fuel is permitted to leak during the overturning test, most manufacturers would not accept any leakage from their vehicles.

UNECE Regulation 34 goes further than the directive and at the manufacturer’s request allows for the approval of vehicles with regard to the prevention of fire risks (part 2). This includes front, lateral and rear-end tests on the vehicle. While the main focus for these tests is the fuel installation, the requirements also state that the battery must be kept in position. TRL understands this to mean the auxiliary battery (rather than a propulsion battery), although it is not stated explicitly in the regulation.

Directive 70/221/EEC and UNECE Regulation 34 ensure that fuel tanks demonstrate a minimum level of safety when it comes to certain fundamental risks associated with the use of liquid fuel. Similar legislation is in place for liquefied petroleum gas tanks, compressed natural gas tanks and for hydrogen systems. However, there is currently no legislation for rechargeable energy storage systems[2]. Nevertheless, many of the properties or features that liquid fuel tanks must display, such as impact resistance, resistance to fire and resistance to high temperature would be desirable for rechargeable energy storage systems too (since they could be exposed to similar hazards). Furthermore, it is likely that there are additional properties specific to these systems that would need to be covered. This is discussed in more detail in Section 4.1.

2.1.3 Proposals for amendments

Purely electric vehicles do not have a fuel tank. Exempting them from the first part of Directive 70/221/EEC (on fuel tanks) or from UNECE Regulation 34 would avoid an

[2] UNECE Regulation 100 includes basic requirements for the protection against excessive current and for the prevention of gas accumulation through ventilation.

unnecessary burden without leading to additional safety risks. The second part of the directive (on under-run protection) is still appropriate for electric vehicles and can be applied without amendment.

The directive is appropriate for hybrid vehicles since the requirements and tests relate to the fuel installation only. This is also the case for the first part of the regulation (on fuel tanks). Adopting more stringent requirements during the overturning test for fuel tanks might reduce the risk of fuel leaking from an overturned hybrid vehicle; and hence also reduce the risk of a fire resulting from a spark from a high voltage component.

The second part of the regulation (on fire risks) may require amendment to include post-collision requirements for hybrid vehicles. While the fuel installation is the focus for the tests, the requirements currently extend to the auxiliary battery. It would be consistent, therefore, to include post-collision requirements for the propulsion battery or capacitor in a hybrid vehicle. Amendments currently being proposed for UNECE Regulations 94 and 95 could form the basis for changes to UNECE Regulation 34 (see Section 2.6). However, it must be noted that part 2 of UNECE Regulation 34 is not required for European type-approval and hence its amendment may not be a priority.

Finally, there are no technical requirements in EC (or UNECE) type-approval for a rechargeable energy storage system. Developing new requirements would remove this potential loop-hole and would improve the harmonisation of rechargeable energy storage system safety. This is discussed in more detail in Section 4.1.

2.2 Braking: Directive 71/320/EEC and UNECE Regulations 13 and 13-H

2.2.1 Overview

Directive 71/320/EEC (as amended) and UNECE Regulation 13 are very similar. They include detailed specifications for the characteristics of a braking system and assess the hot and cold performance of the brakes during a series of straight-line stopping manoeuvres. The requirements extend to the service brake system, the secondary brake system and also the parking brake system. The brake distribution and wheel lock sequence are also assessed and, where fitted, anti-lock systems are subject to additional requirements. Directive 71/320/EEC and UNECE Regulation 13 apply to all vehicles of category M (passenger vehicles), category N (goods vehicles) and Category O (trailers), as defined in Annex II of EC Directive 70/156/EEC (as amended by 2007/46/EC). In contrast, UNECE Regulation 13-H applies to M_1 and N_1 vehicles only.

UNECE Regulation 13-H is a first step towards the harmonisation of European and United States braking requirements. It includes the same tests as UNECE Regulation 13, but the performance requirements are more stringent. However, N_1 vehicles may be approved to either version of the regulation and can continue, therefore, to meet the less stringent requirements in UNECE Regulation 13.

Directive 71/320/EEC and UNECE Regulations 13 and 13-H set out the performance of braking systems in terms of the vehicle stopping distance and the mean fully developed deceleration. The stopping distance is defined as the distance travelled by the vehicle from the instant when the driver begins to actuate control of the system until the instant when the vehicle stops. The mean fully developed deceleration is the deceleration averaged with respect to distance over an interval between 80 percent and 10 percent of the initial speed.

2.2.2 Compatibility with electric vehicles

The fundamental requirements and tests in the braking legislation can be applied irrespective of the type of power train. However, the introduction of regenerative braking systems raises questions about the performance of these systems. Directive 71/320/EEC does not contain any provisions for regenerative braking systems whereas, the more recently amended UNECE Regulations 13 & 13-H include definitions for different categories of system, and technical requirements for the fitment, performance and fail-safe modes. The UNECE regulations also contain provisions regarding the generation of a braking signal to illuminate the stop lamps. Currently the regulation states that *"electric regenerative braking systems, which produce a retarding force upon release of the throttle pedal, shall not generate a signal mentioned above".* This requirement is harmonised with a conventional brake system, which only illuminates the stop lamps when the brake pedal is pressed. However, some electric regenerative braking systems have the potential to provide a greater level of retardation than that generated by engine braking. This could lead to safety issues in the real world if a driver is unaware that the vehicle in front is subject to a retarding force.

2.2.3 Proposals for amendments

Recent discussions within the UNECE Working Party on Brake and Running Gear (GRRF) have led to proposals to permit the illumination of stop lamps when the regenerative braking system produces a certain deceleration. Whilst the principle of this proposal is generally accepted there is some discussion about the values for activation and de-activation. The latest proposal at the 66th session of GRRF in September 2009 suggested the thresholds shown in Table 1.

Discussions were seeking the possibility of harmonising the activation and de-activation thresholds for all vehicle types. However, a threshold of 1.3 m/s² was considered too high for heavy vehicles which would result in the stop lamps illuminating infrequently. Instead it has been proposed that a threshold of 1.0 m/s² is used because this would be in line with a threshold already defined for endurance brakes.

Table 1: Proposal activation and de-activation thresholds for the generation of a braking signal by electric regenerative braking systems

	UNECE Reg. 13-H	**UNECE Reg. 13**	
Condition	M_1	N_1	M_2, M_3, N_2 & N_3
Signal shall not be generated	≤ 0.7 m/s²	≤ 0.7 m/s²	≤ 0.7 m/s²
Signal may be generated	>0.7 m/s² to ≤1.3 m/s²	>0.7 m/s² to ≤1.3 m/s²	>0.7 m/s² to ≤1.0 m/s²
Signal shall be generated	>1.3 m/s²	>1.3 m/s²	>1.0 m/s²

A study by TRL (Dodd *et al.*, 2005) investigated the effects of automatically operated stop lamps. As part of this study, a series of engine braking tests were conducted. These showed that it was possible to achieve a deceleration of between 0.7 m/s² and 1.4 m/s² without activation of the stop lamps, which is in-line with the suggested values in the table above. The same study also included road trials of a system that activated the stop lamps based on the deceleration of the vehicle. The trials did highlight that if a single accelerometer was used to measure deceleration then it could be adversely affected by the gradient of the road, which in turn could affect the level of deceleration needed to activate the stop lamps. The road trials also showed that there was no significant difference in the way that drivers reacted to the brake lights when following a vehicle fitted with a deceleration activated brake system.

2.3 Radio interference (electromagnetic compatibility): Directive 72/245/EEC and UNECE Regulation 10

2.3.1 Overview

Directive 72/245/EEC (as amended) specifies the minimum standards of electromagnetic compatibility for whole vehicles and for electrical/electronic sub-assemblies (ESAs) (i.e. components or separate technical units intended to be fitted in vehicles). It includes requirements regarding the control of radiated emissions from the vehicle, and also the immunity of the vehicle itself to radiated disturbances. For ESAs, *conducted* emissions and immunity to *conducted* disturbances are also assessed. Both broadband and narrowband emissions and immunity are assessed; narrowband emissions are primarily those produced by on-board electronic modules.

Test methods are included in a series of annexes. A CISPR (Comité International Spécial des Perturbations Radioélectriques; in English, International Special Committee on Radio Interference) or ISO (International Organisation for Standardization) standard is referenced for aspects of the method or for a detailed procedure.

UNECE Regulation 10 (as amended) is equivalent to the directive, and the requirements are almost identical. Regulation 10 covers vehicle categories L (two or three-wheel motor vehicles), M (passenger vehicles), N (goods vehicles) and O (trailers), whereas Directive 72/245/EEC only covers categories M, N and O (category L being covered within Directive 97/24/EC). Approval to the UNECE regulation is a recognised alternative to an EC type-approval granted under Directive 72/245/EEC.

Directive 72/245/EEC will be repealed on 1 November 2014 (by Regulation (EC) No 661/2009). From that date, UNECE Regulation 10 will be the only option for obtaining EC automotive type-approval for electromagnetic compatibility.

Radiated broadband emissions from vehicles

This test is carried out to measure the broadband emissions generated by electrical or electronic systems fitted to the vehicle (such as the ignition system or electric motors). The test method in Directive 72/245/EEC describes the vehicle state during the test and the test conditions; however, it also notes that the test should be performed according to CISPR 12:2001 (the fifth edition).

Several revisions and amendments have been made to CISPR 12 since 2001. The first amendment was made in 2005 and a consolidated version of the standard was published: CISPR 12:2001+A1:2005. In 2007, a sixth edition was published: CISPR 12:2007, which has also been amended. It seems that the latest version of the standard is: CISPR 12:2007+A1:2009. UNECE Regulation 10 uses a later version of CISPR 12 than the directive (fifth edition, amendment 1, of 2005), but is still not using the latest edition. Andersen (2009) reports that the sixth edition of CISPR 12 has removed the broadband/narrowband differentiation. Updating the directive and regulation to use the sixth edition would therefore require changes beyond just updating the references to the CISPR document, as both the directive and regulation have separate broadband and narrowband annexes.

The engine state is probably the most important aspect of the test method (for the purposes of this study). If the vehicle is equipped with an internal combustion engine, the engine is operated at 1,500 r/min for a multi-cylinder engine and 2,500 r/min for a single cylinder engine. If it is equipped with an electric motor, the vehicle is driven on a dynamometer without a load, or on axle stands, at a constant speed of 40 km/h (or at the maximum speed if less than 40 km/h). These test conditions are set out in CISPR 12:2001, the version used by the directive. The 2005 amendment (the version used by the UNECE regulation) adds specific instructions for hybrid vehicles; these should be tested with both electric and internal combustion functioning, at 40 km/h. If this is not possible, the vehicle should be tested with the internal combustion engine operating at the engine speed given above and the electric system operating the vehicle at 40 km/h, or at the maximum speed if less.

Radiated narrowband emissions from vehicles

This test is carried out to measure the narrowband emissions such as those that might emanate from microprocessor-based systems or other narrowband sources. Once again, the test method in the directive describes the vehicle state and test conditions. Unless otherwise stated, the test is performed according to CISPR 12:2001 or to CISPR 25:2002 (the second edition). The narrowband emissions of a vehicle are measured with the ignition switched on, but without the engine operating.

UNECE Regulation 10 again refers to the fifth edition, amendment 1, of 2005, of CISPR 12, but it refers to the same version of CISPR 25 as the directive. The latest version of CISPR 25 is the third edition, CISPR 25:2008, including corrigendum 1. As with the sixth edition of CISPR 12, this has had the broadband / narrowband differentiation removed. Updating the directive and regulation to use the latest editions would therefore require changes beyond just updating the references to the CISPR documents.

Immunity of vehicles to radiated disturbances

This test is intended to assess the immunity of the vehicle's electronic systems. The vehicle is subjected to electromagnetic fields and monitored during the test. The test is performed according to ISO 11451-2:2005 (third edition), unless otherwise stated in the directive. This is the current version of the standard. ISO 11451-2 can be applied regardless of the vehicle's propulsion system (e.g. spark ignition engine, diesel engine, electric motor). References are also made to ISO 11451-1:2005 (third edition) for aspects of the test conditions. The latest version of this is ISO 11451-1:2005+A1:2008. In both cases, UNECE Regulation 10 refers to the same edition as the directive.

The vehicle is operated during the test at a steady speed of 50 km/h. The immunity type-approval limits are probably the most important aspect of this test (for the purposes of this study). The directive sets the field strength at 30 V/m RMS in over 90% of the 20 to 2,000 MHz frequency band and a minimum of 25 V/m RMS over the whole 20 to 2,000 MHz frequency band. These figures represent the strength of the electromagnetic radiation that the vehicle must be capable of withstanding. The vehicle must demonstrate no degradation in the performance of 'immunity-related functions'. However, TRL understands that vehicle manufacturers test with much higher field strengths (typically 80 to 90 V/m). Testing is performed to these higher levels to satisfy product liability concerns.

Radiated broadband emissions from electrical/electronic sub-assemblies

This test is intended to measure broadband emissions from sub-assemblies which may be subsequently fitted to vehicles that have passed the whole vehicle test. The test is performed according to CISPR 25:2002. As noted above, the latest version of this standard is CISPR 25:2008. UNECE Regulation 10 uses the same edition as the directive.

Radiated narrowband emissions from electrical/electronic sub-assemblies

This test is intended to measure narrowband emissions from sub-assemblies which may be subsequently fitted to vehicles that have passed the whole vehicle test. The test is performed according to CISPR 25:2002 in both the directive and the regulation.

Immunity of electric/electronic sub-assemblies to radiated disturbances

This test assesses the immunity of electrical/electronic sub-assemblies. The sub-assemblies may comply with the requirements of any combination of the following test methods at the manufacturer's discretion (in both directive and regulation):

- Absorber chamber test according to ISO 11452-2:2004;
- TEM cell testing according to ISO 11452-3:2001;
- Bulk current injection testing according to ISO 11452-4:2005;
- Stripline testing according to ISO 11452-5:2002;
- Stripline testing according to the method in the directive/regulation.

The sub-assembly is exposed to electromagnetic radiation in the 20 to 2,000 MHz frequency range at the intervals specified in ISO 11451-1:2005.

Immunity of electrical/electronic sub-assemblies to conducted disturbances

This test is intended to assess the immunity of sub-assemblies to transient disturbances conducted along supply lines. The directive and regulation state that certain test pulses must be applied to the sub-assembly according to ISO 7637-2:2004. The pulses are applied to the supply lines as well as to other connections that may be operationally connected to the supply lines. ISO 7637-2:2004 specifies bench tests for equipment fitted to passenger cars and light commercial vehicles equipped with a 12 V electrical system or to commercial vehicles equipped with a 24 V electrical system. It applies to all these vehicles irrespective of the propulsion system.

Conducted emissions from electrical/electronic sub-assemblies

This test measures the conducted transient emissions from sub-assemblies to the vehicle power supply. For both the directive and the regulation, measurements are performed according to ISO 7637-2:2004 on supply lines as well as on other connections that may be operationally connected to supply lines.

2.3.2 Compatibility with electric vehicles

The current practices for measuring electromagnetic emissions and immunity were developed initially for internal combustion engines. However, electric vehicle drive systems, including those of hybrid vehicles, differ greatly from conventional automotive electrical system components. The power required by the electric drive is much higher than the power demand of the electrical system in conventional vehicles (Guttowski *et al.*, 2003). Power electronic systems are likely to be the main source of electromagnetic interference within electric drive systems. In particular, high-speed switching devices could be an important source of emissions.

Provisions for electric vehicles in current test methods

Directive 72/245/EEC and UNECE Regulation 10 do not include any specific provisions for vehicles with an electrical power train. However, as detailed in Section 2.3.1, the directive and regulation reference several important CISPR and ISO standards when describing the test methods. These standards, or the parts of them that are referenced, effectively become part of the legislative test methods. Some of these standards have been amended to take account of vehicles with electric drives. For example, broadband emission measurements for vehicles with electric propulsion are made using a steady-state dynamic test at a constant speed of 40 km/h. The equivalent test for vehicles with internal combustion engines would require the engine to be running but not propelling the vehicles.

UNECE Regulation 10 is equivalent to Directive 72/245/EEC and is practically identical. However, there is a difference in vehicle scope, as the directive covers vehicle categories M (passenger vehicles), N (goods vehicles) and O trailers), whereas the UNECE regulation covers these and category L (two and three wheeled vehicles, and quadricycles) as well. (In the EC type-approval system, EMC requirements for category L vehicles are included in Directive 97/24/EC.) This difference in vehicle scope has led to some differences between the two documents in the test procedures annexes: the regulation has extra sections or paragraphs applying only to category L vehicles.

A different version of CISPR 12 is referenced for the broadband emissions tests. The directive refers to the fifth edition of the standard (CISPR 12:2001), while the regulation refers to the fifth edition, including the 2005 amendment (CISPR 12:2001+A1:2005). The latest version is the sixth edition including a 2009 amendment (CISPR 12:2007+A1:2009). The fifth edition used by the directive requires vehicles with electric propulsion motors to be driven on a dynamometer without load, or on non-conductive axle stands, at constant 40 km/h or at the maximum speed if less. The 2005 amendment is important in the context of vehicles with electric drives, because it introduces the specific requirement for hybrid vehicles that both drive systems be functioning, if possible. It would therefore be useful to align the directive with the UNECE regulation so they both used the same version of CISPR 12. While there would presumably be advantages in updating both to the latest version of CISPR 12, the changes in the 2007 sixth edition and the 2009 amendment do not appear to be relevant to electric or hybrid vehicles.

The only other instance where the directive and regulation refer to different versions of a standard appears to be a mistake. The regulation refers to ISO 11452-3:2001 as the third edition, which doesn't exist. The directive refers correctly to ISO 11452-3:2001 as the second edition.

Neither the directive nor the regulation refers to the latest version of CISPR 25, the third edition (CISPR 25:2008 + Corrigendum 1); instead they both use CISPR 25:2002 (second edition). Again, while there would presumably be advantages in updating both to the latest version, the changes in the 2008 third edition do not appear to be relevant to electric or hybrid vehicles. The standard, as part of the test requirements, sets limits for regulation of the vehicle power supply, both with the engine off and the engine running. However, these limits are only specified for nominal 12 and 24 V systems. Additional limits for the high voltage drive systems could be considered for a future amendment. As there may be a large number of nominal voltages used, these limits could perhaps be expressed in percentage terms.

The Society of Automotive Engineers has produced an EMC standard specifically for electric vehicles: SAE J551-5. This was first issued in 1995; the latest revision was in 2004 (Society of Automotive Engineers, 2004). This firstly covers the measurement of magnetic and electric field strengths from 9 kHz to 30 MHz. This therefore introduces additional measurements of broadband emissions at frequencies below those used in the standard test methods (Directive 72/245/EEC (Annex IV); UNECE Regulation 10 (Annex 4); CISPR 12; SAE J551-2), where broadband emissions are measured in the frequency range 30 to 1000 MHz. Andersen (2006) commented that the concerns addressed in SAE J551-5 related mostly to on-board radio reception. Also, it overlaps with CISPR 25, which covers frequencies starting at 150 kHz. Secondly, SAE J551-5 includes conducted emissions tests of electric vehicles in the charging mode. However, these are applicable only if the charging system uses a switching frequency above 9 kHz, are mounted on the vehicle, and where power is transferred by conduction (rather than inductively) from AC power lines.

EMC studies relevant to electric vehicles

There are relatively few published studies of the electromagnetic compatibility of vehicles with electric drive systems. Nevertheless, there is some evidence to suggest that acceleration, deceleration (regenerative braking) and charging cycles may result in higher electromagnetic emissions (Ruddle, 2002). However, there would be significant practical difficulties in making measurements under transient conditions such as acceleration and deceleration. The current approach seems to offer greater reliability and consistency. Nevertheless, it may be appropriate at least to consider these options as possible enhancements of the EMC vehicle standards.

Several authors (Andersen 2006; Nelson *et al*., 2007) have pointed out that the EMC tests do not cater adequately for the high voltage systems used in electric and hybrid vehicles. High voltage systems typically use shielded cables, which create additional issues in terms of applying the current test methods. Another difference between the high voltage systems and low voltage 12 V or 24 V systems is that the former will normally be floating with respect to the vehicle body whereas one side of the low voltage systems will be connected to the vehicle body.

Nelson *et al*. (2007) were specifically investigating the application of the conducted emission test method in CISPR 25 to high voltage components. They state that conventional measurement methods do not always produce vehicle representative results, and that artificial networks as defined in CISPR 25 should not be used to validate high voltage components in conducted voltage or current measurements. Directive 72/245/EEC and UNECE Regulation 10 both refer to ISO 7637-2:2004 rather than CISPR 25 for conducted emissions tests. However, it seems likely that the findings of Nelson *et al*. would be relevant also to the ISO 7637-2 conducted emission test.

The directive includes testing for both the immunity of electrical and electronic systems to transient disturbances and for their emissions. Transient disturbances fall into three general categories: those generated by electrical and electronic systems on the vehicle, electrostatic discharges and lightning. A vehicle with an electric drive system is potentially a source of many transient disturbances, due to the large number of high power components. There are already a number of electronic systems fitted to vehicles that control safety critical applications. The transient performance of the vehicle can therefore have a significant effect on vehicle safety (Simmons and Noble, 1999).

2.3.3 Proposals for amendments

The provisions for the electromagnetic compatibility of vehicles are effectively split between the legislative documents (Directive 72/245/EEC and UNECE Regulation 10) and the CISPR and ISO standards. Proposals to amend the provisions might be more appropriately taken forward by amending the CISPR and ISO standards, rather than by seeking changes to legislation. Nevertheless, TRL proposes the following areas for amendment, based on our own analysis and ideas obtained from the literature. In particular, a number are proposals of, or ideas discussed by, Ruddle (2002).

- Update the directive and the regulation to refer to the latest versions of the CISPR and ISO standards, unless there is good reason not to. This would then make use of many of the recent changes to CISPR or ISO standards that have dealt specifically with problems concerning electric and hybrid vehicles.
    - Rather than continually updating the legislation, the requirement could be changed to always require the use of the latest version of the standard.

However, this would carry the risk of changes effectively being made without the approval of the legislative authorities. Also, it could generate inconsistencies between the documents. For instance, CISPR 12, sixth edition, has removed the broadband/narrowband differentiation; this would require changes the directive with its separate broadband and narrowband annexes, beyond merely updating the references to the CISPR document.

- CISPR 12 requires an electric vehicle to run at 40 km/h, compared with the requirement for an internal combustion engine where the engine should be running but not propelling the vehicle. This puts more load on the electric motor than if just the motor was turning, as well avoiding any conflicts if the vehicle didn't have a clutch or gearbox capable of disconnecting the drive. However, the dynamometer places no load on the vehicle, so the drive power used at 40 km/h is unrealistically low, and hence electromagnetic emissions could also be unrealistically low. Therefore, consideration should be given to placing a realistic load on the vehicle. This would use more power and hence could cause problems with battery capacity; see the suggestions below concerning this.
- Consider whether it would be worthwhile to include testing under acceleration and regenerative braking. While these conditions may potentially produce broadband emissions that exceed the steady state limits, the benefits of testing to control such emissions may be inadequate to justify the increased costs of testing. Also, conventional vehicles may also exceed the limits at high engine speeds, as they are only required to meet the limits at a steady 1,500 r/min (assuming a multi-cylinder engine), so requiring limits under acceleration for electric and hybrid vehicles only could be considered to be discriminatory.
    - Higher emissions during acceleration are likely to be caused by the higher power used or by the higher motor speed, rather than being a direct consequence of the acceleration. If this is the case, it would be more sensible to use a constant vehicle speed, under load conditions that simulated acceleration.
    - Such simulated acceleration would probably be a worst case, so if it were introduced it should be possible to drop the existing steady speed requirement.
    - Similarly, regenerative braking could be simulated under constant speed conditions by powering the dynamometer.
- Ensure that electric vehicles are tested for emissions and immunity when in charging mode.
    - Apparently, the CISPR Steering Committee has agreed that CISPR 11 will be the relevant standard for assessing vehicles in the charging mode (Ruddle, 2002).
    - This should include those types of hybrid vehicles where the batteries can be externally charged (as well as being internally charged using engine power).
    - Any charging equipment external to the vehicle should be included in the test, unless it would be covered by non-automotive requirements.
    - Commercial charging stations may need to be considered as well as domestic charging, particularly if higher charging rates were involved.
    - Vehicle tests in charging mode may need also to include tests for conductive emissions and for immunity to conductive disturbances.

  - As vehicles being charged will typically be parked close to houses, lower radiated emission limits may be necessary than those applying in the driving mode. The limits in CISPR 11 are indeed lower.
  - SAE J551-5 already covers charging to some extent and should be used as an input when developing the legislative requirements. In particular SAE J551-5 requires measurements at both maximum and trickle charge rates and, if the system can operate at different power line voltages, it requires measurements at each line voltage.
- It may be useful to require or encourage manufacturers to provide test modes in their control software, to ensure that the battery and engine power modes could be tested separately or in combination, and at appropriate speeds and/or powers, as required. If necessary, this could include defined short-duration cycles that could be linked to the scanning through the frequency range of the radiated emissions detector.
- Where appropriate, the standards should be revised to cater for engines and electric motors in multiple positions down the length of the vehicle. This affects the position of the antenna in the emissions tests, in relation to the vehicle. Such multiple positions might arise in hybrid vehicles where the electric motor is displaced from the internal combustion engine, and in any vehicle with an electric drive system that has an electric motor for each wheel. It should be possible to define a compromise antenna position in these cases.
- The antenna in the emissions tests is currently aligned with the centre of the engine. This is presumably because spark-ignition engines are likely to provide the principal source of vehicle emissions. However, for electric vehicles the electric motor may not be the principal source of emissions.
- Burke (2008) reports that Wankel rotary engines and gas turbine engines are especially suited to use in series hybrid vehicles. It should be checked that the existing EMC test requirements are appropriate for such engines. For instance, it is possible that the required 1,500 r/min (multi-cylinder) or 2,500 r/min (single-cylinder) engine speed in the broadband emission test might not be appropriate for some engine types. Also, the requirements shouldn't pre-suppose an *internal* combustion engine, as gas turbines are *external* combustion engines.
- Ruddle (2002) reported that the limited battery capacity of electric cars, combined with the time then taken to recharge the batteries, created problems in testing for broadband emissions with the vehicle on a dynamometer, because of the time required to carry out the tests. This problem would be compounded if there was a requirement to test under realistic running conditions or even under acceleration conditions (see above).
  - Minimising the power required by having no load on the dynamometer is not ideal, as low power may equate to lower emissions.
  - Consideration should therefore be given to powering electric vehicles from an external power supply during emissions testing.
  - It is understood that the time taken to carry out the tests is in large part because of the need to scan through the frequencies of interest, from 30 to 1000 MHz. It should be considered whether modern technology could allow for increases in efficiency and hence shorter test durations, by scanning multiple frequencies in parallel.
- Some of the current EMC tests do not cater adequately for the high voltage systems used in electric and hybrid vehicles.
  - Current EMC tests in some cases assume 12 V or 24 V systems. The voltages used in electric drive systems are much higher, however, so

fundamental changes may be required to the test methods, not just a rewording to be less restrictive.

  - Some standards, including CISPR 25, set limits on the voltage of vehicle power supplies during a test, but only provide limits for nominal 12 V and 24 V systems. For systems at other nominal voltages, limits expressed in percentage terms would be more appropriate, as electric drive systems may have a large number of different nominal voltages.
  - It should be considered whether the concept of a nominal voltage is appropriate for electric drive systems, as the drive voltage can potentially be varied at source by switching batteries, and the voltage at the electric motor could presumably be varied according to the power required.

- AC or DC electric drive motors may be used. If the drive system, or at least part of it, uses AC then this may require fundamental changes to some of the test procedures. Even if this is not the case, the text is likely to need rewording to be compatible with systems that are partly AC.
- High voltage systems typically use shielded cables, which create additional issues in terms of applying some of the current test methods.
- Another difference between the high voltage systems and low voltage 12 V or 24 V systems is that the former will normally be floating with respect to the vehicle body whereas one side of the low voltage systems will be connected to the vehicle body.
- Some of the component immunity test methods are not readily applicable to high voltage (over 50 V) systems (Andersen, 2006). Several immunity test methods are provided as alternatives and where one is not applicable another should be.
  - It should be checked that acceptable immunity tests exist for high-voltage systems to cover all necessary frequencies and test modes.
- Vehicles with high voltage drive systems are also likely to have a standard low voltage system for all functions that are ‘normal’ (non-EV) vehicle functions. Standards should be checked to ensure that they are not worded to exclude multiple systems of different voltages on a vehicle, and that the test methods would ensure that all systems be appropriately tested.
- Nelson *et al*. (2007) pointed out issues with conducted emissions tests on high voltage components. Because high voltages and shielded cables are used, the artificial networks defined in CISPR 25 “*should not be used for validation of high voltage automotive components in either conducted voltage or current measurements*” (See also Section 2.3.2). Possibly an alternative artificial network could be developed that would be more acceptable, or an alternative test method may be required.

2.4 Protective steering: Directive 74/297/EEC and UNECE Regulation 12

2.4.1 Overview

Directive 74/297/EEC (as amended) presents a series of technical specifications for the behaviour of the steering mechanism and protection of the driver in a frontal collision. It applies to M_1 and N_1 category vehicles with a mass below 1,500 kg. The specifications include three performance tests:

- Frontal impact test against a barrier

  This comprises a full-scale impact test against a rigid barrier from between 48.3 km/h and 53.1 km/h. The barrier must extend across the entire width of the vehicle. No crash test dummies are used in the test. Limits are placed on the movement of the steering column.

- Body block test

  The steering control is struck by a body block travelling between 24.1 km/h and 25.3 km/h and free from its propelling device. Limits are placed on the force applied to the body by the steering column.

- Head form test

  The steering control is struck by a head form travelling at 24.1 km/h. Limits are placed on the deceleration of the head form.

Directive 74/297/EEC has not been amended since 1991. The directive remains valid for EC type-approval (until the general safety regulation comes into effect in 2014), but UNECE Regulation 12 is more up-to-date. The main specifications and tests in Regulation 12 are identical to the directive. However, the regulation considers the specifications relating to the frontal impact test to have been met if the vehicle complies with paragraph 5.2.2 of UNECE Regulation 94 (on steering wheel displacement). Similarly, if the steering control is fitted with an air bag, the specifications relating to the body block test are met if the vehicle complies with paragraphs 5.2.1.4 and 5.2.1.5 of Regulation 94 (on dummy chest injury limits). The regulation also contains specifications for vehicles powered by an electric motor.

2.4.2 Compatibility with electric vehicles

Directive 74/297/EEC contains no provisions for electric vehicles. Although most of the specifications relate to the steering control, and are therefore independent of the type of power train, there is likely to be a problem when conducting the frontal impact test. It would be necessary to know how to prepare the vehicle for the test and what post-impact requirements it would need to meet. However, UNECE Regulation 12 has been amended and includes specifications for an electric vehicle. The specifications are rather brief, but state that:

- The test shall be carried out with the propulsion battery master switch in the "on" position;
- The monoblocs[3] shall remain fixed in their place;
- No liquid electrolyte shall leak into the passenger compartment, but a limited leakage of up to 7% of the total is permitted outside the vehicle during the first hour following the test.

2.4.3 Proposals for amendments

Further amendments of UNECE Regulation 12 were prepared by a group of interested experts on electric vehicles post-crash (EVPC) provisions. The French expert submitted the proposal for discussion at the 47th session of the Working Party on Passive Safety (GRSP) in May 2010.

The purpose of the amendments proposed by France was to extend the scope of the regulation to include all power train systems above a certain working voltage level. The

[3] Monobloc is defined in the regulation as the smallest unit of the propulsion electric energy source.

proposed specifications were more comprehensive than the electric vehicle specifications in the current version of UNECE Regulation 12. They brought the regulation into line with UNECE Regulation 100, and were complementary to similar proposals to amend UNECE Regulations 94 and 95. Section 2.6.3 includes a more detailed discussion of the post-impact safety requirements for electric vehicles.

2.5 Identification of controls, tell-tales and indicators: Directive 78/316/EEC and UNECE Regulation 121

2.5.1 Overview

Drivers must understand and operate a range of controls and instrumentation. There are the main driving controls and various other buttons and switches that activate equipment in the vehicle. There are also increasing numbers of information and warning indicators, particularly with the introduction of active safety systems in recent years. Directive 78/316/EEC (as amended) describes the symbols to be used for identifying these controls, tell-tales and indicators. A number of other specifications must be met to gain approval. These relate to the characteristics of the symbols (such as their colour and size), or their position.

The directive applies to all M and N category vehicles. The purpose is to harmonise the symbols used by vehicle manufacturers and hence reduce the risk of drivers being distracted. For instance, a driver may become distracted from the driving task while trying to find a control or understand the meaning of a tell-tale or indicator, particularly in an unfamiliar vehicle. The following definitions are used:

- A 'control' is the hand-operated part of a device that allows the driver to bring about a change in the state or functioning of a vehicle;
- An 'indicator' is a device which presents information on the functioning or situation of a system (or part of a system);
- A 'tell-tale' is an optical signal which indicates that a device has been activated, is functioning correctly or not, or has failed to function at all.

There are 23 controls, tell-tales and indicators that must be identified whenever they are fitted. The directive includes symbols to be used (which it states are in accordance with ISO 2575:1982, fourth edition) along with tell-tale colours where applicable. These mandatory symbols deal with lighting and signalling, visibility and key aspects of the maintenance, engine and fuel system of vehicles.

There are a further 11 controls, tell-tales and indicators that may be identified whenever they are fitted, but it is not mandatory. However if they are identified, symbols that conform to the directive must be used. The symbols for optional controls deal with rear visibility, security, safety systems, the engine and fuel system. Controls, tell-tales and indicators that are not listed in the directive can be identified using any other symbol, provided there is no danger of confusion with those listed in the directive.

The most recent amendment to Directive 78/316/EEC was made in 1994. Since that time, the Commission has acceded to UNECE Regulation 121 on the location and identification of hand controls, tell-tales and indicators. In fact, UNECE Regulation 121 will be compulsory for EC type-approval when the general safety regulation (EC No. 661/2009) comes into force. Regulation 121 applies to all M category vehicles and also to N_1 category vehicles. It lists over 40 controls, tell-tales and indicators and the symbols that must be used to identify them. It also includes a number of other specifications. These are similar to those in the directive, but are more comprehensive. For example, the regulation contains specifications relating to the illumination of controls, which do not appear in the directive.

Many of the symbols are identical to those in the directive, but there are additional symbols, which typically relate to safety systems and the engine. If a control, tell-tale or indicator is not listed in the regulation, it recommends that a symbol intended for the same purpose in ISO 2575:2000 is used. However, a manufacturer may use its own symbol if no suitable symbol can be found, provided that it does not cause confusion with any symbol specified in the regulation.

2.5.2 Compatibility with electric vehicles

Directive 78/316/EEC and UNECE Regulation 121 include a symbol to be used with a battery charge tell-tale or indicator. However, this relates to the auxiliary battery (i.e. the battery used to store electrical energy needed to operate the vehicle’s electrical systems). There are no symbols for controls, tell-tales and indicators relating to a propulsion battery or any other parts or features of an electric power train.

An electric vehicle will require symbols to be used with controls, tell-tales and indicators that are not listed in the directive or the regulation. For example, the driver will need to know about the state of battery charge in a plug-in vehicle or whether there are any power train malfunctions. EC Directive 78/316/EEC permits any other symbol to be used when a control, tell-tale or indicator is not listed. However, there must be no danger of confusion with a listed symbol.

UNECE Regulation 121 takes a slightly different approach to the directive and recommends that a symbol from ISO 2575:2000 is used (if available) and that all symbols follow ISO 2575:2000 design guidelines. However, ISO 2575:2000 has been withdrawn; the current version is ISO 2575:2004, with amendments 1:2005, 2:2006, 3:2008 and 4:2009. The standard (and amendments) include a series of symbols to be used with tell-tales and indicators for electric road vehicles. These include:

- State of charge of a propulsion battery;
- Propulsion battery failure;
- Electric motor failure;
- External cord connected;
- Electric motor enabled.

Several of these symbols were not present in ISO 2575:2000, but were added in the later edition or the amendments. There are no symbols in ISO 2575:2004 (or the amendments) to use with a regenerative braking system tell-tale or indicator. It seems likely that a driver will need to be informed of a failure of the regenerative braking system, or if the system is off or not available. Symbols provided for anti-lock braking systems could form the basis for a new regenerative braking symbol by using the letters “RBS” instead of “ABS”.

The symbols needed for an electric vehicle will also be driven (in part) by UNECE Regulation 100 (the construction, functional safety and hydrogen emission of electric vehicles, see Section 2.8). This regulation requires certain tell-tales and indicators to be present in electric vehicles. Directive 78/316/EEC and UNECE Regulation 121 may therefore need to describe a symbol that corresponds to a particular requirement of this regulation. Table 2 lists where (the 01 series of amendments of) UNECE Regulation 100 requires a tell-tale or indicator, and whether a symbol is available in ISO 2575:2004 (and its amendments). The table shows that symbols can be found in ISO 2575:2004 that correspond to requirements in UNECE Regulation 100.

The United States also regulates motor vehicle controls, tell-tales and indicators. FMVSS 101 specifies requirements for their location, identification and illumination. Different forms of identification are permitted, depending on the item. These include words, abbreviations or symbols. Where symbols are used in FMVSS 101, they are the same as those in the directive and regulation. There are no symbols relating to electric vehicles, although an abbreviation (RBS or ABS/RBS) is provided for a regenerative brake system malfunction tell-tale.

Table 2: UNECE Regulation 100 requirements relating to the fitment of controls, tell-tales and indicators

UNECE R100 Requirement (para. 5.3)	Symbol availability in ISO 2575:2004
At least a momentary indication must be given to the driver when the vehicle is in “active driving possible mode”	ISO 2575:2004 includes an electric motor enabled symbol. The symbol is intended to be used with a tell-tale or indicator to inform a driver that the electric propulsion system is engaged.
When leaving the vehicle, the driver shall be informed by an obvious signal (e.g. optical or audible signal) if the drive train is still in the active driving possible mode.	As mentioned above, ISO 2575:2004 includes an electric motor enabled symbol.
The state of the drive direction control unit shall be readily identified to the driver.	The electric motor enabled symbol in ISO 2575:2004 includes direction arrows.

2.5.3 Proposals for amendments

Directive 78/316/EEC and UNECE Regulation 121 do not include any symbols to identify the different controls, tell-tales or indicators that may be found in an electric vehicle. UNECE Regulation 121 recommends that symbols listed in ISO 2575:2000 are used wherever possible, but a manufacturer may design its own symbols.

The type-approval legislation does not refer to the latest version of ISO 2575. This is currently, ISO 2575:2004 (seventh edition), including amendments 1:2005, 2:2006, 3:2008 and 4:2009. However, a proposal to amend UNECE Regulation 121 to refer to ISO 2575:2004 was submitted for discussion at the 98th session of the Working Party on General Safety (GRSG) in May 2010. The status of the proposal was unknown at the time of writing, but it seems likely that it will be adopted. ISO 2575:2010 (eighth edition) is under development and hence a further amendment may be needed in the near future.

In the absence of legislative requirements, there is a risk that different symbols will emerge in the market. With this in mind, the legislation could be amended to include symbols for use with electric vehicles. Several symbols are listed in ISO 2575:2004 (and its amendments). Some, if not all, could be adopted in the legislation without placing an unnecessary burden on vehicle manufacturers. However, although this would encourage harmonisation, evidence is needed that these symbols are understood by the public before they are made mandatory.

2.6 Frontal impact: Directive 96/79/EC and UNECE Regulation 94 / Side impact: Directive 96/27/EC and UNECE Regulation 95

2.6.1 Overview

Directive 96/79/EC and UNECE Regulation 94 set the minimum standards for the frontal impact safety performance of cars (M_1 vehicles only with a mass less than or equal to 2.5 tonnes). When they were introduced they were essentially the same. However, now they are slightly different because some amendments which have been made to update the regulation, most notably recent ones, have not been applied to the directive. They both consist of an impact test in which the car is propelled into an offset, deformable barrier at 56 km/h. The car overlaps the barrier face by 40%, with first contact with the barrier on the steering column side. Currently, the main difference is related to the fitment of instructions for users of vehicles equipped with airbags. The regulation requires this whereas the directive does not.

Directive 96/27/EC and UNECE Regulation 95 set the minimum standards for the side impact performance and cars and vans (M_1 and N_1 vehicles where the reference point of the lowest seat is less than or equal to 700 mm from the ground). As for the frontal impact directive and regulation, when they were introduced they were essentially the same. However, now they are different because amendments have been made to the regulation but not to the directive. They both consist of a test in which a mobile deformable barrier (comprising both an impactor and a trolley which represent a car) is propelled into the side of the vehicle at 50 km/h. The centre of the barrier is aligned with the reference point on the driver's seat. Currently, the main differences are:

- Mobile deformable barrier (MDB): The regulation has been updated to use the new progressive MDB whereas the directive has not.
- Dummy: The regulation has been updated to use the EuroSID-2 dummy whereas the directive still specifies the EuroSID-1 dummy.

The fuel tank is filled with water to 90% of its capacity for both the frontal and the side impact tests. All other vehicle systems, such as the brakes or the cooling system may be empty. However, the vehicle must reach its unladen kerb weight and hence the mass of any liquids that are removed must be compensated for. Occupant injury protection is assessed using instrumented crash test dummies. There are also some important vehicle performance requirements. These include requirements for the integrity of the fuel system. Both directives (and their corresponding regulations) permit a continuous leakage from the entire fuel system, but it must not exceed $5x10^{-4}$ kg/s. If the liquid from the fuel system mixes with liquids from other systems, and the various liquids cannot be separated, all the liquids are taken into account.

Because the regulations effectively represent the most up-to-date version of the legislation, this study will focus on their review rather than a review of the directives. Amendments derived to update the regulations for the assessment of electric vehicles could then be applied to the directives if deemed necessary. At this point the directives could also be amended to be brought into alignment with the regulations in all areas.

In October 2009, a group of interested experts on electric vehicles post-crash (EVPC) provisions for regulation was formed. The aim of the group was to derive amendments to update UNECE Regulations 94 and 95 so that they are appropriate for the assessment of electric vehicles. Amendments to UNECE Regulation 12 (which sets the minimum standards for protection of the driver against the steering mechanism in the event of an impact) were also prepared (see Section 2.4.3). The EVPC group was formed mainly of experts in electrical safety from the GRSP informal working group on electrical safety and experts in crash safety from the GRSP informal working group on frontal impact, hence the group contained both regulatory and industry members. The proposals were submitted to GRSP by the expert from France for discussion at the 47th session in May 2010 (see informal documents: GRSP-47-01/Rev.3; GRSP-47-02/Rev.3; and GRSP-47-03/Rev.3). The work of this group is discussed in detail in Section 2.6.3 below.

2.6.2 Compatibility with electric vehicles

There are no specific provisions for electric vehicles in the frontal and side impact legislation. The test procedures can be performed with any vehicle, regardless of the type of power train. However, new specifications will be needed to cover the preparation of the electrical power train for the impact tests.

The occupant protection requirements are also appropriate for any vehicle, but the post-impact fuel leakage limits are relevant only if the vehicle is equipped with an internal combustion engine that operates on liquid fuel. Furthermore, there are no requirements to deal with hazards associated with the presence of high voltage systems and components during a crash.

There are three potential safety problems to be considered if electric vehicles are to provide a level of safety comparable to that of other vehicles. These are:

- Protection against electric shock during and post impact;
- Retention of the Rechargeable Energy Storage System (RESS) during the impact;
- Leakage of hazardous material, e.g. electrolyte, during and post impact.

In Europe, it is intended that the electrical safety provisions for electric vehicles 'in use' will be controlled by Regulation 100 under the 1958 agreement once it is adapted for technical progress. An informal GRSP working group on electrical safety (ELSA) prepared amendments to Regulation 100 to extend its scope from battery electric vehicles to all kinds of electrical power train systems above a given working voltage level (see Section 2.8).

In the USA, FMVSS 305 is used to control the safety provisions for electric vehicles 'post crash'. This standard specifies requirements for electrical isolation of the chassis from the high voltage system, retention of propulsion batteries and electrolyte spillage. It is interesting to note that electrolyte spillage is measured throughout a static rollover after a barrier impact test. This is not the case for fuel leakage for the current frontal and side impact regulations.

In Japan, Attachment 101 controls the protection of occupants against high voltage in fuel cell vehicles. Attachment 111 controls the protection of occupants against high voltage in other electric vehicles.

2.6.3 Proposals for amendments

As mentioned above, proposals to amend Regulations 94 and 95 were submitted for discussion at the 47th session of GRSP. They were submitted by the expert from France following a series of meetings involving a group of interested experts (the EVPC group). The EVPC proposals comprised definitions, electrical power train adjustments for impact testing and post-impact electrical safety requirements and test procedures[4]. The main features of the EVPC proposals are discussed below.

Adopting the EVPC proposals would require electric vehicles to meet specific provisions for electrical safety following an impact test. At the present time, there are no such provisions in the legislation: an electric vehicle could gain type-approval according the frontal and side impact legislation with no assessment of the post-impact electrical safety. The EVPC proposals therefore represent a step forwards in the frontal and side impact legislation for electric vehicles. Nevertheless, there might also be some additional safety problems for electric vehicles that are not dealt with by the EVPC proposals. These too are discussed below.

Protection against electric shock

There are three ways that a person might receive an electric shock. These are illustrated in Figure 1. It is hazardous only when a person completes a circuit by touching two live parts of different electrical potential, either directly or indirectly via exposed conductive parts, or via the electrical chassis.

[4] The EVPC proposals included test procedures to demonstrate compliance with the post-impact electrical safety requirements, but also permitted alternative procedures to be used.

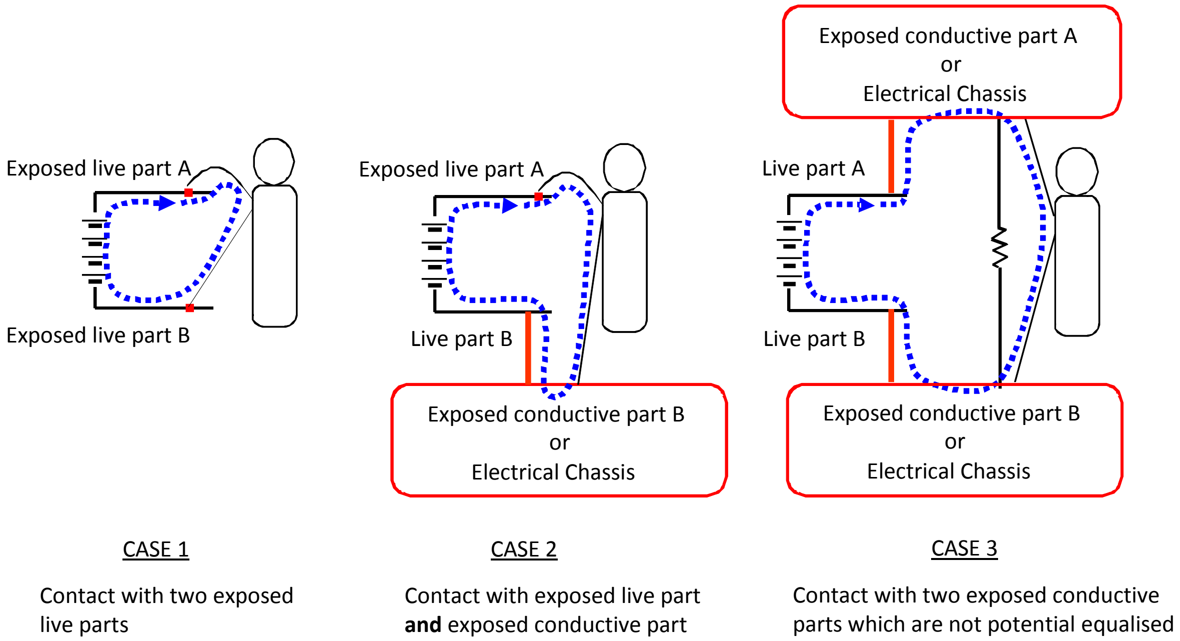

Figure 1: Possible electric shock path cases

The EVPC proposals specify four performance criteria to assess the protection against electric shock following the impact test:

- Physical protection (IPXXB[5] and resistance between exposed conductive parts and electrical chassis < 0.1 ohm);
- Electrical isolation (minimum resistance specified depending whether DC and AC buses are separate or combined);
- Absence of high voltage (≤ 30 VAC or 60 VDC);
- Low electrical energy (< 0.2 Joules).

At least one of these four criteria must be met following the impact test. However, the isolation resistance criterion does not apply if more than one part of the high voltage bus is unprotected (i.e. the conditions of IPXXB are not met). This requirement was added to prevent vehicles meeting the isolation resistance criterion and hence gaining approval while presenting a risk of electric shock (because more than one part of the high voltage bus is accessible).

An automatic disconnect device separates the electrical energy sources from the rest of the high voltage circuit. If the vehicle has such a device, or a device that divides the power train circuit, (one of) the criteria must be met by the disconnected circuit, or by each divided circuit individually after the disconnect function is activated.

Although the EVPC proposals include provisions for vehicles with an automatic disconnect device, there is no requirement for fit one. Two of the four criteria to assess the projection against electric shock can be met with no automatic disconnect device: physical protection and isolation resistance.

[5] The IP (Ingress or sometimes International Protection) Code is defined in IEC 60529. It is an international system of classification for defining the degree of protection provided by electrical enclosures against the intrusion of foreign bodies and moisture.

Retention of the Rechargeable Energy Storage System (RESS)

The requirements in the EVPC proposals for the retention of the RESS depend on its location. A RESS within the passenger compartment must remain in the location in which it was installed and all the RESS components must remain in the RESS boundaries. No part of a RESS located outside the passenger compartment can enter the passenger compartment during the test. These requirements are similar to those in FMVSS 305 for battery retention. The assessment is made by visual inspection only and no guidance or tolerances are provided in the proposals.

The proposals include a separate definition of "passenger compartment" for the electrical safety assessment. In terms of the occupant protection requirements, the passenger compartment is bounded to the rear by the rear compartment bulkhead or the plane of the rear seat back support. However, for the electrical safety assessment, it is bounded by the rear bulkhead or rear gate as well as by the electrical protection barriers and enclosures.

Electrolyte spillage

Electrolyte spillage within the passenger compartment is not allowed in the EVPC proposals. Outside the passenger compartment, it is limited to 7%; except where open-type traction batteries are fitted[6]. For these batteries, spillage outside the passenger compartment is limited to 7% up to a maximum of 5 litres. These requirements are valid over a 30 minute period, starting from the point of impact (i.e. t_0).

The main requirements for electrolyte spillage were derived from the current version of UNECE Regulation 12. The further limit of 5 litres for open batteries is from FMVSS 305.

Batteries have traditionally featured liquid electrolytes; however, solid electrolytes have started to emerge. The EVPC proposals do not distinguish between liquid and solid electrolytes and hence the 7% limit should apply in either case (if the requirement is applied strictly).

Potential safety problems

The list below discusses some potential safety problems not covered, or covered only partially, by the EVPC proposals.

- Validation of proposed amendments

  Ideally, proposals to amend the frontal or side impact legislation would draw on the findings of an experimental study. Few electric vehicles are available on the open market for purchase and testing and hence it would be difficult to specify and conduct independent safety tests in the near future. Nevertheless, performing a series of crash tests (and/or obtaining data from manufacturers) would help to confirm that the EVPC proposals are appropriate.

- Side impact – taller vehicles

  The side impact legislation does not apply to a vehicle if the reference point of the lowest seat is over 700 mm from the ground (hereafter referred to as a taller vehicle). This means that a taller vehicle could gain EC whole vehicle type-approval without being assessed for side impact protection[7]. For example, some common sports utility vehicles might fit into this group. Generally, it is thought that side impact tests to assess occupant protection are unnecessary for these vehicles because they perform so well (according to the current test procedures). This is because the mass and particularly the ground clearance of the mobile deformable

[6] Open-type traction batteries are defined in the proposals as a type of battery requiring liquid and generating hydrogen emissions (e.g. lead-acid batteries).
[7] Side impact testing is not required for EC small series type-approval (≤1000 vehicles) for any seating height.

barrier are the same regardless of the vehicle being tested. A taller vehicle could therefore over-ride the barrier and experience relatively little intrusion because the barrier would strike the lower (and potentially stiffer) parts of the chassis. In these circumstances, the loads recorded by the side impact dummy would probably be very low, and well inside the performance limits in the legislation.

A taller vehicle (including an electric vehicle) might present a low risk of occupant injury if struck in the side by another vehicle (assuming it is not another taller vehicle). Nevertheless, electrical components might be damaged resulting in an electrical safety hazard. Furthermore, vehicles with a higher centre of gravity are potentially more likely to roll-over during a side impact collision, which could expose any damaged electrical parts. Amending the legislation to require taller electric vehicles to undergo a side impact test (for instance, to assess only the post-impact electrical safety) could potentially avoid this hazard. However, it could be said that the fuel system integrity of taller vehicles is not assessed for side impact either and hence amending the legislation for taller electric vehicles might single out these vehicles unfairly. Further research is needed to understand fully the hazards and risks for the post-impact electrical safety of taller electric vehicles.

- Fuel leakage – hybrid vehicles

As discussed in Section 2.1.2, hybrid vehicles could present a new hazard due to their high voltage components, which can generate enough energy to create a spark. This could potentially ignite any fuel vapour present resulting in a fire. The frontal and side impact legislation currently permits fuel (or a substitute) to leak from the fuel system following the impact test at a rate up to 5×10^{-4} kg/s (or 30 grams/min. This implies that a crashed vehicle could leak around 150 grams, depending on the time taken for the emergency services to arrive. Adopting more stringent requirements for fuel leakage with hybrid electric vehicles would overcome this potential problem. Nevertheless (at the present time) there is no evidence that current hybrid vehicles pose a greater risk of fire. It might be the case that, although a limited amount is permitted, most manufacturers would not accept any leakage from their vehicles following the impact tests.

- Automatic disconnection of the electrical energy source

The EVPC proposals specify performance requirements to assess the post-impact protection from electric shock. An automatic disconnection device can be used to provide protection, but is not mandatory, and other means of protection can be provided that do not require an automatic disconnection device to be fitted (e.g. physical protection).

The requirements for type-approval are based around a specific set of impact test conditions. However, real collisions occur in a broad range of conditions. For example, some collisions are more severe than the legislative impact tests. In these collisions, the risk of electric shock from the high voltage system could be greater because of greater deformation of the vehicle. A mandatory requirement to fit an automatic disconnection device could allow the protection against electric shock to be controlled in a broader set of circumstances (assuming that the devices are reliable).

- Structural integrity of the Rechargeable Energy Storage System (RESS)

The EVPC proposals specify requirements that control the movement of a RESS during the frontal and side impact tests. However, there are no requirements for its structural integrity. During an impact test, a RESS could be crushed or subjected to intrusion from other parts of the vehicle.

There is relatively little published research on the crash safety of RESS. Component-level experiments with battery cells have demonstrated that mechanical abuse can lead to shorting and possibly rupture, producing smoke, sparks and even explosions (Doughty, 2010; Sahraei *et al.*, 2010). Amending the frontal and side impact legislation to include post-impact structural integrity requirements for a RESS would reduce the risk of this potential safety problem.

- Electrolyte spillage - limits

The EVPC proposals allow up to 7% of the total volume of electrolyte to spill outside the passenger compartment. This value was chosen because it was specified in UNECE Regulation 12 (this regulation was amended for electric vehicles some time ago, but will also be updated by the EVPC proposals). During meetings of the EVPC group it was unclear how much electrolyte would be dangerous and whether the risk depends on the type of battery chemistry and electrolyte used. There is also the possibility of different electrolytes mixing following a collision between two electric vehicles.

Adopting a limit of 7% may be pragmatic because it appears in other legislation. However, further research is needed if the effects of electrolyte spillage outside the passenger compartment are to be understood fully. Prohibiting electrolyte spillage outside the passenger compartment would avoid this potential safety problem and would be a more cautious approach.

- Electrolyte spillage - static roll

The amount of electrolyte that leaks might increase if an electric vehicle rolls over following a collision. In FMVSS 305, a static roll is required for the assessment of electrolyte spillage, but there is no such requirement in the EVPC proposals. Performing a static roll test following the impact test would assess the potential for electrolyte spillage in a broader set of circumstances. However, a static roll is not required during the fuel leakage assessment for conventional internal combustion engine vehicles. Amending this aspect of the legislation for both conventional and electric vehicles would help to maintain consistency.

2.7 Buses and coaches: Directive 2001/85/EC and UNECE Regulations 66 and 107

2.7.1 Overview

Directive 2001/85/EC applies to passenger vehicles that carry 8 passengers or more (single deck, double deck, rigid or articulated vehicles of category M_2 or M_3). It sets out a series of design requirements for exits, interior arrangements, lighting, handrails and markings, as well as requirements for the protection against fire. There is also a stability test for all vehicles and a test of the strength of the superstructure for single deck vehicles that carry seated passengers. The directive also requires that electrical equipment is well-insulated and that an isolation switch is provided where the voltage exceeds 100 V RMS.

Stability Test

The stability test assesses the roll stability of the vehicle. During this test, the vehicle is tilted in line with the longitudinal axis. The main requirement is that the point at which overturning occurs must be greater than 28°, when tilted to either side. The tested vehicle must be equal to its normal running mass and contain masses representing passengers placed in each passenger seat, or uniformly distributed over the standee area at the correct centre of gravity. Where a vehicle is equipped to carry luggage on the roof, a uniformly distributed mass representing the baggage is attached to the roof. Alternatively, a calculation can be used to verify whether the vehicle would pass the test.

Strength of Superstructure

This part of the directive applies to single deck vehicles that carry seated passengers. Four test methods are described to assess the strength of the superstructure of the vehicle:

- Roll-over test on complete vehicle

  The whole vehicle, with a correct centre of gravity and mass distribution, is rotated at no more than 5 deg/s from a platform with a minimum drop of 800 mm, onto a concrete impact area. Fuel, battery acid and other combustible, explosive or corrosive material may be substituted by other materials as long as the mass distribution is unaffected.

- Roll-over test on a body section(s)

  A bodywork section of the vehicle is subjected to the same test as above. The percentage of total energy absorbed by the bodywork section shall not be less than the percentage of the total mass of the vehicle as specified by the manufacturer.

- Pendulum test on a body section(s)

  A rectangular shaped steel pendulum strikes the vehicle body section at a speed between 3 and 8 m/s. The energy to be applied is a proportion of the energy declared by the manufacturer to be allocated to each cross-sectional rings included in that particular bodywork section.

  Calculations based on the data obtained from a test on a bodywork section may be used to demonstrate the acceptability of another bodywork section which is not identical as long as there are many common structural features.

- Verification of strength by calculation

  A superstructure or sections of a superstructure may be shown to meet the testing requirements by calculation. The validity of the calculation method can be established by comparing the results with physical tests, such as a previously tested similar vehicle.

The vehicle meets the requirements of the test (or calculation) if there is no intrusion into a defined space in the passenger compartment, and if no part of this space projects outside the deformed structure. Additional test methods or calculations may be required if the test method (or calculation) that was used cannot take account of variations in sections of the roof. These variations might be brought about by, for example, the installation of an air conditioning system on the roof. If no additional information is available, the technical service may require that a roll-over test of the complete vehicle is carried out.

There are two UNECE Regulations that are recognised as alternatives to the directive for EC type-approval: UNECE Regulation 66 (Strength of superstructure of large passenger vehicles) and UNECE Regulation 107 (General construction of M_2 and M_3 vehicles). Both regulations would be needed to gain approval. Regulation 66 is based around the same strength of superstructure test as the directive. Regulation 107 contains the same stability test as the directive and the more general requirements relating to the construction of vehicles.

2.7.2 Compatibility with electric vehicles

The main requirements and tests in Directive 2001/85/EC (and the corresponding UNECE Regulations) are generally unrelated to the vehicle's power train. Both the directive and the regulations should for the most part be compatible with electric vehicles. However, there is a section in Directive 2001/85/EC (and UNECE Regulation 107) on the protection against fire risks. In particular, three sub-sections require further examination:

- The engine compartment

  The engine compartment requirements are essentially a series of precautions against flammable materials coming into contact with fuel or sources of heat. They would be inappropriate for a purely-electric vehicle since there is no engine or liquid fuel. However, similar fire or heat protection requirements may be needed for an engine motor compartment or for a battery compartment.

- Electrical equipment and wiring

  The electrical equipment and wiring requirements are a series of electrical protection measures. They were probably not developed with an electrical power train in mind. Nevertheless, some of the requirements seem appropriate irrespective of the type of equipment and wiring. For example, insulation is required, there must be fuse and circuit breakers and the cables must be protected from damage. The legislation states there must be a manually-operated isolating switch capable of disconnecting all circuits from the main electrical supply wherever the voltage exceeds 100 V RMS.

  UNECE Regulation 100 deals with some of these topics in its specifications relating to protection against electric shock.

- Batteries

  The directive and regulation do not say whether the battery requirements relate to an auxiliary battery only, or whether they would also apply to a propulsion battery. The requirements are quite broad: the batteries must be well-secured and easily accessible; the battery compartment must be separated from the driver and passenger compartments and well-ventilated; and the battery terminals must be protected against the risk of short circuit. Since no distinction is made between auxiliary and propulsion batteries, it could be interpreted that the requirements would apply to any battery on the vehicle.

  UNECE Regulation 100 includes requirements for rechargeable energy storage systems on-board M and N category vehicles. These cover protection against excessive current by the provision of a protective device, such as fuses, circuit breakers or main contactors, and the accumulation of gas by the provision of ventilation. However, the requirement may not apply if the manufacturer supplies data to demonstrate that overheating from excessive current is prevented without the protective device.

Directive 2001/85/EC and the corresponding UNECE Regulations do not present any major obstacles for electric vehicles. However, the electrical equipment and battery requirements may be insufficient for vehicles with high voltage systems and components. The electrical safety of buses and coaches (i.e. M_2 and M_3 category vehicles) could be dealt with by UNECE Regulation 100 (see Section 2.8). Regulation 100 contains electrical powertrain specifications for M and N category vehicles. Currently, the regulation is not mandatory for EC type-approval; however, an EC proposal for a Council decision to apply Regulation 100 on a compulsory basis was adopted on 15 June 2010.

The EC type-approval framework was extended to buses and coaches by Directive 2007/46/EC. It will be possible, therefore, to mandate Regulation 100 for these vehicles. Additional bus and coach-specific requirements could be developed to deal with any electrical safety hazards that are particular to these vehicles, although there is no evidence that further requirements are needed at the present time. Nevertheless, UNECE Regulation 107 (on the general construction of M_2 and M_3 vehicles) includes an annex that specifies additional safety prescriptions for trolley buses. This comprises specifications for power collection, tractor and auxiliary equipment, the electrical safety of the passengers and crew and the driver compartment.

The requirements in Directive 2001/85/EC (and UNECE Regulation 107) relating to escape hatches also need to be considered. The legislation specifies the number of escape hatches that must be provided and includes technical requirements. There are currently no requirements regarding the proximity of escape hatches to potential hazards. Nevertheless, it would be appropriate to prevent escape hatches from being situated near to high voltage components.

A proposal to amend Regulation 107 was prepared by the expert from the International Association of the Body and Trailer Building Industry for discussion at the 98th session of the Working Party on General Safety (GRSG) in May 2010. The proposal sought to amend the current text of Regulation 107 to state that "there shall be no escape hatches fitted where technical components are installed which present possible dangers to passengers using escape hatches (e.g. high voltage systems, systems containing dangerous liquids and/or gas, etc)". The status of the proposal was unknown at the time of writing, but it appears to be a reasonable approach to deal with the problem.

2.7.3 Proposals for amendments

An electric bus or coach could be approved to Directive 2001/85/EC (or the corresponding UNECE regulations) if it falls within their scope. The main requirements and performance tests are generally unrelated to the type of power train. However, mandating UNECE Regulation 100 for buses and coaches would ensure that the electrical safety of these vehicles is consistent with the latest knowledge and requirements. Further electrical safety requirements (specific to buses and coaches) would provide additional confidence that public safety has been maintained, but at the present time, there was no evidence of a particular safety problem that would not be dealt with already by Regulation 100).

Amendments to UNECE Regulation 107 were proposed by an expert at GRSG to prevent emergency hatches from being located near to components that might present a risk to passengers. If adopted, the proposal would prevent a potentially dangerous situation whereby passengers leaving the vehicle in an emergency could find themselves in close proximity to high voltage systems.

2.8 Electrical power train: UNECE Regulation 100

2.8.1 Overview

UNECE Regulation 100 applies to category M and N vehicles with a maximum design speed above 25 km/h. A proposal to amend Regulation 100 was prepared recently by an informal working group on electrical safety (ELSA), which was set up under the Passive Safety Working Party (GRSP). The proposal (for the 01 series of amendments to Regulation 100) was adopted by the World Forum for Harmonisation of Vehicle Regulations (WP.29) in March 2010. This section reviews Regulation 100 including the ELSA proposal, although at the time of writing, the new regulation had not been published.

UNECE Regulation 100 applied to battery electric vehicles only and where the energy was supplied exclusively by a traction battery installed in the vehicle. However, the ELSA proposal extended the scope of the regulation to include any type of power train above a certain working voltage level. Hybrid vehicles and fuel cell vehicles were therefore covered by the regulation for the first time.

The regulation comprises specifications and test procedures in four main areas: protection against electric shock; rechargeable energy storage systems; functional safety; and determination of hydrogen emissions.

Protection against electric shock

These electrical safety requirements apply to high voltage buses when they are not connected to external high voltage supplies. They include:

- Protection against direct contact

  Live parts in the passenger or luggage compartments must be protected to a degree of at least IPXXD. Enclosures in other areas must have a protection degree of at least IPXXB. These protection degrees relate to the contact of a jointed test finger and a test wire with hazardous parts. The regulation includes a procedure in an annex. There are also requirements for connectors (including the vehicle inlet) and service disconnects to meet IPXXD or IPXXB and for markings for high voltage equipment.

- Protection against indirect contacts with exposed conductive parts

  Protection against electric shock resulting from indirect contact must be provided by galvanically connecting the exposed conductive parts to the electrical chassis. The regulation specifies a limit for the resistance between all exposed conductive parts and the electrical chassis of 0.1 ohm when there is a current flow of at least 0.2 amperes. There are also specifications for connection of the electrical chassis to the earth ground (for vehicles intended to be connected to a grounded external power supply).

- Isolation resistance

  The ELSA proposals introduced more detailed specifications for isolation resistance. The specifications depend on whether the power train comprises separate or combined DC and AC buses. Limits are specified according to the type of buses and their connections and test procedures are provided in an annex.

Rechargeable energy storage systems (RESS)

The RESS specifications cover the protection against excessive current and accumulation of gas only. The main requirement concerning the protection against excessive current is that the RESS shall not overheat. However, if it is subject to overheating, the RESS must be equipped with a protective device such as fuses, circuit breakers or main contactors. Accumulation of gas is controlled by a requirement to provide a ventilation fan or duct in places containing an open-type battery that may produce hydrogen gas.

Functional safety requirements

The functional safety requirements deal with the safety of occupants, but also those outside the vehicle by preventing (as far as possible) unintentional vehicle movements. Several functional safety requirements were removed from UNECE Regulation 100 by ELSA proposal, possibly because corresponding specifications for conventional vehicles were not legislated.

Determination of hydrogen emissions

These requirements relate to the hydrogen emissions during the charging procedures of open-type traction batteries. Vehicles equipped with non-aqueous electrolyte batteries or sealed “gas recombinant” batteries are excluded. The regulation includes a detailed test procedure with limits placed on the hydrogen emissions.

2.8.2 Compatibility with electric vehicles

UNECE Regulation 100 was developed for electric vehicles and sets out key electrical safety provisions, but it is not included in the list of type-approval acts in Directive

2007/46/EC (the framework directive). Regulation 100 is not needed, therefore, in order to gain EC type-approval. However, Directive 2007/46/EC does not exclude electric vehicles from its scope, and an EC proposal to apply Regulation 100 on a compulsory basis was adopted on 15 June 2010.

The possibility of conflict between Directive 2007/46/EC and Directive 2006/95/EC (the low voltage directive) was recognised by the EC (European Commission, 2009). The low voltage directive applies to all electrical equipment designed to operate between 50 and 1000 V AC and between 75 and 1500 V DC. The term "electrical equipment" is not defined and all electrical products fall within the scope of the directive unless they are specifically excluded by the provisions of an annex. Neither electric vehicles nor their equipment (such as chargers) are excluded from the low voltage directive.

UNECE Regulation 100 covers all vehicle components, including an on-board charger. The specifications and tests for the protection against electric shock apply to all high voltage electrical circuits, including the coupling system for charging the RESS. There are also specific requirements for the vehicle inlet that comply with the requirements of IEC 61851-1 for charging systems for electric vehicles.

Pending further clarification and a future revision of the framework directive or the low voltage directive, the EC proposed the following approach (European Commission, 2009):

- Member States can presume that the low voltage directive is not applicable to electric vehicles (i.e. notably to the batteries destined to be used in electric vehicles) when placed on the market;
- Chargers of batteries of electric vehicles shall be always considered as electrical equipment falling within the scope of application of the low voltage directive.

However, some stakeholders have expressed the view that issues related to the electrical safety of any items on-board the vehicle, including an on-board charger, should be covered by the framework directive rather than the low voltage directive. The specifications in Regulation 100 for the protection against electric shock already apply to an on-board charger and also to the vehicle inlet. However, Regulation 100 does not cover the possible effect of an on-board charger on the electricity grid and any hazards that might arise. If the low voltage directive did not apply there would be no regulatory means of controlling these possible hazards.

2.8.3 Proposals for amendments

UNECE Regulation 100 is not mandatory for EC type-approval. Some manufacturers obtain type-approval to the regulation voluntarily. Nevertheless, with the present situation a vehicle could obtain EC type-approval without UNECE Regulation 100. Mandating the application of Regulation 100 would ensure that all electric vehicles provide for the same level of electrical safety.

Electric vehicles fall within the scope of Directive 2006/95/EC (the low voltage directive). Vehicles with EC type-approval according to Directive 2007/46/EC (the framework directive), and including UNECE Regulation 100, would still be required to obtain a CE mark according to the low voltage directive. Excluding electric vehicles (that are within the scope of the framework directive) from the low voltage directive would avoid potentially unnecessary testing and assessment. Excluding on-board chargers within electric vehicles from the low voltage directive might also be appropriate, but only if UNECE Regulation 100 was amended to cover the possible effects of the on-board charger on the safety of the electric grid.

3 Review of type-approval directives and regulations for environmental performance

This section focuses on the type-approval legislation for environmental performance. It includes EC directives and regulations and the corresponding UNECE regulations. It also includes two directives that are not related to vehicle type-approval. These cover end-of-life vehicles and also batteries and were included to determine whether they might raise any issues for electric vehicles.

3.1 Permissible sound level: Directive 70/157/EEC and UNECE Regulation 51

3.1.1 Overview

Directive 70/157/EEC and its subsequent amendments address the type-approval of motor vehicles in relation to permitted noise levels when the vehicles are in operation (both under moving and stationary conditions). It includes procedures for how a vehicle should be tested and any noise limits required for compliance. All Member States are required to comply with the terms of the directive which must be incorporated into national law, although individual Member States have the right to decide how this achieved. The current amendment of the directive is 2007/34/EC, which takes into account the introduction of a new test cycle which has brought the noise tests closer to real-life conditions.

UNECE Regulation 51 also sets out uniform provisions for the type-approval of motor vehicles in relation to permitted noise levels when the vehicles are in operation (both under moving and stationary conditions). This defines procedures for how a vehicle should be tested and the noise limits required for compliance. All Member States are required to comply fully with all provisions in the regulation, although there is no requirement for the regulation to be incorporated into national law.

As technologies have developed, the test procedures have needed to be regularly adapted. Since regulations are more easily amended than directives, it is the text of the regulations that has been most regularly updated. There is now a move towards referencing the regulation within the directive rather than quoting text verbatim. Directive 2007/34/EC now states that the test procedures are as described in UNECE Regulation 51. All further discussion on the test procedures in this document will refer to Regulation 51 rather than 2007/43/EC.

The test procedures set out in Regulation 51 are as defined in ISO standards, which are internationally recognised standard test methods. These can be summarised as follows:

- *Moving vehicle test 1 (Measurement method A, Annex 3):* The vehicle approaches the test site at a given speed (determined by various factors relating to engine power) and on reaching a specified point the throttle is opened wide until a point 20 m further is reached. The maximum noise level is measured on either side of the vehicle at a distance of 7.5 m from the centre line while the vehicle passes between the start line and a point 20 m ahead. The tests are performed in second and/or third gear depending upon the gearbox and power-to-mass ratio. The test method was defined in ISO 362:1998.
- *Moving vehicle test 2 (Measurement method B, Annex 10):* This test is currently included *for evaluation only* (see later). The vehicle approaches the test site at a given speed (fixed, irrespective of gearbox and transmission control type) and on reaching a specified point the throttle is opened wide until a point 20 m further is reached. The maximum noise level is measured on either side of the vehicle at a distance of 7.5 m from the centre line while the vehicle passes between the start

line and a point 20 m ahead. Unlike the test described above it is based on *defined acceleration rates* which are calculated based on the power-to-mass ratio of the vehicle being assessed. This means that the gear in which the test is performed is not predefined; conditions for the selections of suitable gear ratios are specified based on the type of gearbox and transmission control. The test method is defined in ISO 362-1:2007.

- *Stationary vehicle test (Annex 3):* The test essentially involves holding the vehicle at a set engine speed and measuring the noise level when the throttle is released. The microphone is positioned 0.5 m from the exhaust outlet. It should be noted that the standard specifically states that the procedure is neither a method to check the exhaust sound pressure level when the engine is operated at realistic loads nor a method to check the exhaust sound pressure levels against a general noise limit for categories of road vehicles. The test method is as specified in ISO 5130:2007.

The type-approval noise limits, specified in both the directive and the regulation, address the permissible noise levels for the moving vehicle test only. Limits are specified for eight categories of vehicles (including both passenger vehicles and goods vehicles. These limit values were most recently amended in 1992 in amendment 92/97/EEC and currently range from 74-80 dB(A). There are no type-approval noise limits for the stationary (exhaust noise) vehicle test, however the measured noise levels could be used to provide a reference value for administrations who wish to check exhaust noise in use.

The Working Party on Noise (GRB) is the subsidiary body of the World Forum for Harmonization of Vehicle Regulations (WP.29) that is responsible for preparing regulatory proposals on noise. It is considered by GRB that the moving vehicle test 1 in UNECE Regulation 51 (Measurement method A, Annex 3) is no longer sufficiently representative of current urban driving behaviour. A revised test procedure is currently being trialled in parallel with the existing regulation and comprises the following tests:

- *Moving vehicle test 1:* A wide open throttle test with defined acceleration rates (Measurement Method B, Annex 10);
- *Moving vehicle test 2:* A constant speed test performed at 50 km/h using the same gears as the acceleration test. This does not have a noise limit associated with it but is used to calculate the final result of the vehicle;
- *Stationary vehicle test:* This is the same stationary test as defined in Annex 3 of Regulation 51. Currently this does not have a noise limit associated with it.

This back-to-back testing is to be carried out until mid-2010. A decision on whether to formally adopt the revised test procedures has yet to be taken by WP.29.

Draft proposals have also been prepared for additional sound emission provisions (ASEP) to be included in the amended version of Regulation 51, which are related to the new wide-open throttle acceleration test described above. These are applicable to M_1 and N_1 category vehicles equipped with internal combustion engines and as such, would not be applicable to vehicles powered solely by electric motors/fuel cells. At the present time, there is a preference for hybrid vehicles to be excluded from these provisions due to the likely complexities of the test procedures and insufficient repeatability; however some GRB members have expressed a wish for only a time-limited exemption for hybrid vehicles. Further consideration is to be given to all issues associated with ASEP and the informal group responsible for the draft has been invited to prepare a final proposal.

3.1.2 Compatibility with electric vehicles

Directive 2007/34/EC has been amended to include vehicles incorporating electric motors as the power plant. Appendix 1 of Annex 1 sets out the specific information that must be reported for those vehicles to be successfully type-approved; items 3.3 – 3.4

refer to electric motors fitted to the vehicle (in terms of type, maximum hourly output and operating voltage) and other engines or motors or combinations thereof.

Clause 6.2.1.1 of the current version of Regulation 51 states that "*in the case of a vehicle powered by an electric motor, the emitted noise shall only be measured in motion*". Since the stationary test focuses on exhaust noise rather than engine noise, the exclusion of electrically powered vehicles from such a test is logical.

Hybrid cars and vans falling into the M_1 and N_1 categories are potentially addressed within the main moving vehicle tests within both Regulation 51 and the proposed amendment, even if only in petrol/diesel mode. Although it is not clearly stated, it is assumed that where the vehicle is capable of fully operating in both modes at the moving vehicle test speed then it would most likely be tested in both modes. If the electric motor only operates at very low speeds (below that used in the moving vehicle test) or when idling, it is assumed that it is not tested in this mode.

In relation to the determination of the approach speed used for the moving vehicle test in Regulation 51, there are a number of clauses applicable to vehicles powered by an electric motor: Annex 3, Clause 3.1.2.2 includes specific requirements for vehicles which have no gearbox or transmission control; Annex 3, Clause 3.1.2.3 includes specific requirements for vehicles which have a manually operated gearbox; Annex 3 Clause 3.1.2.4 includes specific requirements for vehicles with automatic transmission. Electric vehicles are most commonly fitted with Continuously Variable Transmission (CVT), a form of automatic transmission. Where automatic vehicles are likely to downshift to gear ratios not normally used for urban driving, modifications to the test procedure to overcome this are included.

In relation to the determination of the vehicle acceleration rates and gear ratio selection in the proposed amendment to Regulation 51, the procedures specifically include vehicles with CVTs, and as such will be suitable for use with electric vehicles.

3.1.3 Proposals for amendments

With the increasing introduction of new vehicle technologies, it is considered that the scope of application of the tests as defined in UNECE Regulation 51 is outdated. A proposal has already been prepared by GRB to amend Clause 6.2.1.1 to read *"in the case of a vehicle where an internal combustion engine does not operate when the vehicle is stationary, or only operates in limited conditions where the vehicle control systems determine the manner of stationary operation, the emitted noise shall only be measured in motion"*. In the context of this report, such vehicles would include, but are not limited to fuel cell vehicles, hybrid vehicles, plug-in vehicles and electric vehicles, and is considered that such a proposal would improve clarity.

Providing that the proposals to amend Regulation 51 are implemented, no further specific amendments to the test procedures are considered necessary to fully accommodate type-approval testing of electric and hybrid vehicles fitted with some form of transmission. The new procedures fully address all transmission types commonly used on electric vehicles.

It is noted that Regulation 51 specifically included approach speed conditions for vehicles with no gearbox, e.g. direct drive electric vehicles. Acceleration conditions in the proposed amendment for vehicles with no transmission appear to have been omitted. It is proposed that the reasons for this omission should be clarified by GRB/ISO, and that if direct drive electric vehicles are to be developed in the future that the regulation be amended accordingly or the text of the regulation clarified.

It is considered that clear specification of the operational modes to be used for the type-approval of hybrid vehicles would improve the clarity of the regulation, i.e. whether or not the vehicle must be tested in both modes.

As a separate issue, GRB has endorsed a proposal to establish an informal group on minimum sound levels for silent vehicles, which would include electric vehicles and hybrids running in electric mode. This issue has been raised due to concerns over the potential safety risks to visually impaired pedestrians caused by quiet vehicles (see Section 4.5). Draft terms of reference for this informal group are scheduled for consideration at the next GRB session. There is very little statistical data available on this issue at the current time. Further research is therefore considered essential before any decisions are taken.

3.2 Emissions from light-duty vehicles: Regulations (EC) No. 715/2007 and 692/2008 and UNECE Regulations 83 and 101

3.2.1 Overview

Various atmospheric pollutants are emitted from 'conventional'[8] road vehicles as a result of fuel combustion and other processes. Since the early 1970s in Europe, emission limits have applied to road vehicles and engines, and the methods of measurement have been standardised. The emission limits apply to carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulate matter (PM) from the vehicle exhaust, as well as evaporative emissions of volatile organic compounds (VOCs). These pollutants are relevant in terms of local air quality. The limits have been reduced many times since they were first introduced, and changes have been made to the test method to make it more realistic and effective.

The emission regulations for new light-duty vehicles - passenger cars (M_1, M_2) and light commercial vehicles (N_1, N_2) - are specified in Directive 70/220/EEC. This directive has been amended a number of times, most notably to introduce new emission standards. Emission-control technologies have developed accordingly. The last amendment of the directive, 2002/80/EC addressed Euro 3/4 vehicles. Subsequent amendments, described below, have been introduced in the form of EC regulations. Regulations ensure that detailed technical provisions are directly applicable to manufacturers, approval authorities and technical services. Furthermore, they can be updated in a more efficient manner than directives. It is intended that the regulations replace the directives, which will then be repealed.

Regulation (EC) No. 715/2007 was published in 2007 and introduced Euro 5 and Euro 6 emission requirements (with compliance required by 2009 and 2014 respectively) as well as significant amendments to the existing requirements. For example, the emission limits for vehicles less than 2,500 kg and greater than 2,500 kg are homogenised, and vehicle manufacturers are required to make information related to their on-board diagnostic (OBD) systems readily available to independent vehicle repairers. This was followed in 2008 by Regulation (EC) No. 692/2008, which deals with the implementation and amendment of 715/2007.

UNECE Regulation 83 also sets out provisions for the approval of vehicles with regard to the emission of pollutants. Regulation (EC) No 692/2008 refers to Regulation 83 for many of its technical requirements, but also sets out various exceptions to the UNECE regulation. Six separate types of exhaust emissions test are specified for vehicles with positive-ignition engines in Regulation No. 692/2008:

- *Type 1:* Cold-start tailpipe emissions test, in which a production-representative vehicle is tested on a dynamometer. The driver must follow a driving cycle and the vehicle's emissions are collected and analysed.

[8] In this sense, the term 'conventional' is used to refer to vehicles with an internal combustion engine (ICE) only.

- *Type 2:* Idle CO test. The CO concentration at the tailpipe is determined at low idle and high idle.
- *Type 3:* Crankcase ventilation test. The pressure in the crankcase is measured for three different operating modes.
- *Type 4:* Evaporative emissions test. Petrol vehicles must be enclosed in an evaporative 'SHED' which measures the volatile organic compounds concentration in the enclosed air.
- *Type 5:* Durability test. A production vehicle with the required mileage is tested to determine the vehicle's deterioration factor. This is used to ensure that over the life of the vehicle, its emissions never fall below the required limits.
- *Type 6:* Cold room tailpipe emissions test. This test is run in the same manner as the Type I test, except it is conducted in a room with an ambient temperature of $-7^{o}C$.

Vehicles with compression-ignition engines are subject to the Type 1 and Type 5 tests. Other test requirements relate to the following:

- In-service conformity
- On-board diagnostics
- CO_2 emissions and fuel consumption
- Smoke opacity

The emphasis here is placed on the Type 1 test, as this addresses the largest contribution to emissions during the lifetime of a vehicle (*i.e.* hot running emissions from the vehicle exhaust). In this test emissions are measured over the New European Driving Cycle (NEDC), which is comprised of a low-speed urban part (ECE15) with four segments (also known as the Urban Driving Cycle, or UDC), and a high-speed part known as the Extra-Urban Driving Cycle (EUDC). The ECE15 is characterised by low vehicle speed, low engine load, and low exhaust gas temperature. The EUDC includes more aggressive driving modes. The maximum speed of the EUDC cycle is 120 km/h. The four ECE segments are repeated without interruption, and are followed by one EUDC segment. Before the test, the vehicle is allowed to 'soak' for at least six hours at a temperature of 20-30°C. Prior to the introduction of the Euro 3 standard in 2000, the vehicle was then started and allowed to idle for 40 seconds before sampling began. However, with the introduction of Euro 3 the idling period was eliminated, and sampling began at engine start. This modified cold-start test is also referred to as the MVEG-B test.

The vehicle exhaust gases are diluted with filtered air to prevent condensation or reaction between the exhaust gas components. The dilution takes place in a tunnel known as a 'constant volume sampler'. The system maintains a constant volumetric flow. During the emission test a sample of the diluted exhaust gas is drawn from the dilution tunnel and collected in a pair of Tedlar sampling bags. One bag is used for the diluted exhaust gas and the other for the dilution air. The latter is used for correction, since the dilution air may also contain small amounts of the compounds being measured. After the test, the content of each bag is analysed. The analysis of the regulated exhaust gases and CO_2 is quite straightforward, and is extensively described in the legislation. Dedicated analysers are used for CO, NO_x, HC and CO_2. The CO and CO_2 analysers operate by non-dispersive infrared. The HC analyser operates by flame ionisation detection and the NO_x analyser by chemiluminescence. Multiplication of the concentration of a given pollutant by the tunnel air flow gives the emission factor in grams per kilometre. Again, the calculation procedure is extensively described in the legislation.

For diesel vehicles only, particulate matter (PM) is collected separately from the other emission components by drawing diluted exhaust gas from the tunnel through a pair of Pallflex filters. The second filter serves to detect and, if necessary, to correct for any sample breakthrough from the first filter. The filters are weighed before and after the test (in both cases, following a period of conditioning under specified temperature and humidity ranges) and their weight increase is used to determine the PM mass emission factor.

The emission standards for passenger cars are shown in Table 3, and those for light commercial vehicles are shown in Table 4.

Table 3: EU Emission standards for passenger cars (category M_1*)[9]

Tier	TA date	Emission standard (g/km)				
		CO	HC	HC+NO_x	NO_x	PM
Compression Ignition (Diesel)						
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025
Euro 5	2009.09[b]	0.50	-	0.23	0.18	0.005[e]
Euro 6	2014.09	0.50	-	0.17	0.08	0.005[e]
Positive Ignition (Gasoline)						
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.2	-	0.5	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.0	0.10	-	0.08	-
Euro 5	2009.09[b]	1.0	0.10[c]	-	0.06	0.005[d,e]
Euro 6	2014.09	1.0	0.10[c]	-	0.06	0.005[d,e]

* At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
a - until 1999.09.30 (after that date DI engines must meet the IDI limits)
b - 2011.01 for all models
c - and NMHC = 0.068 g/km
d - applicable only to vehicles using DI engines
e - proposed to be changed to 0.003 g/km using the PMP measurement procedure

[9] Adapted from http://www.dieselnet.com/. NMHC = non-methane hydrocarbons.

Table 4: EU Emission standards for light commercial vehicles[10]

Category†	Tier	TA date	Emission standard (g/km)				
			CO	HC	$HC+NO_x$	NOx	PM
Compression Ignition (Diesel)							
N_1, Class I ≤1305 kg	Euro 1	1994.10	2.72	-	0.97	-	0.14
	Euro 2, IDI	1998.01	1.0	-	0.70	-	0.08
	Euro 2, DI	1998.01[a]	1.0	-	0.90	-	0.10
	Euro 3	2000.01	0.64	-	0.56	0.50	0.05
	Euro 4	2005.01	0.50	-	0.30	0.25	0.025
	Euro 5	2009.09[b]	0.50	-	0.23	0.18	0.005[e]
	Euro 6	2014.09	0.50	-	0.17	0.08	0.005[e]
N_1, Class II 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	0.19
	Euro 2, IDI	1998.01	1.25	-	1.0	-	0.12
	Euro 2, DI	1998.01[a]	1.25	-	1.30	-	0.14
	Euro 3	2001.01	0.80	-	0.72	0.65	0.07
	Euro 4	2006.01	0.63	-	0.39	0.33	0.04
	Euro 5	2010.09[c]	0.63	-	0.295	0.235	0.005[e]
	Euro 6	2015.09	0.63	-	0.195	0.105	0.005[e]
N_1, Class III >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	0.25
	Euro 2, IDI	1998.01	1.5	-	1.20	-	0.17
	Euro 2, DI	1998.01[a]	1.5	-	1.60	-	0.20
	Euro 3	2001.01	0.95	-	0.86	0.78	0.10
	Euro 4	2006.01	0.74	-	0.46	0.39	0.06
	Euro 5	2010.09[c]	0.74	-	0.350	0.280	0.005[e]
	Euro 6	2015.09	0.74	-	0.215	0.125	0.005[e]
Positive Ignition (Gasoline)							
N_1, Class I ≤1305 kg	Euro 1	1994.10	2.72	-	0.97	-	-
	Euro 2	1998.01	2.2	-	0.50	-	-
	Euro 3	2000.01	2.3	0.20	-	0.15	-
	Euro 4	2005.01	1.0	0.1	-	0.08	-
	Euro 5	2009.09[b]	1.0	0.10[f]	-	0.06	0.005[d,e]
	Euro 6	2014.09	1.0	0.10[f]	-	0.06	0.005[d,e]
N_1, Class II 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	-
	Euro 2	1998.01	4.0	-	0.65	-	-
	Euro 3	2001.01	4.17	0.25	-	0.18	-
	Euro 4	2006.01	1.81	0.13	-	0.10	-
	Euro 5	2010.09[c]	1.81	0.13[g]	-	0.075	0.005[d,e]
	Euro 6	2015.09	1.81	0.13[g]	-	0.075	0.005[d,e]
N_1, Class III >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	-
	Euro 2	1998.01	5.0	-	0.80	-	-
	Euro 3	2001.01	5.22	0.29	-	0.21	-
	Euro 4	2006.01	2.27	0.16	-	0.11	-
	Euro 5	2010.09[c]	2.27	0.16[h]	-	0.082	0.005[d,e]
	Euro 6	2015.09	2.27	0.16[h]	-	0.082	0.005[d,e]

† For Euro 1/2 the Category N_1 reference mass classes were Class I ≤ 1250 kg, Class II 1250-1700 kg, Class III > 1700 kg.
a - until 1999.09.30 (after that date DI engines must meet the IDI limits)
b - 2011.01 for all models
c - 2012.01 for all models
d - applicable only to vehicles using DI engines
e - proposed to be changed to 0.003 g/km using the PMP measurement procedure
f - and NMHC = 0.068 g/km
g - and NMHC = 0.090 g/km
h - and NMHC = 0.108 g/km

[10] Adapted from http://www.dieselnet.com/.

As well as controlling pollutants that are important for local air quality (i.e. CO, HC, NO_x and PM), Regulations No. 715/2007 and No. 692/2008 include technical requirements for CO_2 emissions and fuel consumption. These were previously set out in Directive 80/1268/EC, which was repealed and replaced by Regulation No. 715/2007. UNECE Regulation 101 also deals with this topic and is referred to by Regulation (EC) No. 692/2008. Although limits are applied to the "air quality emissions", there are no performance limits for CO_2 emissions and fuel consumption in this legislation. However, the test results must match the manufacturer's declared value.

Average emissions of CO_2 from *all* new passenger cars (as opposed to individual vehicle models) have, in the past, been controlled through voluntary agreements between the European Commission and the automotive industry. However, average emissions of CO_2 from new cars and vans are now also covered by separate legislation. Regulation (EC) No. 443/2009 sets the CO_2 emission performance standards for new passenger cars. The fleet average to be achieved by 2015 by all cars registered in the EU is 130 g/km. On 28 October 2009 the European Commission also adopted a new legislative proposal to reduce CO_2 emissions from light commercial vehicles. The EU fleet average for all new light commercial vehicles of 175 g/km will apply from 2014.

3.2.2 Compatibility with electric vehicles

In the case of hybrid electric vehicles, the main issue with regard to emission measurement is the so-called 'state-of-charge' correction. When any vehicle completes a chassis dynamometer test the energy provided by the engine is not exactly equal to the total energy required to complete the driving cycle, as some energy can be stored or used in the battery[11]. For conventional internal combustion engine vehicles the difference is not usually significant. However, in a hybrid a significant amount of energy is stored on-board, and the vehicle may remove or add energy to this reservoir during a relatively short period of time. When a hybrid operates in a charge-depleting mode, it effectively borrows energy from the battery to complete the driving cycle. This therefore skews the results – the fuel consumption and emissions are reduced. Conversely, when the engine puts more energy into the batteries than needed to bring the batteries back up to optimal state-of-charge, the results seem high because more fuel is used to cover the driving cycle.

In order to compare the emission test results from a hybrid electric vehicle with those from a conventional vehicle (or with other hybrids), the fuel consumption and emissions data from the hybrid must be adjusted to what they would be for a net change in stored energy of zero. When a vehicle finishes an emission test cycle, if the batteries have the same state-of-charge at the end of the test as at the beginning (a net state-of-charge difference of zero) the data can be used uncorrected. SAE J1711 (a recommended practice for light-duty hybrid tests) covers state-of-charge corrections by limiting the differential to 1 percent of the energy expended during the cycle. SAE J2711 provides similar guidance for heavy-duty vehicles, again using the 1 percent criterion.

As vehicle hybridisation level increases, the effect of ambient temperature on fuel consumption also becomes more important. Higher temperatures tend to increase the battery capacity and thus improve the penetration potential of the electrical system, which leads to better fuel economy. As a result, when testing hybrids the effects of seasonal temperature fluctuation on emissions, which could be up to 12 percent, should be considered (Fontaras *et al*., 2008).

A further adjustment to the test results would need to be made in the case of 'plug-in' hybrids. In this case the energy extracted from the mains supply and from the fuel would need to be calculated separately, and related back to the primary emissions and energy used to arrive at a meaningful figure for comparisons. However, different primary

[11] Kinetic energy is transformed into electrical energy.

energy sources have different emission levels, and this must be borne in mind when comparisons are made.

Clearly, in the case of purely-electric vehicles there are no pollutant emissions from the vehicle itself, because only the stored electrical energy is consumed[12]. Consequently, many of the provisions in the legislation are not relevant for these vehicles. The most important factors to consider are the electrical energy consumption (expressed in watt hours per kilometre – Wh/km) of the vehicle, and the range (in km).

Regulation (EC) No. 715/2007 states that the specific procedures, tests and requirements for type-approval shall, where relevant, apply to vehicles regardless of the type of fuel by which they are powered (including hybrid vehicles).

Regulation (EC) No. 692/2008 refers to two types of hybrid electric vehicle:

- Off-vehicle-charging vehicles, also known as 'externally chargeable' (*i.e.* 'plug-in' hybrids);
- Not-off-vehicle-charging vehicles, also known as 'not externally chargeable'.

Annex X of Regulation (EC) No. 692/2008 deals specifically with the emissions test procedure for hybrid electric vehicles, citing the test procedure in Annex 14 of UNECE Regulation 83. In general, hybrids are tested using the same test methods as conventional internal combustion engine vehicles, although the preconditioning procedures may differ. In some cases the preconditioning for off-vehicle-charging and not-off-vehicle-charging vehicles are different. Full details can be found in Annex 14 of Regulation 83.

For Type 1 testing only, Annex 14 states that off-vehicle-charging hybrids are tested according to two conditions, namely:

- Condition A, in which the test is carried out with a fully charged electrical energy/power storage device.
- Condition B, in which the test is carried out with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity).

In the case of off-vehicle charging vehicles the test procedure is as follows. For both Conditions A and B the storage device is initially discharged with the vehicle being driven at a steady speed of 50 km/h until the internal combustion engine starts up. The engine is then stopped within 10 seconds. The vehicle is then conditioned in the same way as non-hybrid vehicles, by being driven over the regulatory driving cycle. The vehicle is then left to soak at a temperature of 20-30°C for at least six hours prior to the test itself. During the test the prescribed gear-shift points for internal combustion engine vehicles are not used. The principal difference between Condition A and Condition B is that the storage device is charged during the soak for Condition A, whereas it is not for Condition B. The weighted mass emission of each pollutant (in g/km) is then calculated, taking into account the results from the Condition A and Condition B tests, the vehicle's electric range and the distance between two battery recharges (assumed to be 25 km). The state-of-charge profiles of the electrical energy storage device and are given in the annex.

In the case of not-off-vehicle charging vehicles, two complete driving cycles are carried out for preconditioning without the soak. Again, the prescribed gear-shift points for internal combustion engine vehicles are not used. Provisions are also made for hybrid vehicles with and without an operating mode switch.

The Type 2 and Type 3 tests must be carried out with the internal combustion engine running. The manufacturer must provide a 'service mode' that makes the execution of the tests possible. For the Type 4 test, the preconditioning procedure for hybrid vehicles

[12] The production of the electric energy at source (the power station) is a source of air pollution.

is also described in Annex 14 of Regulation 83. Type 5 and Type 6 tests for off-vehicle-charging vehicles are carried out under test Condition B described above.

The profile of the state-of-charge of the electrical energy/power storage device during different stages of the Type 1 test is given in Appendix 1 of Annex 14 of Regulation 83. State-of-charge correction functions for light-duty vehicles are also stated in UNECE Regulation 101. The latter includes a state-of-charge profile for an additional charging period after testing.

Detailed methods and test cycles for measuring electrical energy consumption and range are described in UNECE Regulation 101 and these are referred to by Regulation (EC) No. 692/2008). The electric energy consumption of purely-electric vehicles is dealt with in Annex 7 of the UNECE regulation, while the electric energy consumption of hybrid vehicles is dealt with in Annex 8. Electrical energy consumption is measured over the New European Driving Cycle (NEDC), as for conventional vehicles. Issues addressed include gear selection and vehicle driving mode, where these are available. The test method includes the four following steps: (a) initial charge of the battery, (b) two applications of the NEDC, (c) charging the battery and (d) calculation of the electric energy consumption.

3.2.3 Proposals for amendments

The type-approval legislation on light-duty vehicle emissions already includes specific provisions for electric vehicles. For instance, there are alternative test procedures set out for hybrid vehicles, including those that feature more complex control strategies (i.e. where the internal combustion engine is run in conjunction with the electric motor during periods of high energy demand). The legislation also includes requirements relating to the measurement of energy consumption and range for electric vehicles.

In the short term, it would appear that no further amendments are needed to accommodate electric vehicles in the legislation for light-duty vehicle emissions (over and above the natural development of the legislation that is likely to take place as experience with these vehicles and the test procedures grows). However, it will be important to understand fully the capacity of the test procedures to compare the emissions performance of different vehicles and propulsion technologies, particularly as new technologies emerge.

At the present time, the tail-pipe CO_2 emissions value is an important means of comparing the environmental performance of passenger cars. It is used as the basis for legislation and also for various (financial) incentives. However, the relevance of tail-pipe CO_2 emissions will reduce as electrification increases (because purely-electric vehicles and plug-in hybrids operating in electric mode do not produce tail-pipe CO_2 emissions). UNECE Regulation 101 provides for the measurement of electrical energy consumption and range for electric vehicles, but the CO_2 emissions associated with an electric vehicle (i.e. the emissions from generating the electricity) are effectively ignored. Well-to-wheel emissions or lifecycle emissions are two possible alternatives to tail-pipe CO_2 emissions for electric vehicles. However, there are likely to be strengths and weaknesses with each of these approaches. Further research is needed therefore if the optimum alternative to tail-pipe CO_2 emissions is to be identified for electric vehicles.

3.3 Emissions from heavy-duty vehicles: Regulation (EC) No. 595/2009 and UNECE Regulation 49

3.3.1 Overview

The European emission standards for heavy-duty vehicles apply to all motor vehicles with a 'technically permissible maximum laden mass' of more than 3,500 kg, equipped with compression ignition, positive ignition natural gas or liquefied petroleum gas engines. This covers a wide range of in-service vehicles, and the engine and the body are usually built by separate companies. In order to avoid the complexity and cost of a separate type-approval procedure for all varieties of vehicle, the responsibility for compliance with emissions regulation is borne by the engine manufacturer.

The regulations for heavy-duty engines were originally introduced by Directive 88/77/EEC, followed by a number of amendments. As observed for passenger cars, there has been a transition at EU level from directives to regulations. The most recent amendment is Regulation (EC) No. 595/2009.

The first directive applicable to heavy-duty diesel engines was a restriction on visible smoke (Directive 72/306/EEC). This was determined using a 'free acceleration smoke' test. The first limits on mass emissions of gaseous pollutants were introduced by Directive 88/77/EEC, which set standards for carbon monoxide (CO), total hydrocarbons (THC) and NO_x based on the ECE-R49 test. The ECE-R49 test is a 13-mode steady-state test cycle, introduced by UNECE Regulation 49 and then adopted by Directive 88/77/EEC. It was used for type-approval up to and including Euro II level. The test is normally performed on an engine dynamometer, with the engine being operated through a sequence of 13 engine speed and engine load conditions, and for a prescribed time in each mode. The exhaust emissions measured during each mode are expressed in g/kWh, and the final test result is a weighted average of the 13 modes.

The ESC (European Stationary Cycle, also known as OICA/ACEA cycle) was introduced, together with the ETC (European Transient Cycle) and the ELR (European Load Response) test, for emission certification of Euro III heavy-duty diesel engines in October 2000. The ESC replaced the ECE-R49 test, and is also a 13-mode steady-state procedure. The ELR engine test, which consists of a sequence of load steps at constant engine speeds, was introduced for the purpose of smoke opacity measurement.

The ETC test cycle (also known as the FiGE cycle) was introduced alongside the ESC for emission certification of heavy-duty diesel engines in Directive 1999/96/EC. The FiGE Institute developed the cycle in two variants, as a chassis and an engine dynamometer test, though for the purpose of engine certification the ETC cycle is performed on an engine dynamometer. Different driving conditions are represented by three parts of the ETC cycle. Part one represents city driving with a maximum speed of 50 km/h, and includes frequent starts, stops, and idling periods. Part two represents rural driving, begins with a steep acceleration segment, and has an average speed of 72 km/h. Part three represents motorway driving with an average speed of 88 km/h.

For the Euro VI stage the legislation has been simplified. The directives which needed to be transposed into all of the national legislations were replaced by regulations which are directly applicable. The Euro VI emission standards were introduced by Regulation (EC) No. 595/2009 published on 18 July 2009 (with a correction on 31 July 2009). In the 'split-level' approach, a number of technical details will be specified in the implementing regulation to be developed by the Commission and adopted no later than 1 April 2010. In addition to introducing more stringent emission limits, the regulation includes a limit of 10 ppm for ammonia (NH_3), which can be emitted due to the use of additive-based emission-control systems. A particle number limit is also planned in addition to the mass-based limit. The number limit would prevent the possibility that the Euro VI PM mass limit is met using technologies (such as partial-flow filters) that would enable a high number of ultrafine particles (<0.1 μm diameter) to pass. A maximum limit for the NO_2 component of NO_x emissions may also be defined in the implementing regulation. Furthermore, the world-harmonized steady-state and transient test cycles—WHSC and WHTC—will be used for Euro VI testing. WHSC/WHTC based limit values will be introduced by the implementing regulation based on correlation factors with the current ESC/ETC tests.

The emission standards for heavy-duty diesel engines are shown in Table 5. Emission standards for diesel engines that are tested on the ETC test cycle, as well as for heavy-duty gas engines, are summarised in Table 6.

Table 5: EU emission standards for heavy-duty diesel engines[13]

Tier	TA date	Test	Emission standard				
			CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)	Smoke (m^{-1})
Euro I	1992, < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro II	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro III	*1999.10, EEVs only*	*ESC & ELR*	*1.5*	*0.25*	*2.0*	*0.02*	*0.15*
	2000.10	ESC & ELR	2.1	0.66	5.0	0.10 0.13[a]	0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02	0.5
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5
Euro VI	2013.01		1.5	0.13	0.4	0.01	

a - for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}

Table 6: EU emission standards for heavy-duty diesel and gas engines over the ETC test[14]

Tier	TA date	Test	Emission standard (g/kWh)				
			CO	NMHC	CH_4[a]	NOx	PM[b]
Euro III	*1999.10, EEVs only*	*ETC*	*3.0*	*0.40*	*0.65*	*2.0*	*0.02*
	2000.10	ETC	5.45	0.78	1.6	5.0	0.16 0.21[c]
Euro IV	2005.10		4.0	0.55	1.1	3.5	0.03
Euro V	2008.10		4.0	0.55	1.1	2.0	0.03
Euro VI	2013.01		4.0	0.16[d]	0.5	0.4	0.01

a - for gas engines only (Euro III-V: NG only; Euro VI: NG + LPG)
b - not applicable for gas fueled engines at the Euro III-IV stages
c - for engines with swept volume per cylinder < 0.75 dm^3 and rated power speed > 3000 min^{-1}
d - THC for diesel engines

3.3.2 Compatibility with electric vehicles

There are several reasons why engine-based tests have been the norm for heavy-duty applications, and why the responsibility for compliance with emission regulations is borne by the engine manufacturer. However, the current engine test procedure - which is

[13] Adapted from http://www.dieselnet.com/.
[14] Adapted from http://www.dieselnet.com/.

designed for internal combustion engines - cannot be applied meaningfully to hybrid vehicles, as the instantaneous behaviour of the engine is decoupled from the instantaneous road load, and the standard set of measuring points and their weightings will not be relevant. In addition, engine tests have become increasingly complex with the introduction of each new level of technology, and the time and cost involved in setting up an engine on a test bed can be far greater than the time and cost associated with the actual test itself. It can therefore probably be assumed that vehicle-based legislative tests will be the norm in the future. This in itself introduces certain challenges given the large number of possible vehicle configurations. The other challenge is to ensure that the test procedure accounts for any specific requirements of hybrid technology.

Moreover, the internal combustion engines used in hybrid heavy-duty vehicles are generally smaller than the engines used in conventional heavy-duty vehicles, and may actually be designed for use in light-duty vehicles. This appears to represent a loophole in the legislation, as the engine would not be subject to either the light-duty legislation (which is vehicle-based) or the heavy-duty legislation (as the engine would not meet the 'design' criteria). Again, this issue could be resolved by the use of vehicle-based tests for heavy-duty vehicles.

3.3.3 Proposals for amendments

There are no specific provisions for hybrid vehicles within the EC or UNECE type-approval legislation on emissions from heavy-duty vehicles. Furthermore, the traditional engine testing approach is not compatible with hybrid vehicles because the engine speed and load cycles of hybrids are different from conventional vehicles. One option would be to develop a vehicle-based emissions test procedure for heavy-duty vehicles. In fact, Clause 20 of Regulation 595/2009 states that '*in order to promote the market for clean and energy efficient vehicles, the Commission should study the feasibility and the development of a definition and a methodology of energy consumption and CO_2 emissions for whole vehicles and not only for engines, without prejudice to the use of virtual and actual testing. Such a definition and the methodology should also cover alternative driveline concepts (e.g. hybrid vehicles) and the effects of improvements on vehicles such as aerodynamics, weight, loading capacity and rolling resistance. If a suitable method of presentation and comparison can be identified, the derived fuel consumption and CO_2 emissions should be made publicly available for separate vehicle types.*'

Another option would be to develop an engine-based test procedure that takes the end use of the engine into account. This approach is being explored by an informal group on heavy-duty hybrids, which was set up under the UNECE Working Party on Energy and Pollution (GRPE). The objective of the informal group is to establish an amendment to Global Technical Regulation No. 4[15] with respect to pollutant and CO_2 emissions from heavy-duty hybrids. The group will also consider whether the scope of Regulation No.4 is appropriate, or whether a separate global technical regulation should be considered. Conclusions on this point will be reported to GRPE at the 61st session in January 2011. In addition, the key technical work to be carried out by the informal group includes:

- Investigation of the hardware-in-the-loop simulation approach, which starts from a vehicle cycle and simulates powertrain and vehicle components to result in a hybrid-specific engine cycle for emissions testing;
- Verification of the engine cycle created by hardware-in-the-loop simulation against an engine cycle resulting from a (vehicle) chassis dynamometer test;
- Assessment of the feasibility of a chassis dynamometer-based emissions test as an alternative to hardware-in-the-loop simulation.

[15] Global Technical Regulation No.4 aims to provide a world-wide harmonised method to determine the levels of pollutant emissions from engines used in heavy vehicles.

The informal group will submit its final report on the investigation of hardware-in-the-loop simulation to GRPE at its 65th session in January 2013. The target completion date for the work of the informal group is the 163rd session of WP.29 in June 2014. This date (and the work on the necessity of a chassis dynamometer test) will be reviewed by WP.29 at its 160th session in June 2013.

Further research is needed if the most appropriate means of assessing the emissions from heavy-duty hybrid vehicles is to be understood. The findings of such research could be used to support and influence the outcome of the UNECE informal group on heavy-duty hybrids.

3.4 Engine power: Directive 80/1269/EEC and UNECE Regulation 85

3.4.1 Overview

Directive 80/1269/EEC specifies a test procedure to determine the net engine power of internal combustion engines used in category M and N vehicles. It applies to internal combustion piston engines and also to rotary piston engines. The net power test consists of a run at full throttle for positive-ignition engines and at fixed full load fuel injection pump setting for compression ignition engines. Performance data must be obtained according to a set of conditions defined in the directive. Measurements must be taken at a sufficient number of engine speeds to define correctly the power curve between the lowest and the highest engine speeds recommended by the manufacturer. This range must include the speed of revolution at which the engine produces its maximum power. The directive sets out a number of power correction factors relating to the atmospheric conditions. A test report is required for type-approval containing all the results and calculations required to determine the net power. The net power indicated by the manufacturer for the type of engine is accepted if it does not differ from the values measured on the engine submitted for testing by more than ± 2 percent for maximum power and more than ± 4 percent at the other measurement points on the curve, with a tolerance of ± 1.5 percent for engine speed.

The last amendment to Directive 80/1269/EEC was made in 1999, but since then UNECE Regulation 85 has been amended several times. Most notably, Regulation 85 now applies to electric drive trains as well as internal combustion engines. The tests for internal combustion engines are essentially the same as the directive. In the case of electric drive trains, the net power test consists of a run at the full setting of the throttle controller. Measurements must be taken at a sufficient number of motor speeds to define the power curve between zero and the highest motor speed recommended by the manufacturer. The regulation also includes a test to determine the maximum 30 minutes power (for electric drive trains only). This means the maximum net power that the electric drive train can deliver over a period of 30 minutes, as an average. During the test, the drive train is run at a power which is the best estimate of the manufacturer for the maximum 30 minutes of power. The speed must be in a range, at which the net power is greater than 90 percent of the maximum power measured in the net power test. Speed and power must be recorded and the power must be in a range of ± 5 percent of the power value at the start of the test. The net power and the maximum 30 minutes power indicated by the manufacturer are accepted if they do not differ by more than ± 2 percent for maximum power and more than ± 4 percent at the other measurement points on the curve with a tolerance of ± 2 percent for engine or motor speed.

3.4.2 Compatibility with electric vehicles

Directive 80/1269/EEC is not compatible with electric vehicles and they are excluded from the scope; however, the directive was repealed by Regulations (EC) No. 715/2007 and 595/2009. UNECE Regulation 85 is used for EC type-approval. The regulation has been amended several times after the most recent amendment to the directive and now includes tests for electric vehicles.

3.4.3 Proposals for amendment

UNECE Regulation 85 includes tests for electric vehicles (including hybrids) and TRL is not aware of any need to make further amendments.

3.5 End-of-Life vehicles: Directive 2000/53/EC

3.5.1 Overview

Directive 2000/53/EC first entered into force in October 2000 and applies to all M_1 and N_1 vehicles (passenger cars and light goods vehicles) used in the EU. Its primary objective is *"to make vehicle dismantling and recycling more environmentally friendly"*. The directive's main provisions include:

- It prohibits the use of lead, mercury, cadmium or hexavalent chromium in materials and components of vehicles put on the market after 1 July 2003 (above defined threshold concentrations), with an evolving list of exemptions designed to keep pace with the development of appropriate alternatives.
    - Exemptions include lead in batteries (no viable mass market alternatives to lead-acid yet exist for conventional starter batteries in ICE vehicles and there is already a high level of recycling of lead-acid batteries), and, up until December 2008, cadmium in batteries for electric vehicles. As Ni-MH, NaNiCl and Li-ion batteries developed, though, the case for an exemption for Ni-Cd batteries became inappropriate, hence its recent removal from the list.
    - Spare parts for vehicles sold before 1 July 2003 are also exempted from the heavy metal restrictions. Ni-Cd batteries are also exempt if they are used as spare parts for vehicles put on the market before 31 December 2008.
- It requires Member States to ensure that suitable material coding systems, dismantling information, collection and treatment facilities are established and sets clear quantified targets for the reuse, recycling and recovery of vehicles and their components.
    - By 1 January 2006, a minimum of 85% by an average weight per vehicle and year shall be reused, recycled or recovered, and at least 80% shall be reused or recycled;
    - By 1 January 2015, a minimum of 95% by an average weight per vehicle and year shall be reused, recycled or recovered, and at least 85% shall be reused or recycled;
- It encourages manufacturers to produce reusable, recoverable and recyclable vehicles by publishing information for consumers on:
    - The design aspects of their vehicles and components relevant to recoverability and recyclability;
    - The environmentally sound treatment of end-of-life vehicles, especially removal of fluids and dismantling;
    - The development of new reuse, recycle and recover techniques;
    - Progress towards reducing waste sent to landfill and increasing recovery and recycling rates.

3.5.2 Compatibility with electric vehicles

The end-of-life vehicle treatment process is shown schematically in Figure 2. With the phasing out of nickel-cadmium batteries for electric vehicles and their substitution by alternatives that do not contain significant quantities of lead, mercury, cadmium or hexavalent chromium, the directive's prohibition of these heavy metals does not present any barrier to electric vehicle producers.

Li-ion and the other current battery types have quite short useful lives from the perspective of their use in electric vehicles, because they can only provide reasonable peak power currents for a limited number of charge and re-charge cycles. That said, they tend to retain quite good energy storage capabilities and hence are potentially highly re-usable in stationary applications where energy is more important than power. Used Li-ion batteries, for example, would be well suited to being connected to intermittent electricity generators (e.g. wind turbines or solar PV) to be able to deliver reliable energy at times when the main generators are not working (i.e. when the wind isn't blowing or it's dark), having been charged when the generators are producing energy. Large banks of such batteries could be a very cost-effective way of helping grid operators balance supply and demand, improve the overall efficiency of the generation mix and reduce its carbon impact. Electric vehicles would therefore be likely to have a large proportion of their weight (battery packs of 500 kg are envisaged) made up of components that can find ready markets for re-use, and would thus be well suited to meeting even the more onerous 2015 targets set by the directive. Ultra-capacitors would also be well suited to re-use, either in other vehicles or to provide supplementary peak power capabilities to the stationary battery banks used for electricity system balancing.

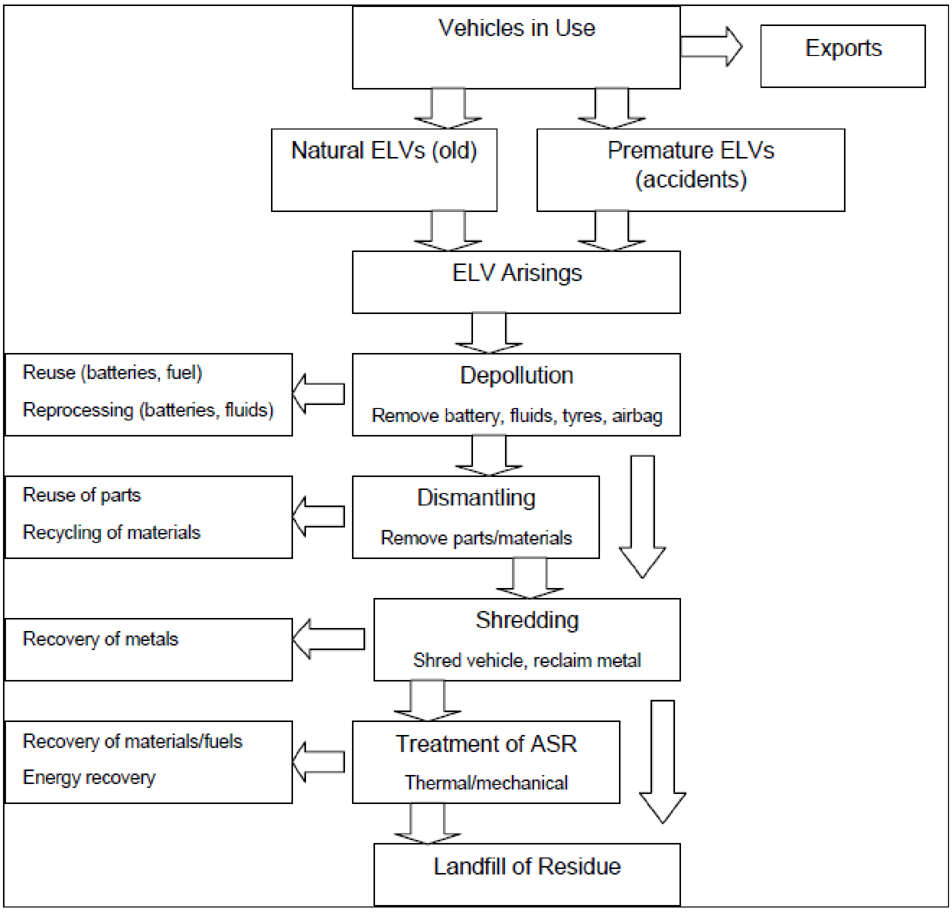

Figure 2: End-of-life treatment process (source: European Commission, 2006)

Note: ASR = Auto-Shredder Residue

These findings are supported by recent research by Matheys *et al.* (2008), which although not considering possible re-use options still concluded from a life-cycle analysis that Li-ion and (to a lesser extent) Ni-MH batteries for electric vehicles had a lower overall environmental impact than lead-acid or nickel-cadmium alternatives, assuming high end-of-life collection and recycling rates (which the directive ensures).

Other common electric vehicle components include chargers, inverters, electronic control units, relays, high voltage connectors, fuses and electric motors. Despite an extensive literature search, no evidence has been found suggesting that these components represent any special or unusual environmental hazard, nor that they would present any major difficulties at end-of-life for recycling or reuse over and above existing internal combustion engine vehicles.

3.5.3 Proposals for amendments

Directive 2000/53/EC defines "reuse" as "any operation by which components of end-of-life vehicles are used for the same purpose for which they were conceived". It is not absolutely clear from this definition that the re-use of Li-ion batteries, for example, in stationary (load balancing) applications would qualify as "re-use" under the directive. Ultra-capacitors reused in vehicles would qualify, but batteries and/or ultra-capacitors used in other applications may not. If the definition of "for the same purpose" is (or can be made) sufficiently flexible to define "electrical energy storage" as their purpose, then whether that storage is on a car or in some other application would be unimportant. For the vehicle manufacturer, the implications, though, are not serious because the directive targets do not distinguish between reusability and recyclability, and its definition of "recycling" covers any reprocessing for other purposes, so whether an electric vehicle component is reusable or recyclable will not actually matter from the perspective of meeting the requirements of the directive.

Member States, though, are required by Directive 2000/53/EC to quantify separately the tonnes per year of material reused, recycled and recovered. For this reason, it is suggested that some amendment or clarification of the reuse or recycled status of end-of-vehicle-life Li-ion and other vehicle batteries that can be "re-used" in other, stationary applications, is considered.

As the directive currently only applies to M_1 and N_1 vehicles, it does not apply to electric vehicles that are either smaller vehicles (e.g. the G-Wiz which is an L_6/L_7 class vehicle/quadricycle) or larger electric buses, coaches or goods vehicles (M_2, M_3, N_2 and N_3). To ensure high end-of-life collection and recycling rates for the batteries and other components of these vehicles, it is further suggested that consideration also be given to extending the scope of Directive 2000/53/EC to cover some or all of these other vehicle types.

3.6 Reusability, recyclability and recoverability: Directive 2005/64/EC

3.6.1 Overview

Directive 2005/64/EC first entered into force in November 2005 and applies to the type-approval of all M_1 and N_1 vehicles. Its primary objective is to support Directive 2000/53/EC (end-of-life vehicles) by ensuring that new vehicles only attain type-approval if they are reusable and/or recyclable to a minimum of 85% by mass and are reusable and/or recoverable to a minimum of 95% by mass: i.e. they can readily meet the directive 2000/53/EC targets for 2015. Its main provisions include:

- For category N_1 (light goods vehicles), only the base vehicle needs to comply in the case of multi-stage builds;

- Manufacturers must make available to the approval authorities the detailed technical information necessary for the purposes of the calculations to be made, in a standard format;
- Manufacturers must first obtain a "certificate of compliance" from a competent body appointed by Member States to confirm that they have put in place satisfactory arrangements and procedures to manage the reusability, recyclability and recoverability aspects of their vehicles;
    - These arrangements include ensuring that the materials used in vehicle construction comply with Directive 2000/53/EC, and that the manufacturer recommends a strategy to ensure dismantling, reuse, recycling and recovery that considers the proven technologies available or in development;
- It applies to all new types from 15 December 2008 and all new vehicles from 15 July 2010;
- It deems a defined list of component parts as non-reusable for the purposes of calculating the recyclability and recoverability rates and prohibits their re-use in vehicle construction. These components include:
    - All airbags, seat belt assemblies, steering lock assemblies, immobilisers, emission after-treatment systems (e.g. catalytic converters and particulate filters) and exhaust silencers.

3.6.2 Compatibility with electric vehicles

Directive 2005/64/EC is in most respects requiring the same of manufacturers as Directive 2000/53/EC (end-of-life vehicles), and thus is highly unlikely to pose any significant further difficulties for manufacturers of any vehicle type, including electric vehicles. The components it prohibits from re-use are also likely to be common to both internal combustion engine vehicles and electric vehicles (e.g. seat belts), or would not be applicable to electric vehicles (e.g. exhaust after-treatment systems). Whilst, therefore, it makes no specific mention of electric vehicles not already covered by Directive 2000/53/EC, there seems no reason to suppose it presents any additional barrier to electric vehicle manufacturers.

3.6.3 Proposals for amendments

Directive 2005/64/EC uses the same definition of "reuse" as Directive 2000/53/EC (end-of-life vehicles), so the same potential issue arises as discussed above, with regard to batteries and ultra-capacitors for electric vehicles and their subsequent use in non-vehicle applications qualifying as reuse or not. Like 2000/53/EC, though, the 2005/64/EC targets do not distinguish between reusability and recyclability, so which category components fall into does not ultimately matter for the manufacturer. They are, however, required by 2005/64/EC to define the weight of the vehicle being type-approved that is recyclable, so consideration should be given to clarifying the reusable or recyclable status of Li-ion and other vehicle batteries, that could be "re-used" in other, stationary applications.

If amendments to Directive 2000/53/EC are considered that would broaden the scope to include other L, M and N class vehicles, then supporting amendments to Directive 2005/64/EC should also be considered.

3.7 Batteries: Directive 2006/66/EC

Directive 2006/66/EC first entered into force in September 2006 and applies to all batteries sold in the EU, with the exception of those used in equipment connected with

Member States' essential security interests and batteries in equipment designed to be sent to space. Its primary objective is "to minimise the negative impact of batteries and accumulators and waste batteries and accumulators on the environment". The Directive's main provisions include:

- Three battery types are defined;
    - Automotive batteries, used for vehicle starting, lighting and ignition power;
    - Industrial batteries, designed for exclusively industrial or professional uses or used in any type of electric vehicle;
    - Portable batteries, sealed, can be hand-carried and are neither industrial nor automotive.
- It prohibits the sale of certain batteries containing mercury or cadmium, specifically all batteries containing more than 0.0005% of mercury by weight (except button cells which must be no more than 2% by weight) and portable batteries containing more than 0.002% of cadmium by weight (except batteries used in emergency and alarm systems, medical equipment or cordless power tools).
    - It confirms that automotive and industrial batteries used in vehicles should meet the requirements of Directive 2000/53/EC (End-of-life vehicles) and that, therefore, the use of cadmium in industrial batteries for electric vehicles should be prohibited, unless exempted by that Directive.
- It promotes a high level of collection and recycling of waste batteries and improved environmental performance of all operators involved in the life cycle of batteries, e.g. producers, distributors and end-users;
    - End-users of portable batteries and automotive batteries from private, non commercial vehicles shall be able to return waste batteries to distributors or to designated collection points free of charge;
    - Producers of industrial batteries shall not refuse to take back waste industrial batteries from end-users;
    - Independent third parties may also collect industrial batteries;
    - Battery producers are required to provide sales data to enable collection rates to be calculated;
    - 25% of all batteries must be collected by September 2012, rising to 45% by September 2016;
    - Recycling processes shall achieve minimum recycling efficiencies – 65% by average weight for lead-acid batteries, 75% by average weight for nickel-cadmium batteries and 50% by weight of other waste batteries;
    - Detailed arrangements should be made for a labelling system to give end-users transparent, reliable and clear information on the batteries and any heavy metals they contain (mercury, cadmium or lead), above threshold levels.
- It prohibits the disposal of industrial and automotive batteries in landfill sites or by waste combustion.

3.7.1 Compatibility with electric vehicles

Conventional automotive batteries, used for starting, lighting and ignition power, usually lead-acid, would be classified as automotive batteries by Directive 2006/66/EC. Purely-electric vehicles would normally have one battery that provides all the motive power, as well as the lighting and other ancillary electrical services, which could be lead-acid, nickel-based, lithium-based or utilise some other chemistry. Such a battery would be classed as industrial by Directive 2006/66/EC. Hybrids tend to have two batteries, one conventional (usually lead-acid) used to start the internal combustion engine and the other used to provide motive power, as per purely-electric vehicles. The former would be classed as an automotive battery by 2006/66/EC, while the latter would be industrial. In any event, 2006/66/EC stipulates that batteries for electric vehicles need to conform to Directive 2000/53/EC (end-of-live vehicles), which prohibits cadmium use after December 2008.

Directive 2006/66/EC does not, therefore, impose any more onerous requirements on electric vehicle batteries than those already laid down by 2000/53/EC (end-of-life vehicles) and 2005/64/EC (Reusability), although it does specify a minimum recyclability efficiency of 50%, whereas 2000/53/EC and 2005/64/EC give targets by weight of the whole vehicle and do not set specific targets for individual components. Given the large weight of the batteries in electric vehicles, as a proportion of the overall vehicle weight, though, it is highly likely that recycling efficiencies for the batteries of over 50% would be needed for the overall 2000/53/EC and 2006/64/EC targets to be achievable.

3.7.2 Proposals for amendments

Directive 2006/64/EC prohibits the use of cadmium in all automotive and industrial batteries, unless exempted by 2000/53/EC (end-of-life vehicles). The 2003/53/EC exemption ceased in December 2008, but this directive only applies to M_1/N_1 vehicles. It is assumed that manufacturers with industrial batteries used in electric vehicles not in categories M_1/N_1 would not be able to claim exemption on the grounds that Directive 2000/53/EC does not apply, but clarification on this point of law may be needed.

Manufacturers of electric vehicles not in categories M_1/N_1 currently have a potential advantage over their M_1/N_1 manufacturer counterparts, because batteries falling outside the scope of 2000/53/EC are only required to be 50% recycled by weight. Directive 2000/53/EC batteries do not have a specific minimum recycling rate, but given the overall vehicle recycling rate requirement of 85%, it is likely that the battery recycling would need to be well over 50%. Consideration should be given to removing this potential market distortion.

Article 8 of Directive 2006/66/EC requires that schemes set up to collect and recycle automotive batteries from private, non-commercial vehicles shall not involve any charge to end-users, nor any obligation to buy a new battery. Consideration should be given to extending this protection to end-users of all private, non-commercial electric vehicles, either by including industrial batteries used in electric vehicles or be redefining all batteries used in vehicles to be “automotive”.

4 Potential risks of electric propulsion

This section discusses some hazards associated with electric vehicles and their technology. It was not the intention to imply that electric vehicles are inherently unsafe or would expose the public to greater risks than conventional vehicles. Instead, the focus was on specific hazards that might not be regulated under current EC or UNECE type-approval legislation. The hazards were identified from the literature and from discussions with stakeholders.

4.1 Rechargeable energy storage systems

A rechargeable energy storage system (RESS) is defined in the type-approval legislation as a system that provides electrical energy for electric propulsion. This could include batteries, capacitors and electromechanical flywheels. Any type of RESS has the potential to be hazardous if it is not designed carefully; but concerns have been raised about batteries in particular. Hazards can emerge during the normal operation of the battery or during conditions or events outside its normal operating range. These include electrolyte/material spillage if the cell casing is damaged, the battery's reaction to high external temperatures and fire, and its electrical properties, e.g. under short circuit, over voltage and voltage reversal conditions.

Some lithium-ion chemistries, such as those using nickel and cobalt-based oxide cathode materials have been known to catch fire when overcharging (BERR and DfT, 2008), albeit rarely. The exothermic reaction as metallic lithium is removed from the cathode and plated onto the anode can lead to 'thermal runaway', where heat continues to be produced even after the charging has stopped. Voltage control at cell, module and battery level, both by electronics and by physical separation of cells, and the elimination of manufacturing defects and impurities are the short-term solutions employed by some electric vehicle manufacturers, e.g Tesla (Berdichevsky *et al.*, 2007). Others are using developments in cathode materials technology that offer inherently safer battery chemistries, e.g. iron phosphate (Voelcker, 2007). Even with the nickel/cobalt designs, the chances of thermal runaway are slim (figures of one in 5 to 10 million are quoted by Voelcker for the most common existing cells).

UNECE Regulation 100 sets out provisions for the approval of the electrical power train in an electric vehicle (see Section 2.8). The regulation deals with the safety of electric vehicles 'in-use' and includes specifications that relate mainly to the protection of users against electric shock. The specifications for a RESS focus on protection against excessive current by preventing the RESS from overheating. In addition, UNECE Regulations 94 and 95 (front and side impact respectively) are being amended to include post-impact electrical safety requirements for electric vehicles that will cover several potential hazards, including RESS retention during the impact test and electrolyte spillage.

While these regulations tackle many of the hazards associated with a RESS, there may be hazards not covered by the legislation. For example, there are currently no requirements in the legislation relating to extreme heat or to fire. It seems likely that most battery and vehicle manufacturers will be aware of the hazards and will design in safety features. Minimising safety risks as far as possible will be vital for future sales growth. Despite the many hundreds of thousands of vehicle fires around the world which involve petrol or diesel, there is a risk that just a few lithium battery fires or other incidents could seriously undermine consumer confidence. There are a number of industry standards and test procedures that subject the battery to various abuse conditions and then monitor its response. These include:

- United States Advanced Battery Consortium (USABC) - Electrochemical storage system abuse test procedure manual;

- EUCAR (European Council for Automotive Research) - Specification of test procedures for safety testing of traction batteries;
- FreedomCAR - Electrical energy storage system abuse test manual for electric and hybrid vehicles;
- United Nations - Transportation of dangerous goods manual of tests and criteria;
- Society of Automotive Engineers (SAE) - Recommended Practice J2464: Electric and hybrid electric vehicle rechargeable energy storage system safety and abuse testing.

SAE J2464 is a comprehensive standard intended to determine the response of a rechargeable energy storage system to conditions and events beyond its normal operating range. Typical abusive conditions include operator negligence, vehicle accidents, device or system defects, poorly informed or trained users and mechanics, failure of the control and support hardware and transportation or handling incidents. The standard includes recommended and optional abuse tests in four key areas:

- Hazardous substance monitoring

This evaluates hazardous substances (airborne volatiles and particulates) released when the rechargeable energy storage system container vents or is compromised by an abusive event.

- Mechanical abuse tests

These comprise shock tests, drop tests, penetration tests, roll-over tests, immersion tests and crush tests.

- Thermal abuse tests

These comprise a high temperature hazard test, thermal stability test, cycling without thermal management, thermal shock cycling and passive propagation resistance test.

- Electrical abuse tests

These comprise short circuit tests, overcharge tests, over-discharge tests and separator shutdown integrity test.

In addition, ISO 12405 (Electrically-propelled road vehicles – test specification for lithium-ion battery packs and systems") is being developed by an ISO technical committee[16]. The standard will combine the test procedures developed by USABC, EUCAR and FreedomCAR and describe performance, reliability and abuse procedures for the battery system (Van den Bossche *et al.*, 2009). Battery standards at the cell-level remain the responsibility of the International Electrotechnical Commission (IEC). These standards include IEC 61982 (Secondary batteries for propulsion of electric road vehicles).

Many of the tests carried out for SAE J2464 (and USCAR, EUCAR and FreedomCAR) are similar in nature to the type of tests in the legislation for fuel tanks, or they tackle similar hazards (see Section 2.1). While there are well-developed standards in place for rechargeable energy storage systems (including batteries) there appears to be a gap in the legislation whereby fuel tanks are subjected to tests and requirements at a component-level but a rechargeable energy storage system is not. Consideration should be given, therefore to the development of a new directive or regulation to harmonise safety requirements for rechargeable energy storage systems.

[16] ISO/TC022/SC21 "Electrically-propelled road vehicles"

4.2 Regenerative braking systems

Regenerative braking systems operate in a different manner to 'conventional' friction braking systems. There is the potential, therefore, for vehicles equipped with regenerative braking to behave differently to conventional vehicles (when braking) and for new safety issues to emerge. For instance, it would be necessary to activate the brake lights and alert following vehicles if the regenerative braking system produces a retarding force on release of the throttle pedal. Although UNECE Regulation 13 prohibits the generation of a braking signal in these circumstances, a proposal that was discussed and agreed at the UNECE Working Party on Brake and Running Gear (GRRF) amends the regulation and sets activation and de-activation thresholds for the generation of a braking signal (see Section 2.2).

Other potential safety issues have been presented in the literature. For example, Viladot *et al.*, (1999) highlighted the potential for battery overcharge if regenerative braking is used at 100 percent state-of-charge. This might occur if a vehicle faces a long coast-down road immediately after being fully charged. However, it seems likely that this would be dealt with through the braking control system, which could prevent the regenerative brakes from functioning above a certain state-of-charge.

Viladot *et al.* (1999) also highlighted the potential for wheel lock-up and cited the findings of a study involving brake tests on wet roads. The study showed that regenerative braking affected the vehicle's handling and caused the rear wheel to lock up (especially on a low friction surface if the vehicle was not fitted with ABS). Once again, however, it seems likely that the braking control system could prevent this problem. Furthermore, UNECE Regulation 13 defines how the braking effort must be distributed between the wheels and 'performance corridors' are provided which define the level of deceleration required for a given brake pressure. Electrical regenerative braking systems are included in these requirements and for cases where the braking capacity is influenced by the state of charge, separate plots of the performance corridors are required to take account of the component under the minimum and maximum conditions of delivered braking force.

Similarly to conventional brake systems, these requirements are not applicable if the vehicle is equipped with an anti-lock device, and instead the vehicle must meet the minimum requirements for the utilisation of adhesion. UNECE Regulation 13 contains a footnote which explains that until a uniform test procedure is established utilisation of adhesion tests may have to be repeated for vehicles equipped with electrical regenerative braking systems in order to determine the effect of different braking distribution values provided by automatic functions on the vehicle.

Recent reports on the autoblog web site have suggested that some drivers of a specific vehicle in the United States have experienced a loss of deceleration during the transition from regenerative braking to friction braking (www.autoblog.com). NHTSA (The National Highway Traffic Safety Administration) opened an investigation and there have been widespread reports in the media. It would appear that the issue relates to a problem with the braking control algorithms in the specific vehicle involved, rather than a wider issue with regenerative braking systems and the existing requirements, within UNECE Regulation 13 for the design of complex control systems, should have dealt with this problem.

4.3 Electromagnetic fields

Considerable concerns have been expressed by the media and the public about possible health effects from exposure to electromagnetic fields (EMF). While the main concerns relate to EMF emissions from mobile phones and power lines, concerns have also been expressed about exposure of electric and hybrid vehicle occupants to EMF (Motavalli, 2008; Peterson, 2009). Research studies that have given some cause for concern include Wertheimer and Leeper (1979) (an apparent association between power frequency magnetic fields and leukaemia in children) and Nordensen *et al*. (2001) (chromosomal aberrations among train engine drivers).

Electric and hybrid vehicles give rise to particular concerns about health effects because they use currents and voltages that are much higher than those used in conventional vehicles, and which can therefore potentially generate much higher intensity EMF. This EMF could be produced in the electric motor(s) and generator, in the motor controller and in the cables connecting them and the batteries. The rest of the vehicle would be unlikely to produce EMF that was qualitatively or quantitatively different to that produced by conventional internal combustion engine vehicles, and which would therefore be outside the scope of the current report. It should not be assumed, however, that conventional vehicles are *necessarily* completely safe.

There are no existing type-approval requirements for vehicles to address the potential health effects of EMF. The requirements for radio interference (see Section 0) are intended to prevent problems with radio reception and with the functioning of safety equipment on the vehicle. Vehicle emissions are measured outside the vehicle. The lowest frequency measured is 30 MHz, well in excess of the frequencies expected from electric vehicle propulsion components.

Muc (2001), in a report for Health Canada, provides a useful account of the health implications of EMF generated by electric vehicles ranging from trains and Maglev to electric cars. He reports that the magnetic fields associated with transportation systems are of greater concern and have been investigated more than the electric fields. He reproduces some results of Dietrich and Jacobs (1999), who measured magnetic fields (or magnetic induction) at frequencies up to 3 kHz in a range of transport modes, including both a 'conventional cars and light trucks' category and an 'electric cars and light trucks' category. Hybrid vehicles were not tested. Over the 5 to 3000 Hz range the average magnetic fields were comparable for both categories (0.57 μT for both). Average fields were also given for narrower frequency ranges within this band. Higher average magnetic field readings were obtained for electric cars and light trucks in the 65 to 300 Hz and 305 to 3000 Hz ranges. Readings for static (<5 Hz) magnetic fields were also given; readings were higher for electric (40 μT) than conventional (32 μT) cars and light trucks. However, for comparison, the earth's magnetic field is 50 to 80 μT.

Muc (2001) points out that for transportation EMFs, variability is an important issue. Measured fields vary spatially within the passenger compartment, and over time. In relation to the above mentioned measurements by Dietrich and Jacobs (1999), Muc reports that the highest levels were obtained near the occupants' feet, and that levels tended to be progressively lower at the waist, chest and head. Variations in frequency also occur; most electric cars use AC motors, where the supply frequency varies with vehicle speed. Muc states that "Any comparison of measured fields to existing standards and guidelines is problematic because they specify limits in terms of temporal and spatial averages assuming exposure is at a fixed frequency."

In his summary, Muc (2001) states "the possibility of significant detrimental effects from the low frequency EMFs associated with transportation systems can only be considered to be rather speculative and remote at the present time", and that "the overall results of research related to concerns about possible detrimental effects of EMFs, particularly in the context of present knowledge about transportation system EMFs, is reassuring rather than alarming".

Viladot *et al*. (1999) also reviewed EMF health effects of electric vehicles, in this case as part of a wide-ranging study of the risks of electric vehicles. Again, in relation to EMF they refer extensively to the Dietrich and Jacobs (1999) study. EMF exposure during charging is also mentioned. They also refer to a National Institute of Environmental Health Sciences (NIEHS) report (NIEHS EMF-RAPID Program Staff, 1999) on health effects from exposure to power-line frequency EMF. They also include extracts from an online document by Moulder, which appears to be no longer available. These extracts include an application of the 'Hill criteria' to the available scientific evidence for a connection between power line frequency EMF and cancer risk. The extracts also include the statement that "Overall, most scientists consider the evidence that power line fields cause or contribute to cancer to be weak or unconvincing."

The magnetic fields produced by electric vehicles are in the extremely low frequency (ELF) range, as are power line frequencies, though the frequencies in electric vehicles are more variable. Nevertheless, if evidence for health effects from power lines is found to be weak, it can be concluded that health effects from electric vehicles are also unlikely. This is useful, as there has been much more research into potential health effects from power lines than from electric vehicles.

The NIEHS report (NIEHS EMF-RAPID Program Staff, 1999) was produced as part of the Electric and Magnetic Fields Research and Public Information Dissemination Program (EMF-RAPID), which was intended to clarify potential health risks from ELF EMF. They concluded that "The scientific evidence suggesting that ELF-EMF exposures pose any health risk is weak." However, they also say that "The NIEHS concludes that ELF-EMF exposure cannot be recognized as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard. In our opinion, this finding is insufficient to warrant aggressive regulatory concern." They also recommend that research should continue in some areas.

Other organisations that are active in conducting and/or evaluating research and setting guideline limits include the World Health Organization (WHO) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). WHO is a part of the United Nations system. ICNIRP is a body of independent scientific experts (without industry representatives). WHO has an EMF Project (website: http://www.who.int/peh-emf/en/) to assess the scientific evidence of possible health effects of EMF. This website includes the statement "The main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health" (World Health Organization, 2010a). The WHO EMF Project has produced a number of online fact sheets and other documents. World Health Organization (2010b) has useful information on the topic. World Health Organization (2000) discusses different cautionary policies including 'As low as is reasonably achievable' (ALARA) and the 'Precautionary Principle'. World Health Organization (2005) discusses (reputed) electromagnetic hypersensitivity (EHS). World Health Organization (2007) is a fact sheet based on the findings of a WHO Task Group that recently concluded a review of the health implications of ELF fields. It includes some recommendations. See also a relevant chapter from the World Cancer Report 2008 (Boyle and Levin, 2008).

4.4 Crash safety

Electric vehicles (especially purely-electric models) are usually fitted with large, heavy battery packs to achieve a reasonable driving range. This can add substantial mass to a vehicle and hence efforts are sometimes made to reduce the mass elsewhere, through the use of lighter components and materials. In fact, many of the first generation of purely-electric vehicles are small, light vehicles designed to maximise range and battery performance. While these vehicles will need to meet basic crashworthiness legislation to gain EC (whole vehicle) type-approval (see Section 2.6), it is unclear whether they will demonstrate the higher levels of safety that many conventional vehicles achieve (indicated by a high EuroNCAP score). Furthermore, these "light" electric vehicles, are likely to perform poorly in a frontal collision with a heavier vehicle. Hence in the absence of compatibility legislation, there could be implications for the collision injury statistics, if in the future there is a greater proportion of lighter vehicles on the road.

The retention of the heavy battery (or any type of rechargeable energy storage system) in a collision is also very important. Amendments are being developed for the type-approval legislation to include post-impact limits on the movement of the rechargeable energy storage system (along with electrolyte spillage and electrical safety requirements). However, the legislative tests include (perpendicular) 56 km/h frontal and 30 km/h side impacts only. It is possible that the battery retention system might perform differently in other impact angles or severities. Clearly, this is the approach with any system of type-approval and similar points could be made about the fuel system in conventional vehicles; however, a great deal is known about the performance of conventional vehicles in a wide range of scenarios. Much less is known about electric vehicles.

Rear impact, in particular, might prove challenging for some electric vehicles if the rechargeable energy storage system (RESS) is located towards the rear of the vehicle. In a rear-end collision there is a risk that the RESS could be crushed, penetrated or intrude into the passenger compartment. However, rear impact tests are not required for type-approval, although there is a test procedure in UNECE Regulation 32 (rear impact) and in UNECE Regulation 34 (fuel tanks/fire risks). In the United States, FMVSS 305 tests for battery movement, electrolyte leakage and electrical isolation in frontal, side and rear impact tests. In the case of the rear-end test, the vehicle is struck from the rear by a barrier moving at 48 km/h and also optionally at 80 ± 1 km/h.

Lim *et al.* (2008) performed rear impact tests on a petrol vehicle with a 150 V lithium-ion battery installed in the luggage compartment (but not connected to the power train). Tests were performed at 48 km/h and at 80 km/h. In each case, the luggage compartment deformed considerably. The batteries were displaced and contacted the bulkhead, but they did not enter the passenger compartment or spill electrolyte. The battery cover remained intact in both tests. The interior of the batteries was not inspected due to "proprietary issues", but the authors assumed that liquid interaction within the batteries did not occur because there were no fires or explosions. However, in the 80 km/h test, the peak acceleration of the battery pack reached 128g. Sahraei *et al.* (2010) suggested that such levels of acceleration could dislodge individual cells from their resting points and further damage the internal contacts and electrical connections.

Vehicles sometimes leave the road and enter water, either in a ditch, canal or river. The problem is rare in most European countries, but more common in the Netherlands where there is more open water (SWOV, 2009). Water exposure and submersion might present a hazard for an electric vehicle. UNECE Regulation 100 includes specifications for the protection of users against electric shock. Although water is not considered explicitly in the regulation, electrical safety features intended to protect users from electric shock should allow the vehicle to operate safely in snow, heavy rain and floods. For example, if water gets into the electrical system, or if a car is submerged, it is likely that a protective device, such as a circuit breaker, would activate. Nevertheless, submersion is a unique situation and very little information was found in the literature. Viladot *et al.* (1999) offered the following observations:

- The current flow would more than likely continue to follow its normal path (if the battery did not disconnect);
- If the circuit came into contact with water, there is a slight chance that the current may flow through it, but the batteries would energise only a small portion of the surrounding water;
- Anyone coming into contact with the water would be safe as long as they were not close to the electric source;
- The batteries could be experiencing over-discharge or a short-circuit and hence the possibility of hydrogen release;
- Hydrogen gas could be generated due to water electrolysis.

GM-Volt.com (an unofficial web-site not affiliated to General Motors) featured an interview with an engineer at the General Motors battery lab who also worked on the GM EV1 program. He described a salt water submersion test on the EV1 with an extensive system of monitors including current detectors placed over test dummies. He stated "When the water reached the battery it shut down. There were some crackles and pops sounds, but in the end no significant current flowed into the dummies". A published account of this testing was not found. Further research is needed to understand fully the effects of submersion on electric vehicles; however, it would appear that the electrical safety features present in electric vehicles should reduce the risk to occupants and those outside the vehicle.

4.5 Acoustic perception

At low-speeds, the contribution of tyre/road noise to the overall vehicle noise is relatively low and powertrain noise becomes the dominant factor. As such, one of the main concerns associated with the operation of low-noise vehicles, such as those powered solely by electric motors or hybrid vehicles operating in electric mode is that the low noise levels from these vehicles may increase the potential for pedestrians (especially visually impaired people) and cyclists to be involved in accidents with these vehicles. Such instances might occur not only during normal urban driving but also during low-speed manoeuvring operations such as parking, pulling away from rest, etc.

Concern has been expressed by organisations such as the Guide Dogs for the Blind Association in the UK. The UNECE Working Group WP.29 has undertaken discussions regarding the potential fitment of audible warning devices to improve the audibility of low-noise vehicles for the visually impaired. The following presents a short overview of work associated with low-noise vehicles and pedestrian safety that has been identified.

4.5.1 Detection of quiet vehicles and accident statistics

A report by NHTSA in the United States has reported on incidences involving collisions between hybrid passenger cars and pedestrians or cyclists (NHTSA, 2009a). This drew on data from 12 states over the period 2000-2007, although the availability of data in certain years varied across the different states. Comparisons were drawn with corresponding statistics for internal combustion engine vehicles. In scenarios where vehicles were slowing or stopping, backing up or entering/leaving a parking space, hybrid vehicles were found to be twice as likely to be involved in pedestrian crashes as their conventional equivalents; in these cases, the differences in noise levels between conventional and hybrid vehicles is the greatest. However, it should be noted that there is no data in the statistics indicating whether the cause of the accident was the driver not being aware of the presence of the pedestrian, or the pedestrian being unaware of the presence of the vehicle. There was no statistically significant difference in the rate of incidence when both types of vehicle were travelling in a straight line. It is noted that none of the crash data used in the study provided any information on the vision status of the pedestrians involved. In terms of accidents involving cyclists, the incident rate was higher for hybrid vehicles than for conventional vehicles. There was no statistically significant difference between vehicle types for collisions on the roadway (the most common), but incidences involving hybrid vehicles at intersections and interchanges were significantly higher.

A presentation by the NHTSA at GRB has highlighted the need to address the issue of visually impaired pedestrians and quieter cars. The presentation was primarily a research plan summarising of the work needing to be addressed, namely an identification of the risks including the critical safety scenarios, identification of the information required by visually impaired pedestrians to ensure safe mobility and an assessment of the potential effectiveness and acceptability of solutions (NHTSA, 2009b).

Rosenblum (2008) reports on subjective assessments of the audibility of hybrid vehicles operating in full electric mode. Blindfolded subjects listened to recordings of cars approaching at 5 mph taken on a test track. They were able to locate the sound of a

2004 Honda Accord from 36 feet (4.9 seconds) away, but were only able to identify a Toyota Prius in electric mode from 11 feet (1.4 seconds) away. When background noise sources were introduced, they were unable to identify the Prius until 0.2 seconds after the vehicle had passed by (1.6 feet), i.e. effectively after the vehicle would have impacted with them. Rosenblum also indicated that at speeds above 15-20 mph, there is sufficient tyre/road noise and aerodynamic noise for vehicles running in full electric mode to be detected.

4.5.2 Audibility warning devices

As discussed in Section 3.1.3, the UNECE Working Party on Noise (GRB) endorsed a proposal to establish an informal group on minimum sound levels for silent vehicles. In the meantime, Japanese research into approach audible systems for hybrid and electric vehicles has been reported at GRB meetings. Key issues being addressed in the study include the type of sound to be used, the need to make the link between the sound and the approaching vehicle, and the potential need for the sound to be permanently operational. A workshop was held where visually impaired peopled were given the opportunity to experience the noise generated by hybrid and electric vehicles and potential sounds for an audible warning system, including chimes, melodies and simulated engine sounds. Feedback from this workshop highlighted that the behaviour of the vehicle was not easily recognised based on the sounds and that simulated combustion engine sounds are preferred because they are recognisable in daily life. It was also acknowledged that pedestrians should be aware that the noise is coming from an approaching vehicle without any prior knowledge from the government's PR activities (JASIC, 2009).

Nyeste and Wogalter (2008) reported on a subjective assessment study of sounds that could be used for audible warning signals on low-noise vehicles. Twenty four subjects were exposed to six categories of sound (engine, horn, hum, siren, whistle and white noise) with three variations in each category. Each sound was displayed in conjunction with a video of a moving hybrid vehicle. The sounds of an engine, white noise and hum sound in that order were the sounds most favoured as an added sound. An earlier study by Wogalter *et al.* (2001) which did not include any auditory trials but was solely based upon responding to a questionnaire arrived at similar conclusions.

Lotus Engineering has developed a system for improving the audibility of electric and hybrid vehicles for pedestrians and cyclists. A loudspeaker mounted in the nose of the car would play an artificial engine sound with the pitch and frequency helping to identify its distance and speed. Since there loudspeakers are front-facing there would be no sound heard once the vehicle has passed. It is proposed that the system would be constantly active on electric-only vehicles, whilst only operating in electric mode on hybrid vehicles (Group Lotus, 2008).

General Motors (GM) has created a special pedestrian alert signal for the forthcoming Chevy Volt electric car. This is an active system, i.e. one activated by the driver, rather than a passive system which would be operational all of the time, and is in the form of a light volume horn-like sound similar to the chirp of some cars keyless entry indicators (General Motors, 2009). GM has formed a partnership with the National Federation for the Blind to identify a "safe level of sound" for such alert systems. Nissan is also reported to be working on similar alert systems.

Owen (2008) presented work investigating both the emission of simulated combustion engine vehicle sounds by quiet vehicles and using Bluetooth technology in combination with mobile phones for alerting visually impaired pedestrians of approaching vehicles. The principle behind the latter approach was to alert the pedestrian via voice prompts or vibratory feedback and alert the driver through a tone or dashboard light. This included the ability to take account of the speed and directionality of the vehicle. Only a very limited trial involving two subjects was undertaken. In the sound emission trial, the subjects found it difficult to differentiate between simulated and real cars sounds. In the vibration pilot study, the users were able to identify the number of cars but not their speed (fast vs. medium and medium vs. slow).

5 Conclusions

5.1 General conclusions

- The review of type-approval legislation found that the main regulatory acts for EC type-approval (i.e. the EC directives) tended to lag behind the corresponding UNECE regulations (which are sometimes recognised as alternatives). The "lag" was most noticeable when it came to provisions for electric vehicles in the safety legislation.
- The current approach in the framework directive is to permit either the EC directive or the UNECE regulation to be used. In the future, Regulation (EC) No. 661/2009 (the general safety regulation) will repeal certain safety directives and will include references to the appropriate UNECE regulation. However, the general safety regulation will not come into force until 2014. In the meantime, an electric vehicle could potentially gain type-approval using EC directives that have no specific safety provisions for electric vehicles. The mandatory application of certain UNECE regulations for electric vehicles would avoid this potential safety problem until the general safety regulation comes into force.
- It was not the intention in conducting this study to imply that electric vehicles are inherently unsafe or would expose the public to greater risks than conventional vehicles. Instead, the focus was on specific hazards that might to be regulated under current EC or UNECE type-approval legislation.

5.2 Review of type-approval directives and regulations on vehicle safety

5.2.1 Fuel tanks and rear under-run protection: Directive 70/221/EEC and UNECE Regulation 34

- Purely-electric vehicles do not have fuel tanks. Exempting them from fuel tanks requirements would prevent unnecessary approvals without resulting in new safety risks.
- Hybrid vehicles are equipped with conventional fuel tanks. The fuel tanks legislation is compatible with hybrid vehicles because it relates only to the fuel tank and its accessories.
- Hybrid vehicles might present a new hazard due to the presence of high voltage components. Adopting more stringent requirements during the overturning test for fuel tanks might reduce the risk of fuel leaking from an overturned hybrid vehicle; and hence also reduce the risk of a fire resulting from a spark from a high voltage component. However, there is no evidence of a particular risk from current hybrid vehicles.
- There are no post-collision requirements for a rechargeable energy storage system in the second part of UNECE Regulation 34 (on fire risks). Amendments currently being discussed for UNECE Regulations 94 and 95 could form the basis for changes to UNECE Regulation 34. However, part 2 of UNECE Regulation 34 is performed at the manufacturer's request and is not required for European type-approval. Its amendment may not, therefore, be a priority.
- There are no overarching technical requirements in EC (or UNECE) type-approval for a rechargeable energy storage system. Developing new requirements would remove this potential loop-hole and would improve the harmonisation of rechargeable energy storage system safety legislation.

5.2.2 Braking: Directive 71/320/EEC and UNECE Regulations 13 and 13-H

- Electric vehicles are fitted with regenerative braking systems. Directive 71/320/EEC does not contain any provisions for vehicles with regenerative braking, but UNECE Regulations 13 and 13-H include definitions and technical requirements for fitment, performance and fail safe modes of regenerative braking systems.
- Some regenerative braking systems produce a retarding force on release of the accelerator pedal that might be greater than conventional engine braking. However, the regulations do not allow the stop lamps to be illuminated. This could lead to potential safety problems in the real world if a driver is unaware that the vehicle in front is subject to a retarding force. Adopting the UNECE Working Party on Brake and Running Gear (GRRF) proposals to allow the illumination of stop lamps when the regenerative braking system produces certain decelerations would help to avoid this potential safety problem.

5.2.3 Radio interference (electromagnetic compatibility): Directive 72/245/EEC and UNECE Regulation 10

- Directive 72/245/EEC and UNECE Regulation 10 each specify performance requirements and tests for radio interference (electromagnetic compatibility), but refer to various international standards for detailed test methods. No specific provisions are made for electric vehicles in the legislation; however, some of the standards have procedures to deal with electric vehicles. In some cases, the legislation does not refer to the latest version of the standard. Amending the legislation to refer to the latest version would ensure that it is up-to-date with the industry standards.
- The broadband emissions test (with an electric vehicle) is performed at a constant speed of 40 km/h, without load. This avoids potential conflicts for vehicles without a clutch or gearbox capable of disconnecting the drive. However, the drive power used is unrealistically low for the speed and hence the electromagnetic emissions may also be unrealistically low. Placing a realistic load on an electric vehicle during this test would potentially lead to more realistic test conditions. Amendments to the standard (CISPP12), rather than the legislation, might be needed because the standard is referenced by the legislation for detailed instructions about the test method. Further research is needed to understand fully the effects on the broadband emissions of an electric vehicle by placing a realistic load the vehicle during the emissions test.
- Electric vehicles might generate broadband emissions that exceed the legislative performance limits during acceleration and deceleration. This would not be assessed by the steady-state tests that are currently required. Testing in conditions of acceleration and deceleration would allow the emissions from the vehicle to be controlled in a broader set of circumstances. Once again, amendments to the standard (CISPR12), rather than the legislation, might be necessary. Further research is needed if the effects of vehicle acceleration and deceleration on the electromagnetic compatibility of electric vehicles are to be fully understood.
- The antenna in the emissions test is currently aligned with the centre of the engine. An electric vehicle may be fitted with more than one electric motor, and in fact, the motor may not be the principal source of emissions. If tests of electric vehicles are to provide a measure of emissions in conditions equivalent to tests of internal combustion engines, the antenna should be aligned with the principal source (or sources) of emissions. Further research is needed if the optimum antenna position for electric vehicles is to be identified.
- The type-approval legislation does not deal with emissions and immunity during charging for electric vehicles. This may be covered (for externally charged vehicles) by Directive 2006/95/EC (the low voltage directive). Amending the EMC legislation to

include charging would help to ensure that a potential vehicle-related problem is dealt with by EC type-approval. However, a corresponding exemption of electric vehicles from the low voltage directive would be necessary.

- Some manufacturers are exploring the use of different engine types for use in hybrid vehicles such as rotary engines and gas turbines. Further research is needed to understand whether the test procedures are appropriate for these technologies.

5.2.4 Protective steering: Directive 74/297/EEC and UNECE Regulation 12

- There are no specific provisions for electric vehicles in Directive 74/297/EEC, but UNECE Regulation 12 was amended some time ago and specifies the state of the power train (for the frontal impact test) and post-impact battery retention and electrolyte leakage requirements. However, Regulation 12 does not deal with electrical safety in a comprehensive way or reflect the electrical safety approach in UNECE Regulation 100.
- Further amendments of UNECE Regulation 12 were prepared by a group of interested experts on electric vehicles post-crash provisions for discussion at the 47th session of the Working Party on Passive Safety (GRSP). The purpose of the amendments was to extend the scope of the regulation to include all power train systems above a certain working voltage level and to bring the regulation into line with UNECE Regulation 100. The proposal complimented similar proposals for UNECE Regulations 94 and 95. See 5.2.6 for conclusions regarding the post-impact safety requirements for electric vehicles.

5.2.5 Identification of controls, tell-tales and indicators: Directive 78/316/EEC and UNECE Regulation 121

- Directive 78/316/EEC and UNECE Regulation 121 do not include any symbols to identify the controls, tell-tales and indicators that are particular to an electric vehicle. Symbols are available in ISO 2578:2004 and amendments 1:2005, 2:2006, 3:2008 and 4:2009. Amending the legislation to include new symbols for electric vehicles might reduce the risk of different symbols emerging in the market, but care is needed to avoid confusing drivers.

5.2.6 Frontal impact: Directive 96/79/EC and UNECE Regulation 94 / Side impact: Directive 96/27/EC and UNECE Regulation 95

- Amendments to the frontal and side impact legislation are needed to accommodate electric vehicles. Proposals to amend UNECE Regulations 94 and 95 were prepared by a group of interested experts (the EVPC group) and submitted for discussion at the 47th session of the Working Party on Passive Safety (GRSP). Adopting the EVPC proposals would require electric vehicles to meet specific provisions for electrical safety following an impact test.
- The EVPC proposals were developed by deriving key provisions from other standards, and by discussions amongst the expert group. The proposals were not validated experimentally. Performing a series of crash tests (or at least obtaining data from manufacturers) would help to confirm that the EVPC proposals are appropriate and consider all the hazards associated with electric vehicle crash safety.
- The side impact legislation (Directive 96/27/EC or UNECE Regulation 95) does not apply to a vehicle if the reference point of the lowest seat is over 700 mm from the ground. This recognises that taller vehicles tend to perform very well in side impact tests. While this could apply to an electric vehicle too, the electrical components might be damaged resulting in an electrical safety hazard even when there is a low risk of physical injury. Amending the legislation to require taller electric vehicles to

undergo a side impact test (i.e. to assess only the post-impact electrical safety) could potentially avoid this hazard.

- The frontal and side impact legislation permits fuel (or a substitute) to leak from the fuel system following the impact test, but limits the leakage rate to $5x10^{-4}$ kg/s (i.e. 30 grams/min). However, hybrid electric vehicles could present a new hazard due to their high voltage components, which can generate enough energy to create a spark. Adopting more stringent requirements for fuel leakage with hybrid vehicles might reduce the risk of fuel leaking from a hybrid vehicle following a collision and coming into contact with high voltage components.
- The EVPC proposals specify performance requirements to assess the post-impact protection from electric shock. An automatic disconnection device can be used to provide protection, but it is not mandatory, and other means of protection can be provided that do not require an automatic disconnection device to be fitted. A mandatory requirement to fit an automatic disconnection device could allow the protection against electric shock to be controlled in a broader set of circumstances.
- The EVPC proposals specify requirements to control the movement of a rechargeable energy storage system (RESS) during the frontal and side impact tests, but there are no requirements for its structural integrity. Mechanical loading of a RESS can lead to shorting and possibly rupture, with the risk of sparks, fire and explosion. Amending the frontal and side impact legislation to include post-impact structural integrity requirements for a RESS would reduce the risk of this potential safety problem.
- The limit of 7% specified in the EVPC proposals for electrolyte spillage outside the passenger compartment was derived from UNECE Regulation 12. However, it is unclear how much electrolyte would be dangerous and whether the risk depends on the type of battery chemistry and electrolyte used. Prohibiting electrolyte spillage outside the passenger compartment (as well as inside) would avoid this potential safety problem.
- The amount of electrolyte that leaks might increase if an electric vehicle rolls over following a collision. Performing a static roll test following the impact test would assess the potential for electrolyte spillage in a broader set of circumstances.

5.2.7 Buses and coaches: Directive 2001/85/EC and UNECE Regulations 66 and 107

- There are no specific provisions for electric buses and coaches in Directive 2001/85/EC and UNECE Regulations 66 and 107. However, the main requirements and performance tests are generally unrelated to the power train. Approving an electric vehicle using the current legislative requirements should not present any additional safety risks, provided that the vehicle is approved to UNECE Regulation 100, and particularly if the Working Party on General Safety (GRSG) proposals to amend the requirements for safety hatches are adopted.

5.2.8 Electrical power train: UNECE Regulation 100

- UNECE Regulation 100 is not mandatory for EC type-approval. However, an EC proposal for a Council decision to apply Regulation 100 on a compulsory basis was adopted on 15 June 2010. Mandating the application of Regulation 100 will ensure that all electric vehicles provide for the same minimum level of electrical safety.
- Electric vehicles fall within the scope of Directive 2006/95/EC (the low voltage directive). Vehicles with EC type-approval according to Directive 2007/46/EC (the framework directive), and including UNECE Regulation 100, would still be required to obtain a CE mark according to the low voltage directive. Excluding electric vehicles (that are within the scope of the framework directive) from the low voltage directive

would avoid potentially unnecessary testing and assessment. Excluding on-board charges within electric vehicles from the low voltage directive might also be appropriate, but only if amendments were made to UNECE Regulation 100 to cover the possible effects of the on-board charger on the safety of the electric grid and to UNECE Regulation 10 to cover the electromagnetic compatibility of the charger (whilst the vehicle is charging).

5.3 Review of type-approval directives and regulations on environmental performance

5.3.1 Permissible sound level: Directive 70/157/EEC and UNECE Regulation 51

- Both the directive and the regulation include provisions for electric vehicles. In some cases, the directive refers to the regulation for detailed instructions about the test procedures. Proposals to amend Regulation 51 have been prepared by the UNECE Working Party on Noise (GRB). These specify tests that are potentially more representative of current urban driving behaviour, but new provisions for electric vehicles (specifically hybrid vehicles) have also been made. Adopting the GRB proposals would update the legislative tests for noise. No further amendments are necessary at the present time for electric vehicles.

5.3.2 Emissions from light-duty vehicles: Regulations (EC) No. 715/2007 and 692/2008 and UNECE Regulations 83 and 101

- The legislation on light-duty vehicle emissions already sets out specific provisions for electric vehicles. This includes hybrid vehicles and also purely-electric vehicles (i.e. for energy consumption and range measurement). No further amendments are needed to accommodate electric vehicles in the short term. However, the legislation does not provide any alternative measurement to tail-pipe CO_2 emissions for electric vehicles that takes into account the generation of the electricity. Further research is needed if the optimum alternative to tail-pipe CO_2 emissions is to be identified for electric vehicles.

5.3.3 Emissions from heavy-duty vehicles: Regulation (EC) No. 595/2009 and UNECE Regulation 49

- Regulation (EC) No. 595/2009 repealed and replaced EC Directives 2005/55/EC and 2005/78/EC and introduced the Euro VI heavy-duty emissions requirements. In addition, it specified a number of other changes to the heavy-duty emissions requirements. These covered CO_2 emissions, particulate emissions, drive cycles, durability, access to vehicle repair and maintenance information and engine power. A new regulation will be published in the near future to implement Regulation 595/2009 and to specify more detailed technical provisions.
- The heavy-duty vehicle emissions test is performed on the engine rather than the whole vehicle. The test procedure cannot be applied meaningfully to hybrid vehicles. Further research is needed to develop vehicle-based test procedures (or engine-based procedures that take the end use of the engine into account) before any amendments can be made to accommodate hybrid vehicles. An informal group on heavy-duty hybrids has been set up under the UNECE Working Party on Energy and Pollution (GRPE) to investigate this issue. The work will be completed in 2014.

5.3.4 Engine power: Directive 80/1269/EC and UNECE Regulation 85

- Directive 80/1269/EC does not include any provisions for electric vehicles, but it has been repealed by Regulations 715/2007 and 595/2009. UNECE Regulation 85 is the main type-approval act on engine power and has been amended already for electrical power trains. No further amendments are necessary at the present time.

5.3.5 End-of-life vehicles: Directive 2000/53/EC

- Directive 2000/53/EC is not part of the type-approval framework, but it prohibits the use of certain materials (with an evolving list of exemptions). It requires Member States to establish systems to deal with end-of-life vehicles and sets targets for reuse, recycling and recovery. The directive does not present any particular problems for electric vehicles; however, consideration could be given to the definition of "reuse" and the possibility of reusing automotive lithium batteries in stationary applications.

5.3.6 Reusability, recyclability and recoverability: Directive 2005/64/EC

- Directive 2005/64/EC supports and compliments Directive 2000/53/EC (end-of-life vehicles) by ensuring that new vehicles only attain type-approval if they are reusable and/or recyclable to certain minimum levels. There do not appear to be any particular challenges for electric vehicles.

5.3.7 Batteries: Directive 2006/66/EC

- Directive 2006/66/EC applies to all batteries sold in the EU (with certain exceptions). It aims to minimise the potential negative impact of batteries on the environment. It is not part of the type-approval framework for vehicles, but automotive traction batteries would be covered by the directive and classified as industrial batteries. The requirements do not present any particular problems for electric vehicles.

5.4 Potential risks of electric propulsion

5.4.1 Rechargeable energy storage systems

- A rechargeable energy storage system (RESS) provides the electrical energy needed for electric propulsion. The safety of a RESS is related to its electrical integrity, thermal integrity and mechanical integrity.
- Type-approval requirements for a RESS are included in UNECE Regulation 100 and in proposed amendments to UNECE Regulations 94 and 95, but these are focussed on very specific topics. Many of the hazards associated with a RESS will not be dealt with by these regulations.
- There are various industry standards that subject a RESS to abuse conditions and monitor its performance. These include component-level tests that are similar in nature to those in the type-approval legislation for fuel tanks; or they deal with similar hazards.
- Developing component-level type-approval requirements for a RESS would harmonise the safety performance of this key vehicle component and would be consistent with the legislative approach for fuel tanks.

5.4.2 Regenerative braking systems

- Vehicles equipped with regenerative braking systems may behave differently to conventional vehicles during certain manoeuvres that involve braking. While some potential safety problems were discussed in the literature (including recent problems with a specific vehicle), there is insufficient evidence at the present time for any new safety hazards that are not controlled already by UNECE Regulation 13 and 13-H. Further monitoring of the performance of regenerative braking systems would help to maintain confidence in these systems and avoid potential safety problems in the future.

5.4.3 Electromagnetic fields

- There is considerable public concern about the effects of electromagnetic fields (EMF) on human health, particularly with respect to EMF from mobile phones and power lines. However, scientific evidence for any effect at the intensity levels typically found remains weak, though research continues.
- Guidelines on safe limits have been produced by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). However, given current knowledge, these are primarily intended to avoid known effects at high intensities, such as damage due to the heating effect of EMF, though with wide safety margins.
- Electric and hybrid vehicles are likely to expose occupants to higher EMF intensities than internal combustion engine vehicles only at very low frequencies (from quasi-static to a few kilohertz). At these frequencies, magnetic fields probably have the greater potential to be a problem.
- The application of current standards to electric vehicles is complicated by the EMF frequency normally varying with vehicle speed. Also, field intensities will vary significantly around the passenger compartment, and hence by body region and seating position. The duration of exposure may also be important.
- A survey of electric and magnetic fields in the passenger compartments of electric vehicles on the European market could be carried out, and repeated at intervals as the market develops. The readings obtained could then be compared with current guidelines to determine whether there is a case for regulation.
- The current state of knowledge on EMF safety should be reviewed at intervals. As well as non-vehicle specific and electric vehicle research, some of the research on EMF in trains, including Maglev, could be relevant.
- Given the continued uncertainty on safe levels for EMF, electric vehicle manufacturers should be encouraged to achieve EMF levels that are ‘As low as is reasonably achievable’ (ALARA) or to use the ‘Precautionary Principle’.
- There are considerable health benefits for society as a whole from widespread use of electric vehicles, due to reduced atmospheric pollution. Issues of possible safety deficiencies for which there is weak scientific evidence should be considered in this context.

5.4.4 Crash safety

- Most purely-electric cars are small, light vehicles (e.g. superminis) designed to maximise range and battery performance. Such vehicles are at a disadvantage in frontal collisions with heavier cars which can lead to poorer performance (regardless of the type of power train). However, there are currently no legislative requirements to deal with the compatibility of vehicles in collisions. In the future, there may be a greater proportion of lighter electric (and also conventional) vehicles on the road. These vehicles offer benefits in terms of reducing carbon dioxide emissions, and consumers are sometimes encouraged to buy them by their government (with tax savings and other incentives). Compatibility legislation is needed if drivers of small electric vehicles are not to be exposed to greater risks in a collision.

- Retention of the potentially very heavy rechargeable energy storage system (RESS) could be very important in a collision. Amendments to UNECE Regulations 94 and 95 specify post-impact limits on the movement of the RESS. The legislative tests include (perpendicular) 56 km/h offset frontal and 30 km/h side impacts only. Further research is needed to understand fully the performance and safety of battery retention systems in other collision scenarios.
- In some vehicles, the RESS (or part of it) is located towards the rear. In a rear-end collision there is a risk that the RESS could intrude into the passenger compartment. Rear impact tests are not currently required for EC type-approval, although test procedures and requirements are specified in UNECE Regulation 32 (rear impact) and in UNECE Regulation 34 (fuel tanks/fire risks). Mandating rear impact tests for electric vehicles would reduce avoid this potential problem.
- Vehicles sometimes leave the road and enter water. Water exposure and submersion might present a hazard for an electric vehicle. UNECE Regulation 100 includes specifications for the protection of users from electric shock. Although water is not considered explicitly, electrical safety features intended to protect users from electric shock should allow the vehicle to operate safely in snow, heavy rain and floods. However, submersion is a unique situation and studies investigating the risks have not been published. Further research is needed to understand fully the risks of submersion on electric vehicles.

5.4.5 Acoustic perception

- Electric vehicles are potentially quieter than internal combustion engine vehicles, particularly at lower speeds (where there are fewer effects of tyre, road and aerodynamic noise). Quieter vehicles may represent a new hazard for cyclists and pedestrians, especially if they rely on audible cues to alert them of an approaching vehicle. For example, visually impaired people have expressed particular concerns about electric vehicles.
- Evidence of an increased risk to vulnerable road users from electric vehicles in collision statistics is relatively weak, but the number of electric vehicles could rise in the future. There is some evidence that an electric vehicle moving at a low speed will be detected later than a conventional vehicle, if at all when background noise is added. However, this does not necessarily mean that a collision would occur.
- Warning devices have been fitted to vehicles for experimental trials and these have revealed that artificial engine sounds tend to be preferred. An informal group on minimum sound levels for silent vehicles has been set up within the UNECE Working Party on Noise (GRB). Other solutions have been proposed including the use of mobile phones to alert visually impaired people of an approaching vehicle.
- Further research is needed to understand fully the risk to vulnerable road users from electric vehicles and to develop appropriate solutions, if necessary.

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References

Andersen, P. (2009). The present status of the international automotive EMC standards. In: IEEE Electromagnetic Compatibility Society (Ed.), *IEEE International Symposium on Electromagnetic Compatibility*, 17-21 August 2009, Austin, Texas. Piscataway, NJ: IEEE Operations Centre.

Berdichevsky, G., Kelty, K., Straubel, J. B. and Toomre, E. (2007). The Tesla Roadster battery system*.* Retrieved February 8, 2010 from: http://webarchive.teslamotors.com/display_data/TeslaRoadsterBatterySystem.pdf

BERR and DfT, (2008). *Investigation into the scope for the transport sector to switch to electric vehicles and plug-in hybrid vehicles.* Retrieved November 10, 2009 from http://www.bis.gov.uk/files/file48653.pdf

Boyle, P. and Levin, B. (eds). (2008). Electromagnetic radiation. *In: World cancer report 2008*, Lyon, France: International Agency for Research on Cancer, pp 171-173. Retrieved April 9, 2010 from: http://www.who.int/peh-emf/publications/reports/WCR2008_212.pdf

Burke, A. F. (2008). *Electric and hybrid vehicle design and performance*. In: M. Kutz (Ed), Environmentally conscious transportation. Hoboken, NJ: John Wiley & Sons, Inc.

Dietrich, F. M. and Jacobs, W. L. (1999). *Survey and assessment of electric and magnetic field (EMF) public exposure in the transportation environment*. Report No. PB99-130908. USA: US Department of Transportation, Federal Railroad Administration.

Dodd, M., Elliott, M., Fenn, B., McKillop, J. and Sexton, B. (2005). *Criteria for the automatic operation of stop lamps, volume 1 – final report* (PPR068). Crowthorne: Transport Research Laboratory.

Engineering and Physical Sciences Research Council (EPSRC). (2009). Air-fuelled battery could last up to 10 times longer. *EPSRC press release,* May 18, 2009. Retrieved February 8, 2010 from http://www.epsrc.ac.uk/newsevents/news/2009/Pages/airfuelledbattery.aspx

European Commission. (2006). *CARS 21 A competitive automotive regulatory system for the 21st century.* Retrieved November 9, 2009 from: http://ec.europa.eu/enterprise/sectors/automotive/files/pagesbackground/competitiveness/cars21finalreport_en.pdf

European Commission. (2009). *Legal framework for the placing on the market of electric vehicles and related equipment.* Retrieved November 9, 2009 from: http://ec.europa.eu/enterprise/sectors/electrical/files/lvdwg2009_electvehicles_en.pdf

European Commission. (2010). *Proposal for a council decision on the compulsory application of regulation 100 of the United Nations economic commission for Europe for the approval of motor vehicles with regard to electric safety.* Retrieved June 24, 2010 from World Wide Web: http://ec.europa.eu/enterprise/sectors/automotive/files/pagesbackground/competitiveness/com-2010-0280_en.pdf

Fontaras, G., Pistikopoulos, P. and Samaras, Z. (2008). Experimental evaluation of hybrid vehicle fuel economy and pollutant emissions over real-world simulation driving cycles. *Atmospheric Environment, 42*, 4023–4035.

General Motors. (2009). *National Federation of the Blind teams with Chevrolet and GM to incorporate a safe sound alert for electric vehicles* and hybrids. Retrieved February 8, 2010 from: http://www.gm.com/vehicles/hybrids-and-electric/news/2009/blind_112509.jsp

Group Lotus. (2009). Lotus introduces 'safe and sound' hybrid'. *Group Lotus News Release,* August 5, 2008. Retrieved February 8, 2010 from: http://www.grouplotus.com/mediacentre_pressreleases/image/406.pdf

Guttowski, S., Weber, S., Hoene, E., John, W. and Reichl, J. H. (2003). EMC issues in cars with electric drives. In: IEEE Electromagnetic Compatibility Society (Ed.), *IEEE Symposium on Electromagnetic Compatibility*, 18-22 August 2003, Boston. Piscataway, NJ: IEEE Operations Centre.

SWOV. (2009). Cars submerged in water. *SWOV factsheet.* Retrieved June 24, 2010 from: http://www.swov.nl/rapport/Factsheets/UK/FS_Cars_in_water.pdf

JASIC (2009). *A study on approach audible system for hybrid vehicles and electric vehicles – Second report* (GRB-50-08). Presentation at 50th meeting of GRB, September 2009. Retrieved February 8, 2010 from: http://www.unece.org/trans/doc/2009/wp29grb/ECE-TRANS-WP29-GRB-50-inf08e.pdf.

Lim, J. M., Seo, S., Suk, J. and Kim, G. (2008). *Evaluation of crash protection for hybrid electrical vehicle under rear impact* (2008-01-0189). Warrendale, PA: SAE International.

Matheys, J., Van Mierlo, J., Timmermans, J-M. and Van den Bossche, P. (2008). Life-cycle assessment of batteries in the context of the EU directive on end-of-Life vehicles. *International Journal of Vehicle Design* 46 (2), 189-203.

Maher, B. (2005, February). Ultracapacitors and the hybrid electric vehicle, by Bobby Maher. *Earthtoys emagazine,* February 2005. Retrieved February 8, 2010 from http://www.altenergymag.com/emagazine.php?issue_number=05.02.01&article=maxwell

Motavalli, J. (2008). *Fear, but few facts, on hybrid risk*. Retrieved April 7, 2010 from: http://www.nytimes.com/2008/04/27/automobiles/27EMF.html?_r=4&ref=automobiles&oref=slogin

Muc, A. M. (2001). *Electromagnetic fields associated with transportation systems*. Report for Health Canada under contract reference 4500016448. Toronto, Canada: Radiation Health and Safety Consulting. Retrieved April &, 2010 from: http://www.rhsc.ca/TransEMF.pdf

Nelson, J. J., Goodwin, W., Steffka, M., Ivan, W. and Kopp, M. (2007). High voltage automotive EMC component measurements using an artificial network. *Proceedings of the 18th International Zurich Symposium on EMC*, 24-28 September 2007, Munich, Germany. Piscataway, NJ: IEEE Operations Centre.

NIEHS EMF-RAPID Program Staff (1999). *NIEHS report on health effects from exposure to power-line frequency electric and magnetic fields*. NIH Publication No. 99-4493. USA: National Institute of Environmental Health Sciences, National Institutes of Health. Retrieved April 8, 2010 from: http://www.niehs.nih.gov/health/docs/niehs-report.pdf

NHTSA. (2009a). *Incidence of pedestrian and bicyclist crashes by hybrid electric passenger vehicles* (DOT HS 811 204). Retrieved February 8, 2010 from: http://www-nrd.nhtsa.dot.gov/Pubs/811204.PDF

NHTSA. (2009b). *Quieter cars and the safety of blind pedestrians* (GRB-50-09). Presentation at 50th meeting of GRB, September 2009. Retrieved February 8, 2010 from: http://www.unece.org/trans/doc/2009/wp29grb/ECE-TRANS-WP29-GRB-50-inf09e.pdf

Nordenson, I., Hansson-Mild, K., Jarventaus, H., Hirvonen, A., Sandstrom, M., Wilen, J., Blix, N. and Norppa, H. (2001). Chromosomal aberrations in peripheral lymphocytes of train engine drivers. *Bioelectromagnetics,* 21, 01-10

Nyeste, P. and Wogalter, M. S. (2008). On adding sound to quiet vehicles. *Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting,* 1747-1748.

Owen, J. M. (2008). Quiet vehicle avoidance systems for blind and deaf pedestrians. *VCU Bioinformatics and Bioengineering Summer Institute*, Summer 2008. Retrieved February 8, 2010 from: http://ramsites.net/~owenjm/Owen%20Final%2008.pdf

Peterson, J. (2009). *How electric cars and hybrids affect your health*. Retrieved April 7, 2010 from: http://planetgreen.discovery.com/food-health/electric-cars-hybrid-health.html

ReVolt Technology, (2009). *Rechargeable Zn-Air batteries.* Retrieved February 8, 2010 from: http://www.revolttechnology.com/res/news/2009%209%2025%20Rechargeable%20Zinc-air%20Batteries.pdf

Rosenblum, L. D. (2008). *Testing the audibility of quiet cars*. Presentation at the National Highway Transportation Safety Administration Public Forum on Quiet Cars, 23rd June 2008. Retrieved February 8, 2010 from: http://www.nfb.org/images/nfb/Video/Larry_Rosenblum_Quiet_Cars.wmv

Ruddle, A. R. (2002). *Investigation of electromagnetic emissions from alternative powertrain road vehicles* (01-845060). Nuneaton, UK: MIRA Ltd.

Sahraei, E., Wierzbicki, T., Hill, R. and Luo, M. (2010). *Crash safety of lithium-ion batteries towards development of a computational model* (2010-01-1078). Warrendale, PA: SAE International.

Van den Bossche, P., Van Mulders, F., Verbrugge, B., Omar, N., Culcu, H. and Van Mierlo, J. (2009). The cell versus the system: standardisation challenges for electricity storage devices. *Proceedings of the International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium,* 13-16 May 2009, Stavanger, Norway.

Viladot, A., Palsson, I., Jonsson, H. and Torstensson, H. (1999). *Risk in connection with electric vehicles* (SSPA Research Report No. 111). Gothenburg, Sweden: SSPA Sweden AB.

Voelcker, J. (2007, September). Lithium batteries take to the road. *IEEE Spectrum,* September 2007.

Wertheimer, N. and Leeper, E. (1979). Electrical wiring configurations and childhood cancer. *American Journal of Epidemiology,* 109, 273-284.

Wogalter, M. S., Ornan, R. N., Lim, R. W. And Chipley M. R. (2001). On the risk of quiet vehicles to pedestrians and drivers. *Proceedings of the Human Factors and Ergonomics Society* 45, 1685-1688.

World Health Organization (2000). *Electromagnetic fields and public health: Cautionary policies*. Retrieved April 9, 2010 from: http://www.who.int/docstore/peh-emf/publications/facts_press/EMF-Precaution.htm

World Health Organization (2005). *Electromagnetic fields and public health: Electromagnetic hypersensitivity - fact sheet N°296.* Retrieved April 9, 2010 from: http://www.who.int/mediacentre/factsheets/fs296/en/index.html

World Health Organization (2007). *Electromagnetic fields and public health: Exposure to extremely low frequency fields - fact sheet N°322.* Retrieved April 9, 2010 from: http://www.who.int/mediacentre/factsheets/fs322/en/index.html

World Health Organization (2010a). *Standards and guidelines*. Retrieved April 9, 2010 from: http://www.who.int/peh-emf/standards/en/

World Health Organization (2010b). *What are electromagnetic fields?* Retrieved April 9, 2010 from: http://www.who.int/peh-emf/about/WhatisEMF/en/